Third Party Verification of a Non-Regionally Specific Appliance Recycling Model Using On-Site Metering

Pace Goodman, Navigant Consulting, Inc., Boulder, CO
Rosanna Jimenez, Consolidated Edison, Inc., New York, NY
Steve Hastie, Navigant Consulting, Inc., Philadelphia, PA
Chris Wassmer, Navigant Consulting, Inc., Boulder, CO

ABSTRACT

While metering studies can yield the most accurate estimates of gross verified savings for utility demand side management (DSM) programs, these studies can be expensive, result in delayed estimates of savings and may be specific to a given program year and location. When evaluation resources do not support a metering effort for refrigerator recycling programs, the Uniform Methods Project (UMP) recommends applying an existing regression model (whose development was based on metering data) to local program and weather data to estimate the unit energy consumption (UEC) of recycled refrigerators. This approach can theoretically provide an inexpensive and quickly available estimate of savings that can reflect program-specific conditions, such as the average age of participant refrigerators and local weather conditions, which are inputs to the model. The crux of the potential for this recommendation is the accuracy of that model. The authors' evaluation of the Consolidated Edison Company of New York's (CECONY's) Appliance Bounty Program found that metered results for recycled refrigerators in the CECONY area differed from the UMP model's predicted estimates by 11%. This finding indicates that utilities can use the UMP regression model for a low cost and relatively accurate estimate of refrigerator UEC. More broadly, this finding provides one positive case study of using metered-based regression models generated from data in other territories to provide reliable estimates of savings when the contribution of savings and/or evaluation resources does not justify metering, or when timely estimates of savings are required.

Introduction

Navigant conducted an impact evaluation of Consolidated Edison Company of New York's (CECONY's) Appliance Bounty Program in 2014. This program reduces residential energy consumption by incenting CECONY customers to recycle inefficient refrigerators, freezers and window and wall air conditioning (AC) units through the program. The evaluation included engineering review, participant surveys and participant refrigerator metering. This paper specifically discusses the results and implications of the refrigerator metering study through the following sections:

1. Background on Refrigerator Recycling Programs' Implementation and Evaluation
2. CECONY Appliance Bounty Impact Evaluation Methods and Results
3. Discussion of CECONY Study Results
4. Next Steps to Build on this Research

Background on Refrigerator Recycling Programs' Implementation and Evaluation

This section provides context for the impetus of this research. In this section, the writers describe the evaluated program's implementation strategy and evaluation cycle, industry standard evaluation methods and a brief declaration of the research objectives.

The Evaluated Utility's Implementation Strategy and Evaluation Cycle

The CECOY program sends a truck and small crew to participant homes, where the crew picks up the refrigerator and then delivers it to a recycling facility. The program picks up and recycles the refrigerator at no charge to the customer and also offers a financial incentive to the customer to encourage program participation. The program costs include the cost of a truck, a crew, recycling fees, warehouse expenses and any incentives to the customers. The benefits of the programs include avoided energy generation, transmission and distribution, as well as additional environmental benefits from avoiding improper disposal of refrigerators and refrigerant.

During the CECONY program period being evaluated, the utility provided qualifying customers with cash incentives for removal of inefficient and operational refrigerators. Eligibility requirements included the following:

- Only open to customers in residential dwellings with one to four units
- Refrigerators must be secondary – not the primary – units
- Refrigerators must be at least 10 cubic feet in size (internal cooling space)
- Refrigerators must be in working condition and plugged in and operating on the day of removal
- There is a limit of two refrigerators per customer
- The customer must provide a clear, safe path to the unit being removed

The evaluated program was marketed primarily through point-of-sale materials, internet and newspaper advertising and bill inserts. When the appliance was collected by the implementer, the participant confirmed with a signature on an electronic handheld device that their contact information was correct and that the number and types of appliances collected had been correctly entered. This information then was entered into the utility's tracking system for incentive payment processing.

The program is evaluated in three-year cycles. Every three years an independent third party verifies the energy savings for the program over the past three years and provides an estimate of energy savings for the future three years.

