New Results and Uses for Measure-Based NEBs/NEIs: Smart Thermostats, and NextGen LED Bulbs

Lisa A. Skumatz, Ph.D., Skumatz Economic Research Associates, Silverthorne, CO
Ann Vander Vliet, Skumatz Economic Research Associates, Loveland, CO

ABSTRACT

More measure-based NEIs are likely to be needed to support program NEI estimation, as programs change over time to introduce new measures, shift the mix of existing measures, change targets, and generally evolve over time. The historic focus on program-based NEIs meant that new NEI estimation work had to be conducted with each new program or program year, because the programs were not static regarding these underlying features. Measure-based NEIs can be more easily used with confidence as programs change the ratio of measures within programs, and a measure-based approach can provide NEI values that are more likely to be transferable across programs.

This paper discusses several aspects of measure- vs. program-based NEIs, and provides new research on NEI values, and the potential that approaches used to estimate measure-based NEIs can have beyond traditional NEI work.

The paper reports on two studies that used hundreds of surveys to develop NEI estimates for two measure types:

- Wi-Fi and Smart thermostats, which have become an increasing part of program portfolios. The results of existing programmable (not Wi-Fi) thermostat NEI studies are presented, alongside new NEI results for new Wi-Fi and smart thermostats, to help identify whether there are differences in NEI estimates or rankings for older vs. newer types of efficient thermostat technologies.
- Next-gen LED residential and commercial lighting technologies (incorporating advanced features related to glare, flicker, color rendition, dynamic lighting, improved outdoor lighting color and other features), which are likely to be future measures for energy efficiency (EE) programs, even as current LEDs phase out.

The research used labeled scaling methods, and the advanced “next gen” LED research added a second approach for comparison (ranking plus willingness-to-pay / WTP). Beyond providing measure-based NEI estimates by sector, the research showed strong market value associated with various “next-gen” LED improvements, and that NEIs can be used to demonstrate the market is willing to pay higher costs for specific EE measure features.

INTRODUCTION – MEASURE VS. PROGRAM-BASED NEIS

The early NEIs literature includes both program-wide NEIs and measure-based NEIs for residential and commercial programs. Where possible, measure-based NEIs are preferred, because they can be applied to new programs, and are adaptable to variations in the mix of measures in a program. Both can be appropriate and relevant. In some cases, the program’s core design includes delivery of a package of core measures and services that may be difficult to separately identify as the independent cause of the NEIs effects to participants. In others, measures are installed singly or in varying combinations of measures that are not duplicative in effects (e.g., installing multiple measures that all contribute to comfort). Sometimes measure-based is appropriate, but other times, such estimates are not feasible or appropriate.

Some NEIs can be estimated for each measure, even when measures may be installed as bundles. This is because a number of NEIs are calculated directly based on their energy savings impacts. For example, even if multiple appliances are always installed together their societal health effects from greenhouse gas (GHG) reduction are calculated using the savings from each measure, and run though EPA's CO-Benefits Risk Assessment model (COBRA) and AVoided Emissions and generation Tool (AVERT) models, as described earlier (in Skumatz 2019). These well-vetted models simplify calculating NEIs to about a 20-minute exercise for a state. COBRA is accessed at https://www.epa.gov/cobra; tutorial at https://www.epa.gov/sites/default/files/2017-10/documents/cobra_training_eic_2017.pdf , and AVERT and training is accessed at https://www.epa.gov/avert. This is one example where it is not strictly necessary to have these measures installed in separate groups, so long as the measure definitions in the Technical Resource Manual (TRM) or other sources have specific, individual savings estimates.

Other NEIs are driven off measure costs and lifetimes, like deferred replacement costs, and again, can be calculated independently, even if the measures are installed as a group or bundle. Models for job and output NEIs (like IMPLAN™or RIMS II) will depend on the specific measures installed and their proportions, and cannot be well-estimated using only program-wide savings. Previous research demonstrates dramatically that all savings are *not* the same in regard to output and jobs results (see Gardner and Skumatz 2007; Skumatz 2006).

Estimating measure-based NEIs increases costs because it requires statistical samples for each measure – or each bundle of measures – of interest. Early commercial NEI studies include the program-wide Seattle Operations Resource Assessment (ORA) program, and its measure-specific air compressor program. Early residential NEIs studies include the program-wide California low income retrofit program, and the measures-specific NEIs estimates provided for New York State Energy Research and Development Authority (NYSERDA's) individual appliances in the retail products program.

