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Memorandum

Date:	May 27, 2011
To:	David Nichols and ComEd Residential Lighting Interested Parties
CC:	Jeff Erickson and Randy Gunn; Navigant Consulting
From:	Amy Buege and Jeremy Eddy; Navigant Evaluation Team
RE:	Lighting Logger Study Results – Version 2

This memorandum presents the results from the lighting logger study conducted as part of the PY3 ComEd Residential Lighting Program evaluation. This memo outlines the data collection and analysis activities that have taken place as part of this study and presents the hours of use (HOU) and peak coincidence factor (CF) estimates stemming from these activities.

Background

As part of the PY3 evaluation of ComEd's Residential Lighting program the Navigant Consulting team conducted a lighting logger study[1] in order to estimate the average Hours of Use (HOU) and Peak Coincidence Factor (Peak CF) of CFLs installed in homes within ComEd's service territory. HOU and Peak CF are two key parameters used to estimate residential lighting gross energy and peak demand savings. Currently the ex ante HOU and Peak CF being used to estimate program impacts are 2.34 and 0.081, respectively. The 2.34

[1] A detailed description of the lighting logger study can be found in a document titled *ComEd Residential Energy Star Lighting Program Metering Study: Overview of Study Protocols*. Submitted to ComEd on June 3, 2010.

average HOU is a deemed value adopted by the Illinois Commerce Commission from testimony made by Val Jensen, then of ICF.

Sampling and Data Collection

To estimate HOU and Peak CF for ComEd's residential lighting program the Navigant Consulting Team installed Dent Lighting Loggers (hereafter referred to as "loggers") in 67 households where CFLs were currently in use. These loggers allow for the calculation of the usage of a particular CFL by recording the exact date and time each light is switched on or off. The PY2 General Population survey served in part to prescreen ComEd households for inclusion in this logger study. All surveyed customers who had purchased a discounted CFL in the past year were asked if they would be willing to participate in the lighting logger study and 32 of the 122 queried agreed. In order to meet our study requirements of 67 participating households we next reached out to CFL purchasers identified through the PY2 in-store intercept surveys or the PY1 General Population or coupon surveys. All customers who agreed to participate in the logger study were called back within a few weeks of the initial prescreen call to schedule a time for a technician to come to their home to complete a lighting inventory and install lighting loggers on a sample of the CFLs the customer had installed inside or outside their home. All customers who participated in the logger study received two $50 gift cards (one at the time of logger installation and one and the time of logger removal) in appreciation for their participation in the study.

A total of 527 lighting loggers were installed across the final sample of 67 homes between June and August 2010. These loggers were left in place for approximately 7.5 months and were removed from the field between January and March, 2011.

Data Quality Inspection

A total of 515 of the initially installed 527 loggers were removed from the field (10 were lost due to home foreclosure and two others were missing when the technician returned to collect them). An additional 16 of the installed loggers had either been removed by the homeowner, had fallen off the light fixture, had malfunctioned, or had a dead battery and so were excluded from the analysis dataset. Data from an additional 8 loggers was not used in the analysis as a result of the logger being placed on an incorrect bulb type (a non-CFL), or the bulb being replaced by a non-CFL bulb or burning out during the metering period (this was noticed and recorded at the time of logger removal)[2]. Data from the remaining 491 loggers was downloaded and visually inspected for signs of unrealistic patterns of on/off switching that could be the result of the logger picking up ambient light or other mechanical or measurement problems. The purpose of this individual/visual inspection was to ensure that the loggers had been installed correctly and had functioned properly throughout the monitoring period.. In all, 132 loggers were identified as problematic and were thus dropped from the analysis dataset based on this inspection[3]. This quality inspection of the logger data yielded a final sample of 359 loggers with good data from a total of 65 homes.

HOU Analysis

The Navigant Consulting Team developed the HOU calculation using all logger data sufficient for use in the analysis[4] which yielded a final analysis sample of 346loggers. Total on-time for a given logger on a given day was calculated by summing the intervals during which the logger was detecting light in each 24-hour period.