Industry Standard for Refrigerator Recycling Program Evaluation

The Department of Energy's (DOE's) Uniform Methods Project (UMP) recommends methods or method options to evaluators and is intended to achieve increased uniformity in evaluation practices across the industry. The recommended methods are widely vetted with industry professionals prior to final publication. In other words, the evaluation methods in the UMP can be considered industry standard, or at least close to it.

Chapter 7 of the UMP, titled Refrigerator Recycling Evaluation Protocol, contains two high level equations for evaluating refrigerator recycling programs (Bruce & Keeling 2013). These equations account for annual unit energy consumption (UEC), the percent of the year recycled refrigerators are typically in use, the impact on energy savings from the program causing participants to replace their recycled refrigerators with new ones, and net-to-gross adjustment (commonly low for these types of programs). Equations 1 and 2 contain more detail.

Equation 1. The UMP's recommended equation for estimating gross energy savings for refrigerator recycling programs

$$GROSS\_kWh = N * EXISTING\_UEC * PART\_USE$$

Equation 2. The UMP's recommended equation for estimating net energy savings for refrigerator recycling programs

$$NET\_kWh = N * (NET\_FR\_SMI\_kWh - INDUCED\_kWh)$$

The variables within these equations correspond to the following:

- GROSS_kWh: Annual electricity savings measured in kilowatt-hours (kWh)
- N: The number of refrigerators recycled through the program
- EXISTING_UEC: The average annual unit energy consumption of participating refrigerators
- PART_USE: The portion of the year the average refrigerator would likely have operated if not recycled through the program
- NET_FR_SMI_kWh: Average per-unit energy savings net of naturally occurring removal from grid and secondary market impacts
- INDUCED_kWh: Average per-unit energy consumption caused by the program inducing participants to acquire refrigerators they would not have independent of program participation

While all of these components have interesting nuances, this paper focuses on the annual unit energy consumption (UEC). The UMP recommendation for UEC provides an intriguing and unique approach to evaluation.

There are several challenges unique to estimating UEC for refrigerator recycling programs. First, the standards for manufacturer measurements of annual energy consumption are unrealistic (e.g., a 90F ambient and no door openings) (Electronic Code of Federal Regulations 2015). Additionally, metering participant refrigerators is challenging as there is nothing to meter in the post implementation case since the recycled refrigerator is gone. As a result, any metering requires tight coordination between the implementation and evaluation team, where participant units are metered at a minimum of 10-14 days prior to being removed from the participant site. Furthermore, when metering is performed, the evaluation team must implement additional attention, effort and possibly incentives to capture seasonality due to lower participation levels in months of extreme weather. In the CECONY study, it was difficult to meter refrigerators during the winter due to low participation. In conclusion, the combination of unrealistic manufacturer estimates of energy consumption and the limited opportunity for metering leads to a greater likelihood of inaccurate deemed and even verified energy savings estimates for refrigerator recycling programs.

Fortunately the UMP offers a regression equation to estimate annual UEC, in lieu of utility-specific metering. This equation accounts for many key drivers of refrigerator energy consumption, including age, size, configuration, local weather and whether the refrigerator operates in conditioned or unconditioned space. The UMP created this equation using metering data from utility evaluation studies across the country. The recommendation is intriguing because it offers a flexible and simple approach that can estimate utility-specific average annual UEC with reasonable accuracy and without any expensive metering.

Research Objective

The UMP's recommended equation potentially benefits refrigerator recycling programs by reducing the need for refrigerator metering, which can be very expensive. However, very few studies to date have verified the model's accuracy and some utilities across the country are still allocating money toward their own refrigerator metering studies. The research presented in this paper was intended to obtain the most accurate estimate of recycled refrigerator average annual UEC for CECONY as possible, as well as to assess the accuracy of the UMP model for potential inclusion in the state-wide technical reference manual (TRM).