Paper's Examples of Measure-Based NEIs

This paper provides a focus on measure-based NEIs for two measures -- thermostats and LEDs – and presents new NEI estimates for Wi-Fi thermostats. The paper also attempts to show how a focus on measure-based NEIs can go beyond the traditional. The study develops NEI results using several different NEI measurement methods, and explores the feasibility of estimating NEIs from non-utility sourced data (thermostats). The last section also demonstrates that NEI approaches may be useful in valuing "hard to measure" effects (here, for LEDs), and that NEI-type measurement approaches may even be useful in other applications.

NEIS FOR RESIDENTIAL NON-WIFI THERMOSTATS

The source for the data on thermostat NEIs is a comprehensive NEI literature survey database developed and maintained by the authors. This database (SERA's "NEB-It" database) has more than 44,000 data elements including NEI values and NEI calculation inputs used in more than 500 NEI studies conducted in the US and internationally. The entries indicate measures, program types, state, primary vs. secondary estimate, and a host of other information to make the database sortable, and a rich and transparent source for NEI and NEI input values for an associated NEB calculation model (SERA's "NEB-It" model, estimating more than 100 NEIs).

The authors mined that database for the data on thermostats. The studies included in the database ranged in vintage from 2011 to 2020, and included thermostat NEI estimates for the residential, multi-family, and commercial sectors. These studies cover programmable thermostats, which can control heating and cooling in a home based on a preset schedule. These are not Wi-Fi and not smart thermostats which, in addition to being programmable, can connect to Wi-Fi. A Wi-Fi connection allows the thermostat to be controlled by a smart phone and offers features such as geofencing (adjust temperatures when a resident leaves and returns), voice control through home ecosystem integration (Alexa, Google Home, Apple Homekit), use of room sensors for target rooms that may or may not sense occupancy, and may "learn" an occupants routine to automatically set or adjust a program.

There is one NEI measurement in the literature for commercial thermostats. Russel (2015) cites MA-EEAC (2012) with a total NEI savings of $0.14/therm for the commercial sector. A review of SERA's "NEB-It" database finds that a total of six studies have provided estimated NEIs for thermostats. A review of the study data indicates the studies address utility-installed programmable thermostats, but do not address Wi-Fi thermostats. A few of the studies are a little vague on whether they clearly conducted the estimation work showing the NEIs associated with the new thermostat relative to the baseline (a long-standing key best practice). Beyond the commercial value noted above, the database finds estimates for the following counts of NEI values.

Multi-family Thermostat NEI Estimates

- Property Manager (PM) Operations &Maintenance O&M impacts (6 estimates);
- Property Manager Property value changes (5)
- PM-Marketability effects (4),
- PM-tenant complaints (4 and a 2)
- Household / Unit level comfort (3)
- Household / unit level Health (all) (3)
- Household / unit level Fuel Price hedging (2)
- Household / unit level rate discounts (2)

Single Family Thermostat NEI Estimates ((1) if blank)

- Rate discounts (2)
- Fuel Price Hedging (2)
- Cold Stress
- Heat stress
- Missed Work
- Comfort
- Home durability
- Productivity
- Asthma

Figures 1, 2, and 3 show the average values for the specific NEIs noted above. Figure 1 shows the NEBs as a percent of energy bill savings, a method that can help with transferability, and a value that immediately shows the relative impact on benefit-cost ratios.