HOU Weighting

In order to expand the collected lighting logger data to the entire ComEd customer population, two levels of weighting were applied to each logger. The first served to weight each individual logger up to the total number of CFLs controlled by the same light switch as the loggered CFL. The second weight was applied by room type and served to align the room-type distribution of the loggered CFLs used in the HOU analysis (from 65 homes, 346 loggers, and 557 lamps loggered) to the room type distribution of the installed CFLs found during the onsite lighting inventories (142 homes, 2,148 total lamps). This second weight was calculated as the ratio of the number of CFLs installed by room type over the number of

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[2] This number appears higher than in the version of the memo since the order in which the drop occur have been changed. Previously the problematic loggers were first dropped and then any remaining logger data coming from bulbs that had burned out or been replaced with non-CFLs were dropped.

[3] A typical reason that a logger was thrown out was that the logger was logging natural or ambient light, rather than the intended lamp. Often this was identified by the technician when they were extracting the logger and confirmed by the visual inspection of the data.

[4] Note the requirement for each logger to have at least 16 weeks of good data was removed and replaced with a detailed review of all documents (including all installation and removal technician comments, as well as homeowners self-reported HOU estimates) pertaining to each of the 14 loggers that were previously dropped. Based on this review a keep or drop decision was made on a logger by logger basis. This resulted in keeping nine loggers and dropping five.

CFLs loggered[5] by room type. Table 1 below shows the distribution of the installed CFLs from the onsite inventory population, the distribution of the loggered CFLs (weighted by lamps per logger) used in the HOU analysis, and the resulting room-based HOU weights that were applied. As the table below shows, the average room-based HOU weight applied was approximately 3.86.

Table 1. Distribution of CFLs by Room Type, Inventory vs. HOU Analysis Population

Room Type	Distribution of CFLs Installed from Onsite Inventory (n=142)		Distribution of Loggered CFLs (wt'd) used in Analysis (n=65)		Room-based HOU Weights
Basement	225	10%	77	14%	2.92
Bathroom	304	14%	79	14%	3.85
Bedroom	371	17%	107	19%	3.47
Dining	61	3%	13	2%	4.69
Foyer	51	2%	11	2%	4.64
Garage	68	3%	10	2%	6.80
Hallway	65	3%	33	6%	1.97
Kitchen	265	12%	45	8%	5.89
Laundry/Closet	150	7%	40	7%	3.75
Living Room	322	15%	93	17%	3.46
Office/Den	94	4%	40	7%	2.35
Other	24	1%	2	0%	12.00
Outdoor	148	7%	7	1%	21.14
Total	**2,148**	**100%**	**557**	**100%**	**3.86**

As the table above shows, the loggered CFLs in outdoor spaces were assigned unusually high weights. An in-depth review of the outdoor logger and inventory data found these high

[5] The number of loggered CFLs in this ratio was calculated after the first weight had been applied so that it was representative of all CFLs controlled by the same light switch as the single loggered CFL.

weights were assigned due to the limited usable outdoor lighting logger data (outdoor CFLs comprised 7% of the CFLs installed in a home but only 1% of the usable logger data). This limited data resulted from the fact that fewer loggers were installed on CFLs in outdoor spaces due to issues accessing the bulbs and difficulty getting quality data as a result of ambient light issues which are prevalent in outdoors locations. Across all room types, loggers were installed on approximately 42% of the CFL fixture groups found in a home compared to outdoor fixture groups where only 21% were loggered. And across all of the loggers installed, 65% of the data was deemed "good" and thus included in the analysis; whereas only 19% of the logger data from outdoor spaces was usable (4 of 21 loggers installed). As a result, the evaluation team recommends discarding the outdoor logger data from the HOU analysis and adjusting for that fact in the analysis, as described below.