CECONY Appliance Bounty Evaluation Study Methods and Results

In this section the authors describe the methods and results in estimating the average annual unit energy consumption (UEC) of refrigerators recycled through the CECONY Appliance Bounty Program. This study involved metering participant refrigerators, developing a CECONY-specific regression model that estimates UEC for all participant refrigerators (including those not metered) and assessing the accuracy of the UMP recommended model for estimating recycled refrigerator UEC.

Methods

The program evaluation generally followed the UMP's chapter 7 guidance, including utility specific metering and one area of added rigor. The evaluation team included an estimate of the program's impact on heating and cooling energy consumption using an HVAC interaction factor. This factor accounts for the reduced internal heat gain associated with removing a refrigerator from the premises for refrigerators stored in conditioned space.[1]

With regards to the annual UEC and the main purpose of this paper, the evaluation team estimated the UEC and assessed the accuracy of the UMP model in the following steps:

1. Data collection, which included:
    a. A little over three weeks on average of metering (energy consumption and ambient room temperature) for 69 recycled refrigerators (see Table 1 for more information on the metering devices)
    b. Tracking data (e.g., configuration, size, age, etc.) for the 69 metered refrigerators
    c. Local weather data (actual and typical)
2. Annualization of the metered energy consumption

[1] The location of the refrigerator is collected in the CECONY program tracking data and was verified as a part of the metering study.

3. Fitting a program-specific regression model such that the annualized UEC for each of the 69 metered refrigerators is the dependent variable and configuration, size, age and other tracking variables are the independent variables
4. Applying the program-specific regression model and the UMP recommended model to the tracking data of the 69 metered refrigerators
5. Calculating each model's accuracy and precision
    a. For both the UMP and program-specific models, the evaluation team used the ratio of the model-of-interest's predicted average UEC for the 69 metered refrigerators over the metered average UEC for the 69 metered refrigerators to estimate the accuracy of each model
    b. Precision corresponds to the differences between the model predicted UEC and the actual UEC at each of the 69 metered refrigerators

Data Collection. As indicated above, on-site metering was conducted successfully for 69 participant refrigerators. The evaluation team attempted to meter 77 refrigerators, but removed 8 sites from the analysis due to data quality concerns. The evaluation team metered the energy consumption of the unit, ambient air temperature where the unit was located and the temperature inside the refrigerator. Table 1 describes the metering devices.

Table 1. Instrumentation installed at the 69 metering sites

Metering Point	Manufacturer / Model	Interval	Parameter
Plug	PMI Eagle 120	1 minute	kWh, run time, true power
Vicinity of unit	HOBO UX100-001	1 minute	Ambient temperature
Inside refrigerator	HOBO UX100-001 Temperature Data Logger	1 minute	Internal unit temperature

The relevant tracking data included refrigerator vintage, configuration, interior size (cubic feet), whether the unit had automatic defrost and whether the unit was previously operating in a conditioned or unconditioned area. The evaluation team also collected actual and typical weather data for New York City in order to properly estimate annual UEC for refrigerators kept outdoors and to estimate the HVAC interaction factor for refrigerators kept indoors.

Annualization of the Metered Energy Consumption. The evaluation team extrapolated the metered energy consumption data (roughly three weeks on average) to a full year for each metered refrigerator using outdoor and ambient room temperature. When applicable, the evaluation team used the relationship between outdoor temperature and the metered ambient room temperature during the metering period to estimate the annual ambient temperature around the refrigerator. For example, Figure 1 shows a site where the relationship between outdoor temperature and ambient room temperature best fits a change point linear model with a balance temperature of about 60F. To extrapolate this data to the year, the analysis team applied this relationship to local weather data for non-metered days. If the outdoor temperatures were below 60F, the ambient temperature was calculated as function of outdoor temperature using the relationship describing the orange circle data points. If the outdoor temperatures were above 60F, the ambient temperature was calculated as function of outdoor temperature using the relationship describing the gray square data points. .