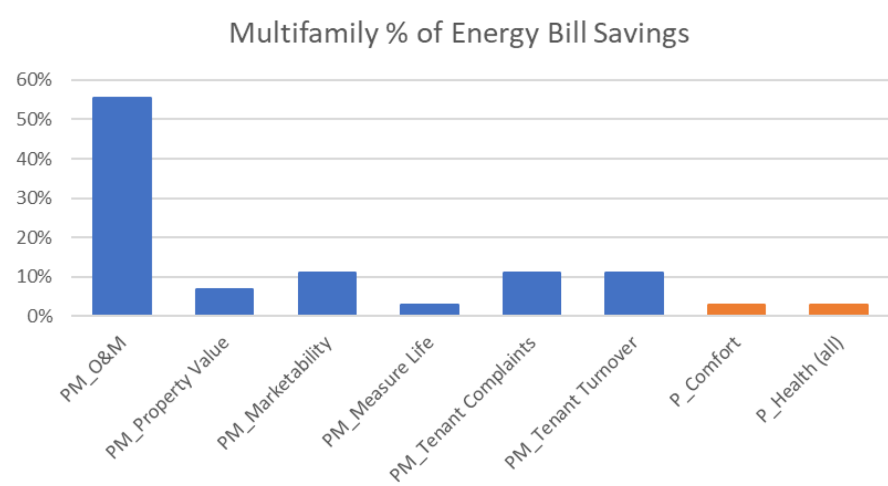


Figure 1. NEIs as a Percent of the energy bill savings for Multifamily Property Managers (PM) and Tenants (P) (average). *Source*: SERA "NEB-It" Database

Figure 2 presents multifamily *building level* NEIs. Figure 3 presents the values from the *household-level* for single- and multi-family studies in the various terms examined. The various bars present results in terms of: dollars per thermostat (multifamily), dollars per building per year (multifamily), dollars per unit per year (multifamily), and dollars per household per year (single family), as noted. Averages are presented; recall that the number of studies is low (noted above). The value for the NEI of multi-family "property value" is divided by

15, to normalize to the 15-year lifetime of the thermostat measures. Readers can easily divide by a different lifetime as appropriate for their application.

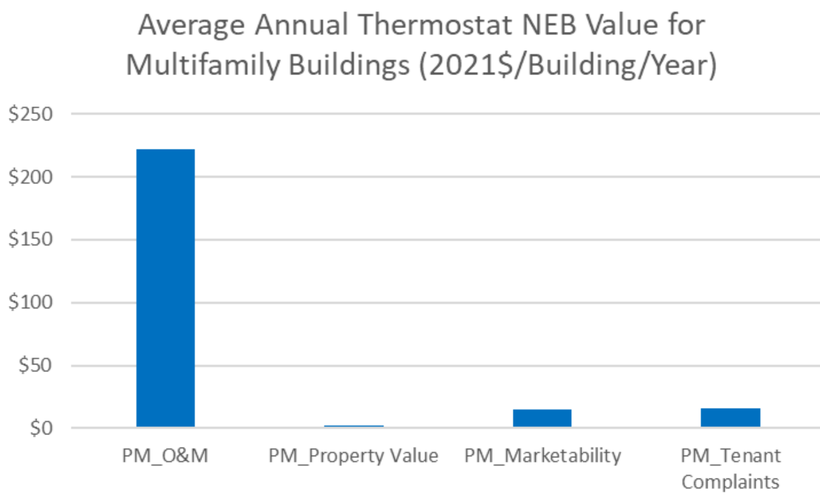


Figure 2. NEI value – dollars per year per Multifamily Building (average)
Source: SERA "NEB-It" Database

