Date: January 31, 2013

To: Karen Kansfield, Jonathon Jackson (AIC) and Jennifer Hinman (ICC)

From: Jane Colby and Jason Christensen, CadmusGroup Inc

Re: Appliance Recycling Update

Cadmus performed a regression analysis using the ComEd refrigerator and freezer metering sample of 130 units, combined with 238 units of similar metering data from Consumer’s Energy and DTE Energy in Michigan (collected in two waves between 2010 and 2012 covering both winter and summer seasons). The purpose of the analysis was to update the Illinois Technical Reference Manual (TRM) for estimating savings from appliance recycling programs. By combining the datasets, the sample sizes forming the basis for the current TRM increased from 102 to 288 for refrigerators, and from 28 to 79 for freezers. The increased sample size allowed for development of separate regression models for refrigerators and freezers.

We made two other changes to the dataset:

1. Excluded two units from the ComEd metering study that were smaller than those eligible to participate in the program (less than 10 cubic feet).
2. Removed six outliers from the dataset that exhibited unreasonable low energy use (less than 393 kWh/year for refrigerators between 16 and 24 cubic feet[[1]](#footnote-1)). These unreasonably low estimates indicate either a metering or equipment problem.

Collectively, these changes resulted in a wider diversity of equipment and metered climate conditions that improve the model’s predictability.

Both datasets included hourly kWh consumption along with relevant appliance characteristics for the metered appliances used to inform the evaluation’s regression modeling. These characteristics include: size, age, configuration details, airport weather station, appliance location (within the home), and whether the location was conditioned (regulated by an HVAC system).

Cadmus aggregated the hourly kWh consumption to the daily level and then a daily average kWh value was calculated for each appliance.

Initially we modeled both appliance types with the specification proposed in the current TRM. We compared this model to the model we optimized with the additional data. The additional data changed the model specification in the following ways:

* Pre-1993 – The model coefficient to control for the change in consumption due to first update of the National Appliance Energy Conservation Act was changed to pre-1990, when the NAECA standards were first implemented. This change was made largely due to confounding interactions between the pre-1993 dummy variable and other characteristics controlled for in the model, namely single-door units or side-by-side primary units (defined by units used in the kitchen). This confounding was not present when controlling for units pre-1990 rather than pre-1993.
* Manual Defrost – This coefficient was also dropped due to confounding interactions with other characteristics – namely single-door, primary units.
* Heating Degree Days1 \* Unconditioned Space – a term was added to account for the effect of cold weather on units kept in unconditioned spaces which typically require less energy to keep the unit cold.
* Cooling Degree Days1 \* Unconditioned Space – a term was added to account for the effect of warm weather on units kept in unconditioned spaces which typically require more energy to keep the unit cold.
* Chest Freezer – This was excluded due to the coefficient being statistically insignificant and, more importantly, the coefficient had the opposite sign. That is to say, on average, chest freezers were estimated to use more energy (which is inconsistent with similar freezer models developed as part of other evaluations), holding all other factors constant.

The refrigerator model specification is as follows:

ΔkWh = [261.57 + (Age \* 11.59) + (Pre-1990 \* 340.04) + (Size \* 20.34) + (Single-Door \* -767.24) + (Side-by-side \* 449.78) + (Proportion of Primary Appliances \* 20.22) + (CDDs\* unconditioned \*1.44) + (HDDs\*unconditioned \*-20.4)] \* Part Use Factor

Where:

Age = Age of retired unit

Pre-1990 = Pre-1990 dummy (=1 if manufactured pre-1990, else 0)

Size = Capacity (cubic feet) of retired unit

Side-by-side = Side-by-side dummy (= 1 if side-by-side, else 0)

Single-Door = Single-Door dummy (= 1 if Single-Door, else 0)

Primary Usage = Primary Usage Type (in absence of the program) dummy

(= 1 if Primary, else 0)

Interaction: Located in Unconditioned Space x CDDs = Proportion of units in unconditioned spaces interacted with CDDs

Interaction: Located in Unconditioned Space x HDDs = Proportion of units in unconditioned spaces interacted with HDDs

Part Use Factor = To account for those units that are not running throughout the entire year.

= 0.877[[2]](#footnote-2)

Applying the average refrigerator characteristics from AIC’s PY4 program results in the following equation:

ΔkWh = [261.57 + ( 22.81 \* 11.59) + (0.45 \* 340.04) + (18.82 \* 20.34) + (0.1 \* -767.24) + (0.17 \* 449.78) + (0.34 \* 20.22) + (1.29 \* 1.44) + (6.49 \* -20.4)] \* 0.877

= 944 \* 0.877

= 828 kWh

The freezer specification model is as follows:

ΔkWh = [-33.29 + (Age \* 15.7) + (Pre-1990 \* 93.37) + (Size \* 36.52) + (CDDs\* unconditioned \*27.44) + (HDDs\*unconditioned \*-6.13)] \* Part Use Factor

Where:

Age = Age of retired unit

Pre-1990 = Pre-1990 dummy (=1 if manufactured pre-1990, else 0)

Size = Capacity (cubic feet) of retired unit

Interaction: Located in Unconditioned Space x CDDs = Proportion of units in unconditioned spaces interacted with CDDs

Interaction: Located in Unconditioned Space x HDDs = Proportion of units in unconditioned spaces interacted with HDDs

Part Use Factor = To account for those units that are not running throughout the entire year.

= 0.877[[3]](#footnote-3)

Using the average freezer characterization for AIC’s PY4 program, we calculate the following average result:

ΔkWh = [-33.29 + (26.92 \* 15.7) + (0.6 \* 93.37) + (15.9 \* 36.52) + (6.61 \* 27.44) + (1.3 \* -6.13)] \* 0.877

= 1021 \* 0.877

= 895 kWh

We did not perform a separate regression model to estimate kW demand savings and propose using the coincident factor of 0.00012 from past Cadmus evaluations.

1. http://www.energystar.gov/index.cfm?fuseaction=refrig.calculator [↑](#footnote-ref-1)
2. Weighted average PY2 and PY3 part use factor from Opinion Dynamics, May 31 2012 memo; “Fridge & Freezer Recycle Rewards Program PY4 Metering Study: Preliminary Savings Results”. [↑](#footnote-ref-2)
3. Weighted average PY2 and PY3 part use factor from Opinion Dynamics, May 31 2012 memo; “Fridge & Freezer Recycle Rewards Program PY4 Metering Study: Preliminary Savings Results”. [↑](#footnote-ref-3)