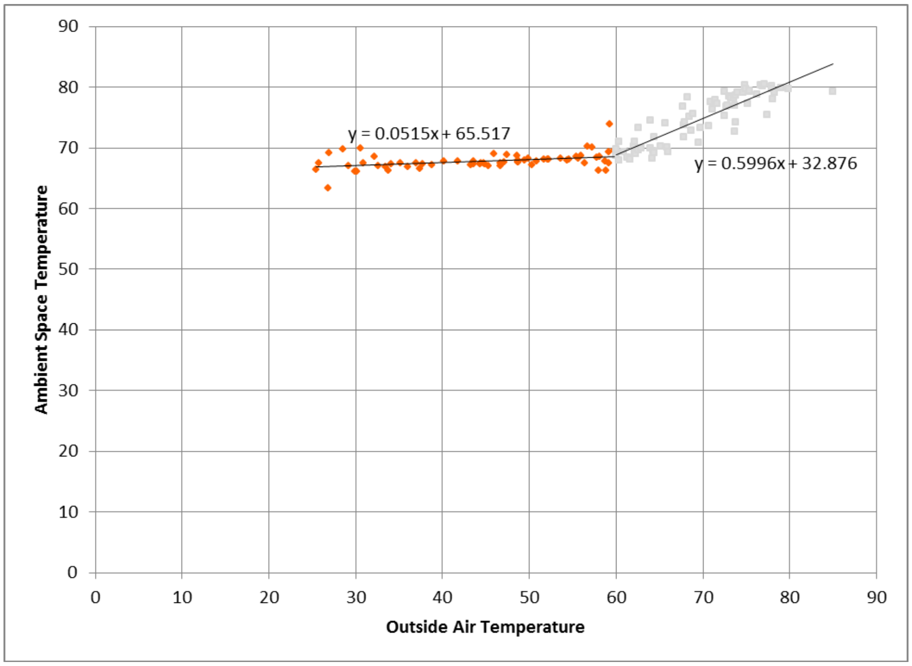

Figure 1. The relationship between daily ambient and outdoor temperature for an indoor, conditioned space

Similarly, the evaluation team then used the relationship between ambient temperature (an annual file at this stage of the analysis) and the metered energy consumption during the metering period to estimate the annual UEC for each of the 69 metered refrigerators. Figure 2 demonstrates an example of this relationship during the metering period. For non-metered days, the analysis team calculated energy consumption as a function of ambient room temperature using the linear equation displayed in Figure 2.

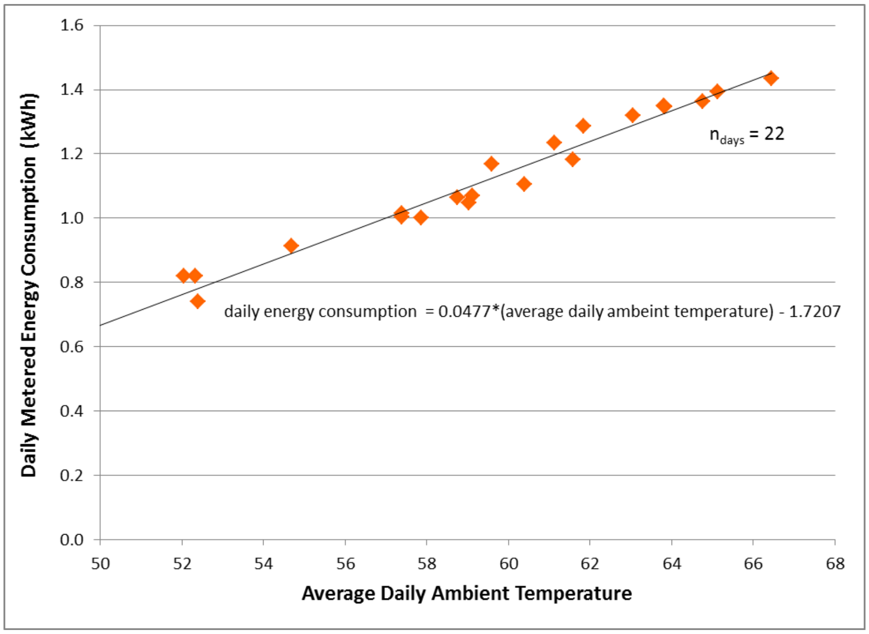

Figure 2. Energy consumption versus ambient temperature for a refrigerator operating in unconditioned space

Fitting a Program-Specific Regression Model. Using a least squared regression approach, the evaluation team specified and fit a model as described in Equation 3.