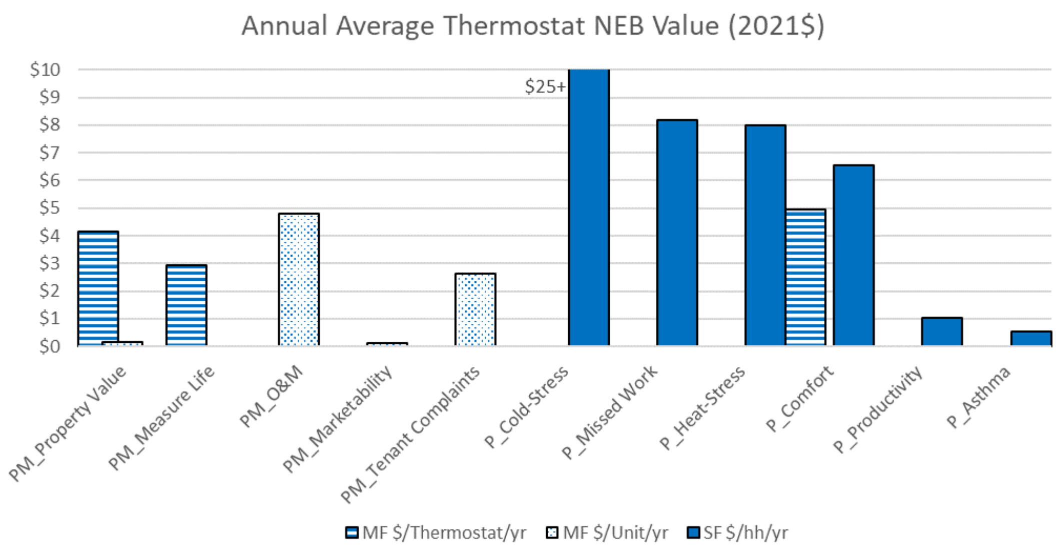


Figure 3. NEI values for Single and Multi-family thermostats (average); Units identified in Key
Source: SERA "NEB-It" Database

Both percentages and dollar value approaches have advantages and disadvantages, and both are useful. Note that the values for all averages were scaled to current dollars; the values for percent multipliers do not have to be adjusted. Note one final comment on the presentation of NEBs in somewhat different units. The NEIs literature would be greatly enhanced if every NEI study presented the results in terms of the size of the effect if the participant is affected as well as weighted to program-wide numbers based on the percentages of participants that do and don't receive certain measures or treatments. Including the former allows numbers to be transferred to other programs more easily; the percentage of participants that would be expected to have an effect (have a causal measure, for instance) could be changed, and results within a utility could be easily adjusted over time as the measure mix changes. This applies to both percentages and to dollar NEI results.

Recall that the number of responses for each NEB are presented in bullets above and are six or fewer in all cases. The results show:

- The highest valued-NEBs for Multifamily are Property Manager Equipment Maintenance and Tenant Complaints, and this is the same for the studies that expressed their results in terms of dollars vs. percentages.
- Single Family NEIs for thermostats in the literature are largely health related. The highest valued NEI for Single Family households is Cold-related thermal stress reduction, followed by Missed Work, Heat-related thermal stress, and Comfort. These impacts may be positive marketing approaches.
- The NEIs related to Measure Life and Property Value for Property Managers, and Comfort and Health for Occupants of Multifamily buildings are lower value in both sets of studies. Productivity, reduction in Asthma, and Home Durability are the lowest values for Single Family households.
- The sum of the value of the Multifamily NEIs is about 1.05 times the energy savings (from the studies in Figure 3). These results indicate that participants (Property Mangers) recognize a simple payback from thermostats that is half as long as would result from a payback based on energy savings alone. Almost half of this value is from reduced equipment maintenance.

Program planners may find it useful to consider these bigger-picture valuation results as they consider refinements to incentive levels.

NEIS FOR RESIDENTIAL WI-FI AND SMART THERMOSTATS

As the review of the literature indicated, all of the publicly available NEI estimates for thermostats pre-date the development of Wi-Fi / smart / learning thermostats and cover “programmable” thermostats. To address part of this gap, the authors conducted an NEIs study of residential Wi-Fi or “smart / learning” thermostats. This section discusses the results for the participant and priority societal NEIs for smart thermostats.

The study was not based on a utility program. Instead, the authors conducted a survey of households in three states – Connecticut, Massachusetts, and New Hampshire. This was because the SERA survey was more comprehensive than NEIs alone. The study was designed to also obtain information from the at-large population on which types of thermostats are installed in all households, so the researchers could identify remaining potential from non-Wi-Fi thermostats, and also gathered data on smart thermostat lifetimes, satisfaction, use of programmable features, age, and other data (subjects of a future paper). The study also had a broader goal of testing approaches using non-utility samples for NEI and other purposes.

In this study, households were asked whether they had installed Wi-Fi or smart thermostats (using photos) and asked about the age and use of the measures, as well as a series of questions to allow estimation of the NEIs *beyond simpler, non-Wi-Fi, programmable models*. The study is based on results from 369 total respondents. The responses were obtained from purchased sample, using a web approach, with qualifying questions of having identified at least one Wi-Fi thermostat installed (identified via specific photos) and living in one of the states of interest. Extensive additional cleaning was conducted to improve reliability; and Covid has definitely affected these purchased samples. Data cleaning steps removed those with too many thermostats (clicking many to qualify), speeding through the survey (click-through’s), inconsistent responses, inappropriate / irrelevant information in open-ended boxes, and other cleaning work.