Annualization

Because the logger data used in the analysis was collected over a portion of the year (roughly 7 1/2 months) it was necessary to annualize the logger data in order to generate an average HOU estimate representative of the entire year. Because the days when loggers were installed were more heavily weighted toward winter days when the shorter daylight hours typically lead to longer average HOU, it was anticipated that the annualization process would yield an average annual HOU lower than that of the raw logger data. To annualize the data a LengthOfDay variable was created for each day that was included in the analysis dataset. This variable was created using a sinusoid curve and took a value between -1 (on the winter solstice) and 1 (on the summer solstice) and was equal to 0 on the spring equinox and fall equinox. The formula used in SAS to derive this variable was as follows:

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LengthOfDay = sin(3.14159*('21sep2010'd - date)/182.5);

where ('21sep2010'd - date) is the number of days between the current date and the fall equinox.
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A regression was then run in SAS for each of the loggers in the analysis dataset that generated a modeled sinusoid estimate of daily HOU across the entire year. The estimated annual hours of use for each logger could then be aggregated to generate an overall average HOU estimate across all loggers, by household, or by specific room type. In the previous version of the memo we dropped all loggers having less than 113 days of data that could be included in the regression. Each of the 14 loggers dropped for this reason were individually re-inspected and a keep/drop decision was made for each based the logger data, comments from the technician removing the logger and the homeowners self-report of how many hours per day they estimated the CFL was in use. Based on this re-inspection the decision was made to keep 9 of these 14 loggers. However, due to the shorter time frame of available data, the evaluation team decided to use the raw observed HOU from these 9 loggers in the calculation of an overall average HOU value, as opposed to the modeled, annualized HOU used for the loggers with 113 or more days of collected data. The average difference between the observed HOU and the modeled HOU for these 9 loggers was 0.03 hours/day.

Interior HOU Results

The weights described above were applied to the individual logger HOU estimates to come up with the average interior HOU estimate of 2.57 hours +/- 0.34 (13%). Table 2 below provides the HOU estimates by room type, the 90% (two-tailed) confidence intervals for each of these estimates and the number of loggers each estimate is based on for each of the interior room types. As this table shows, the HOU estimates vary significantly by room types from a low of 1.54 HOU/day in laundry/closet areas to a high of 7.16 HOU/day in foyers. It should be noted that some of these results (such as those for foyers, dining rooms and garages) are based on relatively small sample sizes and thus have high levels of uncertainty at the room type level. As one might expect, the CFLs found in the common living spaces have HOU estimates right around the mean (such as living rooms and dining rooms), while CFLs in kitchens typically have higher than average use and those in bedrooms and bathrooms have lower than average use.

Table 2: Average Daily Hours of Use by Room Type

Room Type	n	Average HOU	Lower 90% CL[6]	Upper 90% CL
Basement	41	2.24	1.50	2.98
Bathroom	34	1.70	1.03	2.36
Bedroom	74	1.69	1.12	2.25
Dining	7	2.94	0	6.66
Foyer	7	7.16	0.80	13.52
Garage	8	2.94	0	7.67
Hallway	21	4.39	2.23	6.54
Kitchen	18	4.09	2.70	5.49
Laundry/Closet	32	1.54	0.54	2.55
Living Room	69	2.61	1.96	3.26
Office/Den	29	2.59	1.01	4.16
Other	2	2.82	1.38	4.26
Mean HOU	**342**	**2.57**	**2.23**	**2.91**

Interior HOU Results by Month

Table 3 below shows the average daily HOU by month that resulted from the regression models and the percentage of the maximum monthly HOU each of these values represented. As this table shows the longest regression based daily HOU estimate for the year was found in December (2.95 hours) and the shortest was found in June (2.22 hours and 75% of the December daily HOU estimate).

[6] Lower Confidence Limits were set equal to a minimum of 0.

Table 3: Average Daily Hours of Use by Month

Month	Regression HOU Estimate	% of Max HOU
June	2.22	75%
July	2.25	76%
August	2.37	80%
September	2.55	86%
October	2.74	93%
November	2.89	98%
December	2.95	100%
January	2.92	99%
February	2.80	95%
March	2.63	89%
April	2.44	82%
May	2.29	77%

Exterior and Overall HOU Results

As mentioned above, due to the very limited amount of outdoor loggered CFL data available (4 loggers) and the relatively large proportion of the CFLs installed outside the home (they represent 7% of total bulbs), the evaluation team recommends estimating HOU for exterior CFLs using secondary research rather than logger data collected as part of this study[7]. Table 4 below provides a listing of the studies found that included separate HOU estimates for exterior CFLs. This table also shows the percent of CFLs that were installed in exterior locations for each of these studies and the resulting overall, interior and exterior HOU estimates. Using this data, two ratios were calculated; the ratio of the overall HOU to the interior HOU and the ratio of the exterior HOU to the overall HOU. The average overall/interior ratio was 107% and the average exterior/overall ratio was 180%. The distribution of CFLs installed in interior versus exterior locations was estimated for each study based on the interior, exterior and overall HOU results. As this table shows the average percentage installed in outdoor locations across these four studies was found to be 7%, which matches the percentage installed in outdoor locations in ComEd's service