Equation 3. Program-specific model specification

$$UEC = function.of(Age, Pre.1993, Size, Single.Door, Side.by.Side, Uncond, HDD)$$

The variables within Equation 3 correspond to the following:

- UEC: Annual unit energy consumption in kWh per year
- Age: years since manufacturing prior to 2014
- Pre.1993: a binary indicator as to whether the unit was manufactured before or after 1993, when certain federal standards regarding refrigerator manufacturing came into effect
- Size: interior size of the refrigerator in cubic feet
- Single.Door: a binary indicator as to whether the unit is of single door configuration
- Side.by.Side: a binary indicator as to whether the unit is of side-by-side door configuration
- Uncond: a binary indicator as to whether the unit was operating in conditioned or unconditioned space
- HDD: annual heating degree days[2]

[2] The analysis did not include CDD due to co-linearity with HDD. For regression models developed at the annual level, HDD and CDD may be too co-linear to include both variables depending on the geographic range of the study. Furthermore, the data indicated the HDD alone had a stronger effect on energy consumption than did CDD.

The results of the fitted model are described in Equation 4. This equation estimates the UEC of a refrigerator based on the refrigerator's age, size, etc. The UEC generated from the equation (UEC.pred) is the "predicted UEC" and will only perfectly match the measured (or actual) UEC if the precision of the model is 0%. Models with 0% precision typically have specification issues, such as over-fitting. The value of generating this model is that an evaluation team can estimate (or predict) UEC for refrigerators where the measured UEC is unknown, but the independent variables are known.

Equation 4. The program-specific regression model

$$UEC.pred = 430.39 - 12.85 * Age \ + \ 338.36 * Pre.1993 \ + 47.00 * Size - 432.17 * Single.Door - 406.78 * Side.by.Side \ - 0.0558 * Uncond * HDD$$

Applying the Regression Models (Program-Specific and UMP Recommended) to the 69 Metered Refrigerators' Tracking Data. Using tracking data and local weather data, the evaluation team input the necessary variables to calculate the predicted UEC for each of the 69 metered refrigerators. The UMP recommended model includes similar inputs and the evaluation team could also calculate the UMP predicted UEC (UEC.pred.UMP). Equation 5 describes the UMP recommended model in more detail.

Equation 5. The UMP recommended regression model

$$UEC.pred.UMP = 365.25 * (0.582 \ + \ 0.027 * Age \ + \ 1.055 * Pre.1990 \ + 0.067 * Size - 1.977 * Single.Door + \ 1.071 * Side.by.Side + \ 0.6054 * Primary \ + \ 0.02 * Uncond * CDD.daily - \ 0.045 * Uncond * HDD.daily)$$

The variables included in Equation 5 match previously mentioned equations. The additional variables are described below:

- UEC.pred.UMP: the predicted UEC based on the UMP recommended model
- Pre.1990: a binary indicator as to whether the unit was manufactured before or after 1990
- Primary: a binary indicator as to whether the unit was used as the primary or secondary refrigerator
- CDD.daily: average daily cooling degree days
- HDD.daily: average daily heating degree days

Calculating Each Model's Accuracy and Precision. At this stage in the analysis, the evaluation team had the predicted UEC from the program specific model (UEC.pred), the predicted UEC from the UMP recommended model (UEC.pred.UMP), and the actual UEC for each of the 69 metered refrigerators.

As a metric indicative of accuracy, the evaluators divided the average UEC.pred.UMP by the average actual UEC. This ratio describes whether the UMP model over or under predicts UEC for the 69 metered refrigerators on average. By definition of a least squares regression, the program-specific model (UEC.pred) will predict the actual average UEC.