The study used the <u>labeled scaling method</u> for a number of NEIs, asking households in verbal terms, how much more / less valuable the NEI was than the energy savings associated with the measure. Briefly, that approach avoids asking respondents for dollars or willing-to-pay answers to value NEIs, but instead, uses <u>*scaled word phrases*</u> to ask how much more or less valuable the NEIs are relative to something with known dollar value (here, energy savings, but many options are possible). Skumatz (Gardner and Skumatz 2002; Skumatz, Khawaja, and Colby 2009) pioneered and adapted the approach from journal articles on labeled scaling (e.g., Lim 2011 and earlier publications), which have demonstrated that wide ranges of populations assign very similar multiplicative factors to these specific sets of scaled word phrases, allowing easy answers to survey respondents (allowing larger samples, higher quality responses, and better statistics), plus (academically-) defensible multiplicative factors to assign and use. However, as an additional check on in-sample consistency, in SERA surveys, we also ask respondents to translate that labeled scale value to percentage terms for about one-third of the NEIs for which they responded. These percentage values were averaged across all survey respondents to estimate an in-sample percentage multiplier value for every labeled scaling response. The study used a 9-point labeled scale approach. Of course, both positive and negative effects were queried, and respondents were reminded repeatedly to express effects beyond the baseline. Note that the results do not include any decreases for local or program Net to Gross (NTG); therefore, users transferring these results will need to apply relevant values for that factor for program attribution. Additional analytical steps involve correcting for reports of overlap, and normalizing the multipliers so the sum matches the total.

Additional NEIs were estimated using survey responses on changes in incidence of a NEI effect – specifically related to illnesses. Again, the “net” effects were requested. It goes without saying that the degree to which households can answer these questions correctly is always suspect; studies that can, instead, include non-participants / control groups and collect pre-post incidence values are always preferred and should be strongly encouraged for NEIs and a number of other types of evaluation studies.

The list of NEIs caused by thermostats was based on a review of the literature on previous studies, and previous research the authors had conducted on favorite features and (positive and negative) experience with smart thermostats. The study included NEIs that are included in benefit-cost work, but also some that provide angles for some of the other uses of NEIs that can be useful for these thermostats, including marketing angles. The list below indicates the NEIs using labeled scaling vs. survey-reported incidence or occurrence changes that were valued based on secondary health literature or other secondary data (e.g., wages, etc.). The results of the NEI estimation work for residential smart thermostats are presented in Figure 4 and 5. NEI values from Wi-Fi-thermostat-attributable changes in the following effects were examined.

- Thermal Comfort (LS)
- Installation and ease of operation (LS)
- Indoor noise from indoor equipment (LS)
- Safety (LS)
- Doing Good for the Environment (LS; for marketing)
- Aesthetics, Chic / Pride / Prestige (LS; for marketing)
- Various Occupant Illnesses (incidence) including: Asthma and similar chronic conditions, and cold /flu symptoms
- Missed days from work (incidence)
- Missed days from school (incidence)
- Heat and cold stress (not included here)
- Utility NEB from reduced carrying charges on arrearages (bill savings based, and measure-agnostic)
- Societal effects from fewer illnesses and deaths from avoided emissions (model-based, and measure-agnostic)

	Changes in…	Comfort	Doing good for the environment	Installation / Ease of operation	Noise from equipment within home	Safety	Aesthetics / Chic / Up to date / Pride / Prestige
1	Net NEI Multiplier, population wide, In-s	0.262	0.251	0.216	0.138	0.209	0.214
2	*Estimated Dollar NEI per household/year*	$11.52	$11.06	$9.49	$6.08	$9.17	$9.43
3	Positive NEI Multiplier In-Sample Estimat	0.39	0.40	0.34	0.34	0.39	0.30
4	Negative NEI Multiplier In-Sample Estima	-0.024	-0.007	-0.010	-0.019	-0.007	-0.015
5	Percent experiencing Positive Effect	66.9%	62.6%	62.6%	39.8%	52.6%	71.3%
6	Percent experiencing Negative Effect	3.8%	1.9%	1.9%	3.8%	2.2%	3.3%
7	Percent experiencing no change	29.3%	35.5%	35.5%	56.4%	45.3%	25.5%
8	*Net NEI Multiplier, Population-wide - Academic for information purposes*	*0.25*	*0.24*	*0.22*	*0.14*	*0.20*	*0.23*
9	*Positive NEI Multiplier for those experiencing an effect - Academic values (for information purposes)*	*0.38*	*0.38*	*0.36*	*0.33*	*0.38*	*0.33*
10	*Negative NEI Multiplier for those experiencing an effect - Academic values (for information purposes)*	*-0.022*	*-0.008*	*-0.010*	*-0.024*	*-0.008*	*-0.016*

Table Note: Savings of about $44 per year identified from literature.