[7] The data from the four usable outdoor loggers had HOU estimates of 0, 3, 15, and 24 hours resulting in a weighted HOU estimate of 10.4 hours +/- 11.8 hours (133%).

territory. Applying these ratios to the ComEd Interior HOU estimate resulted in an exterior HOU estimate of 5.00 hours and an overall HOU estimate of 2.74 hours.

Table 4: Exterior HOU Ratio Estimation

Study (Yr)	% Exterior[8]	Overall HOU Estimate	Interior HOU Estimate	Ratio of Overall/Interior	Exterior HOU Estimate	Ratio of Exterior/Overall
Efficiency Maine (‘05-‘06)	7%	3.2	3.2	107%	5.5	172%
CA Metering Study (‘06-‘08)	10%	1.9	1.7	112%	3.8	200%
CA Metering Study (‘05)	4%	2.3	2.3	103%	3.1	132%
EmPower Maryland (‘10)	5%	2.9	2.7[9]	106%	6.2	217%
Average	**7%**			**107%**		**180%**
ComEd HOU Ratio Estimate		**2.74**	**2.57**	**107%**	**5.00**	**182%**

Snapback

A literature review was conducted to determine whether previous lighting evaluations had considered snapback resulting from the installation of CFLs[10], and if so, what methods had been used to measure it. A few older studies (mostly pre-2002) were found that attempted to assess the level of snapback resulting from CFL installations. Each of these studies used customer self-reports of pre/post CFL-installation behavioral changes from telephone surveys, as opposed to physical measurements, to gauge the level of snapback. The results from each of these studies found evidence of a low to moderate level of snapback, however all but one of these went on to state that the data was not reliable enough to alter the resulting ex post impact estimates[11]. Based on this review, we do not believe there is adequate data in

[8] Estimated based on Interior, Exterior, and Overall Results.

[9] Estimated based on distribution of interior and exterior bulbs. Report did not provide interior HOU estimate.

[10] Snapback refers to an increase in usage of energy efficient devices due to the lower cost associated with operating them.

[11] Studies reviewed that included an investigation into snapback included: 2002 evaluation of Cape Light’s CFL program (ODC), 1999 evaluation of IFC/GEF Poland CFL program (Navigant), 1994/1995 Exeter and

the secondary literature around which to base whether a credible snapback estimate can be calculated.

Peak CF Analysis

In order to estimate the Peak CF resulting from the lighting logger study the Navigant Consulting Team calculated the percentage of time a given logger was turned on during the "peak" time period. The results presented here are for the ComEd "peak" defined as weekdays from 1 p.m. to 5 p.m.[12] Logger data from the period between June 24th and August 31st was used to estimate the Peak CF and all loggers having at least 11 days worth of data during this period were included in the analysis dataset (325 loggers, 536 lamps loggered).

Peak CF Weighting

Weights for the Peak CF analysis were developed in the same manner as for the HOU analysis. The HOU and Peak CF weights differ slightly due to the different population of loggers used in the two analyses. Table 5 below shows the distribution of the installed CFLs from the onsite inventory population, the distribution of the loggered CFLs (weighted) used in the Peak CF analysis, and the resulting room-based Peak CF weights that were applied. As the table below shows, the average room-based weight applied was approximately 4.01.

Hampton Electric evaluation (WECC conference paper), 1993 EPEC paper (Steven Nadel), 2007 Efficiency Maine Lighting Program (NMR). The Poland evaluation was the only that included snapback in their estimation of program impacts.

[12] This is also the PJM bidding "peak" (2 p.m. to 6 p.m. Eastern Standard Time).