Precision indicates the closeness of the predicted UEC and the actual UEC at each site, rather than on average. For example, the predicted UEC and actual UEC may be very close on average, but the difference between predicted UEC and actual UEC at each site may differ substantially. Precision corresponds to the degree of that variation at each site.

Results

The evaluation team found that the UMP model estimated annual UEC at 89% of the metered value on average and at 12% relative precision. The model created specifically for CECONY had a tighter precision (9%) and estimated annual UEC at 100% of the metered value on average. The accuracy of the CECONY-specific model (100%) is expected and somewhat misleading. A regression model that is fit to a certain set of data will estimate the value of interest for that specific data set with 100% accuracy on average by definition of a least squared regression fit. The accuracy of estimating data points not included in the development of the regression model is of more interest.

Table 2. Accuracy and precision results for the program-specific and UMP recommended regression models

Model	Sample Size	Ratio of the Average Model Predicted UEC over the Average Actual UEC	Model Precision
CECONY	69	1.0	9%
UMP	69	0.89	12%

Due to these results, the evaluation team recommended that CECONY use the model developed from their metering data, but recommended that the state-wide technical manual provide the UMP model for utilities where program-specific metering data is not available or too costly.

Figures 3 through 5 demonstrate the value of this recommendation. Figure 3 shows the fit between metered annual UEC and the CECONY-specific model predicted values; Figure 4 shows the fit between the metered annual UEC and the UMP model predicted values; and Figure 5 shows the fit between metered annual UEC per site and an average value. The CECONY specific model performs better for CECONY's data than the UMP model, and is most applicable for CECONY's needs. However, for utilities where a metering study is too costly, the UMP model performs better than an average value from a secondary source.

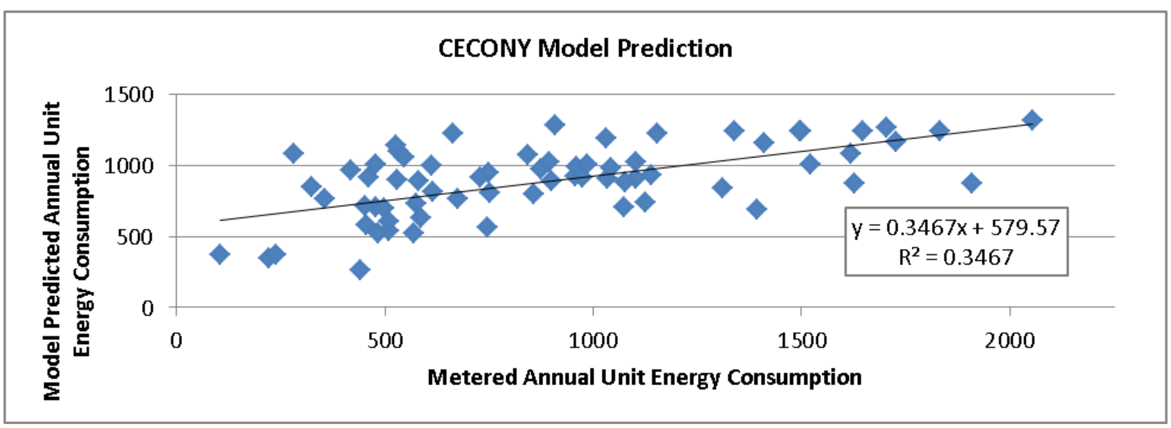

Figure 3. Modeled versus metered annual unit energy consumption for the CECONY model

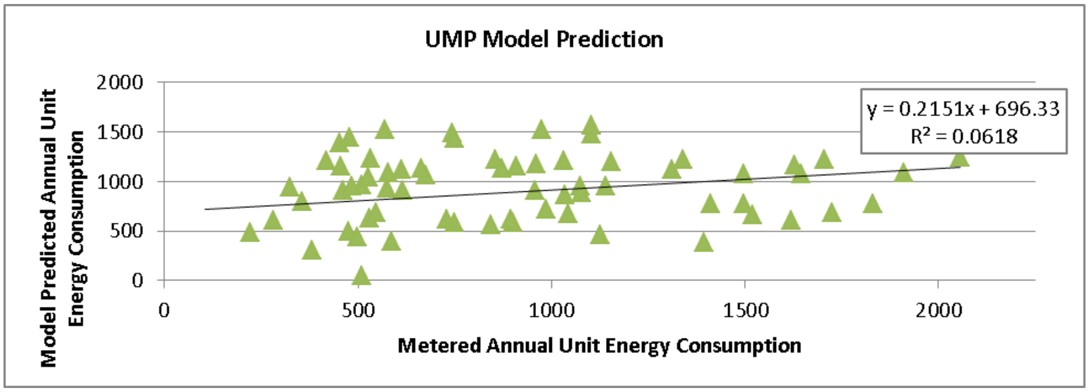

Figure 4. Modeled versus metered annual unit energy consumption for the UMP model

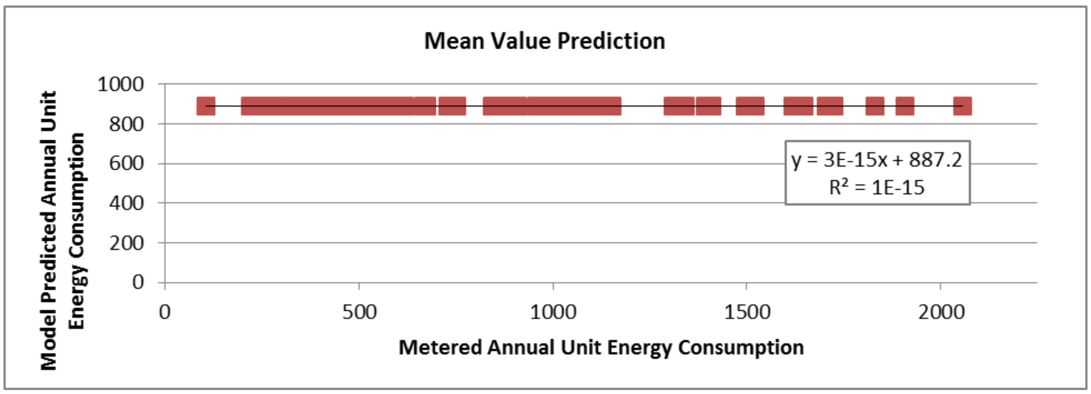

Figure 5. Modeled versus metered annual unit energy consumption for a mean value model

Additionally, the evaluation team noticed two unexpected and important findings to consider when applying this methodology. First, the accuracy of this approach is dependent on the quality of tracking data. The evaluation team noticed increased error for sites where the tracking data incorrectly identified a refrigerator as operating in conditioned or unconditioned space. Second, the model predicted some unrealistic UEC values, even negative values, for certain refrigerators. This finding indicates that the model results should be used at the program level and not at the site-specific level.

Discussion of CECONY Study Results

This study's findings have some immediate implications for refrigerator recycling evaluation, as well as some potential implications for energy efficiency evaluation as a whole.

Implications for Appliance Recycling Evaluation

The CECONY Appliance Bounty Program evaluation found that the UMP model underestimated UEC by 11% for 69 refrigerators metered as a part of the study. This finding has two primary implications for the future of refrigerator recycling program evaluation.

This finding implies that the UMP's recommended model provides a reasonably accurate approach to estimate UEC without expensive metering, making it ideal for generating deemed savings or for inclusion in a broader technical reference manual for refrigerator recycling programs. Utilities can use the UMP model, already collected utility-specific tracking data and local weather data to estimate UEC within 11% +/-12%. The certainty of this approach isn't perfect, but it's a significant improvement over manufacturer estimates of UEC and deemed estimates taken from previous single-utility or single-state studies.

Furthermore, the CECONY study results indicate that a metering study will likely have a relatively small impact on program savings compared to simply using the UMP model's predicted UEC. For CECONY, the expense of the metering study increased their savings by 11% and the net-to-gross adjustment reduced savings by almost 50%. To take this concept further, this finding indicates that money spent on metering refrigerators to estimate UEC may be better spent on other areas of uncertainty, such as investigating the net to gross ratio.