Table 5. Distribution of CFLs by Room Type, Inventory vs. Peak CF Analysis Population

Room Type	Distribution of CFLs Installed from Onsite Inventory (n=142)		Distribution of Loggered CFLs Installed used in Analysis (n=65)		Room-based Peak CF Weights
Basement	225	10%	85	16%	2.65
Bathroom	304	14%	76	14%	4.00
Bedroom	371	17%	102	19%	3.64
Dining	61	3%	12	2%	5.08
Foyer	51	2%	11	2%	4.64
Garage	68	3%	10	2%	6.80
Hallway	65	3%	28	5%	2.32
Kitchen	265	12%	43	8%	6.16
Laundry/Closet	150	7%	39	7%	3.85
Living Room	322	15%	83	15%	3.88
Office/Den	94	4%	38	7%	2.47
Other	24	1%	2	0%	12.00
Outdoor	148	7%	7	1%	21.14
Total	**2,148**	**100%**	**536**	**100%**	**4.01**

Similar to the HOU weights, the CF weights for outdoor spaces were unusually high and thus the evaluation team recommends discarding the outdoor logger data from the Peak CF analysis and adjusting for that fact in the analysis, as described below.

Interior Peak CF Results

The weights described above were applied to the individual Peak CF estimates to come up with the average interior Peak CF estimate of 0.095 +/- 0.017(18%). Table 6 below provides the Peak CF estimates, the 90% confidence intervals for each of these estimates and the number of loggers each estimate is based on across all interior room types. As this table shows, the Peak CF estimates vary significantly by room types from a low of 0.043 in the bedroom to a high of 0.237 in foyers. Again it should be noted that some of these results (such as those for foyers, dining rooms and garages) are based on relatively small sample sizes and thus have high levels of uncertainty that surround around them at the room type level.

Table 6: Peak CF Results by Room Type

Room Type	n	Average Peak CF	Lower 90% CL[13]	Upper 90% CL
Basement	41	0.128	0.068	0.189
Bathroom	31	0.072	0.032	0.111
Bedroom	69	0.043	0.026	0.059
Dining	6	0.134	0.010	0.258
Foyer	7	0.237	0	0.517
Garage	8	0.099	0	0.275
Hallway	19	0.095	0.047	0.143
Kitchen	17	0.149	0.055	0.243
Laundry/Closet	31	0.066	0.020	0.113
Living Room	62	0.094	0.053	0.136
Office/Den	28	0.105	0.032	0.178
Other	2	0.062	0	0.393
Mean CF	**321**	**0.095**	**0.079**	**0.112**

Exterior and Overall Peak CF Results

As mentioned above, due to the very limited amount of outdoor loggered CFL data available (4 loggers) and the relatively large proportion of the CFLs installed inside or outside a home (they represent 7%), the evaluation team recommends estimating Peak CF using the ratio estimation method employed within the HOU analysis for exterior CFLs rather than the data collected for this study[14]. This method resulted in an exterior Peak CF estimate of 0.184 and an overall Peak CF estimate of 0.102.

Ex-Ante versus Ex-Post Results

Table 7 below presents the Ex-Ante versus Ex-Post results based on the PY3 ComEd loggering study. As this table shows the Ex-Post result for HOU was 17% higher than the Ex-Ante estimate and the 90% confidence interval on the Ex-Post estimate does not include

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[13] Lower Confidence Limits were set equal to a minimum of 0.

[14] The data from the four usable outdoor loggers had Peak CF estimates of 0, 0.01, 0.99, and 1 resulting in a weighted Peak CF estimate of 0.570 +/- 0.663 (116%) which includes both 0 and 1 (the minimum and maximum Peak CF estimates).

the Ex-Ante estimate. The Ex-Post result for Peak CF was 25% higher than the Ex-Ante estimate and again the 90% confidence interval on this Ex-Post estimate does not include the Ex-Ante estimate.

Table 7: Ex-Ante versus Ex-Post Results

Estimate	Ex-Ante	Ex-Post	Lower 90% CL	Upper 90% CL	% Increase in Ex-Post
HOU	2.34	2.74	2.41	3.07	17%
Peak CF[15]	0.081	0.102	0.085	0.118	25%

[15] The precision associated with the one-tailed 90% CL on the Peak CF estimate is 12.5%.