Implications for Other Measure Evaluation

Evaluating a utility energy efficiency program typically involves a utility hiring an independent third party to provide an unbiased evaluation of the program's energy impact. These evaluations may leverage secondary literature at a high-level, but there is limited opportunity to compare the evaluated utility and the secondary data with any statistical validity. As a result, the evaluation team often collects data specific to that utility and may or may not provide publicly available data points that are only qualitatively useful for the evaluation. Furthermore, the data collected through each utility-specific study is often similar. The results of this study indicate that there may be a more efficient approach to energy efficiency evaluation as a whole.

The ability for the UMP's recommended model to estimate UEC for a utility that had not contributed any prior metering data serves as an interesting case study for sharing evaluation results (and potentially costs) among utilities for the greater good of the industry. The DOE leveraged metering data, relevant tracking data and weather data from refrigerator metering studies across the country in order to provide a reasonably accurate equation for estimating UEC for utilities not willing or able to conduct their own metering studies. If this concept were applied to other areas of evaluation, it could free up considerable evaluation resources to investigate other areas of uncertainty (e.g., net-to-gross), explore additional opportunities for savings (e.g., alternative program designs), or explore other factors (e.g., the effect of different marketing strategies on participation) as a part of the program evaluation.

An example of where this approach may be valuable is lighting hours of use, where commercial lighting likely offers a more easily achievable second case study for this type of approach than residential lighting. Key drivers for hours of use may include space type, availability of daylight, bulb type, wattage, lamp type, occupancy per square foot, number of bulbs in the room, maturity of the program, etc. Similarly, lighting hours of use is commonly metered, because lighting efficiency savings often contribute a substantial portion of utility portfolio savings. If parallel metering studies could be coordinated (e.g., same on-site protocol, same data collection fields, same sampling protocol) as occurred for refrigerator recycling metering studies, it may be possible to develop a regression model that predicts annual hours of use based on key variables, such as space type. If that regression model was as accurate as the UMP's recommended model to estimate UEC, utilities could potentially collect data on the key variables included in the model and reduce the need for any additional metering expenses, such as the cost of equipment, its installation, its retrieval and the cost of analyzing and summarizing the meter data.

Each service territory and each program is unique, but with adequate data sharing, adequate data collection and an organization willing to conduct the analysis, the evaluation industry could reduce the need for duplicate, utility-specific metering studies. This might ultimately free up resources for other, less well-understood research topics.

Next Steps to Build on this Research

In order for the implications discussed above to take effect, the authors offer three recommendations.

First, before utilities can truly trust the UMP's recommended model to estimate UEC, other studies should replicate the analysis presented here in order to add robustness in assessing the accuracy of the UMP model. While this study found the UMP model to be reasonably accurate in an east coast city, other studies may find contradictory results. For any refrigerator recycling metering study, this added analysis component is actually quite simple, and could even be conducted following the program specific evaluation. With adequate funding, the DOE could even implement a "with-holding sample" type of analysis, where they would with-hold a randomly selected sample of refrigerators' metering data (roughly 20% of refrigerators) and assess the accuracy of the resulting model's ability to predict UEC for the 20% of refrigerators not included in the model development. This analysis can be repeated, selecting a new 20% of refrigerators to with-hold with each iteration, to provide the best assessment of accuracy. Typically the final, publicly available model will be developed using the entire dataset.

Secondly, if other studies also find that the UMP's recommended model is reasonably accurate, the DOE (or other entities in the evaluation community) should explore other opportunities to implement this approach, such as for commercial building lighting hours of use.

Lastly, it is critical for the success of this novel approach to evaluation that these models be maintained. Mainly, the model should be updated as new metering data becomes available (the approach will always require some degree of metering in the industry as a whole), and the entity developing the model should use a "with-holding sample" type of analysis to assess the accuracy of their model.

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