Figure 4. Survey-Based NEI values and supporting information for Wi-Fi / Smart Thermostats

Source: SERA survey in CT, MA, NH

	Changes in…	Asthma	Cold symptoms	Missed days from Work	Missed Days from School
A	Net NEI, Dollars per Household per year	$1.74	$3.18	$9.54	$11.97
B	NEI value for households experiencing the Effect	$839.47	$9.40	$60.50	$80.28
C	*Net Change in Incidences (from survey)*	0.2	0.34	0.16	0.14

Table note: Asthma has additional calculations related to percent with affected children, ect.

Figure 5. Non-Survey-Based NEI Estimates (Dollar/participant/year) for Wi-Fi / Smart Thermostats

Source: SERA survey in CT, MA, NH and calculations

Calculation of these incidence-based NEIs used SERA's "NEB-It" model, along with the incidence changes noted by the survey respondents. NEI for missed days from school used data on childcare wages, percent of families with parents employed full-time, percent of families with children that rely on some form of childcare, and other data. The NEI for missed days from work used data on hourly wages, percent of workers for whom sick leave is available, and other inputs from state, regional, and national sources. The computation of the NEI for changes in asthma relied on asthma incidences, presence of children in the home, direct medical costs, and the average out-of-pocket percentage of payment. Cold symptom results incorporated only the over-the-counter medication costs, and omitted doctor visits and more aggressive strategies.

Key results and conclusions we reach from these two tables include:

- High Net Population-wide NEI Multipliers: Comfort and Doing Good for the Environmental had the highest NEB multipliers, representing 26% and 25% of the value of the energy savings (Line 1).
- Highest NEIs for those experiencing an effect: Comfort, Doing Good for the Environment, and Safety had the highest multiplier for those reporting the effect (line 3). We also examined the percentage of responses across all the labeled scale vales (of the 9-point scale). The results showed that more than 30% of those reporting an effect from both Comfort and from Doing Good for other Environment" reported the two highest multipliers (Not in the table).
- Highest barriers: Negative NEIs represent barriers, or effects that are worse than the baseline measure / situation. All NEIs had some negative reports, varying from 2% to 3.8% of the respondents (line 5). Most common were Comfort (harder to control directly/override/get immediate response from), Noise from Equipment (cycling on/off more often, depending on settings), and Aesthetics (more visible, lighting up). The negative Comfort NEI was also the worst barrier noted, with a multiplier of -0.024 for those experiencing it; not a very strong number.
- In-sample NEI multipliers tracked very closely to similar research: Published articles on labeled scaling (e.g., Lim 2011) show that the phrases used in labeled comparative responses (e.g., extremely more, slightly more, etc.) translate to numeric multipliers that are consistent across populations. We computed the thermostat NEBs using both the in-sample multipliers (Lines 1, 3, and 4) and using values adapted from published studies (Lines 8, 9, and 10). Comparisons of Lines 1, 3, and 4 against the values in lines 8, 9, and 10 show only small differences in the resulting total / aggregated multiplier estimates, suggesting the values have applied well to EE respondent groups, indicating that it may be possible to use the approach and values from publications when numeric in-sample data cannot be collected for budget or survey-space reasons.
- Illness impacts seem high: The results in Line A seem in line with some of the results seen in other estimates for heating equipment, but there have not been many estimates for thermostats. We suspect that respondents had difficulty sorting out effects solely from the thermostats, or the net change from a baseline. However, the SERA "NEB-It" database search finds similarly with orders of magnitude estimates from other studies. There is a value of $3.05 for Colds & Flus from thermostats and heating systems; Missed Work associated with thermostats showed another value of $7.21, and the overall impact of Missed School was £63 in a European study. Asthma incidences from heating systems was about $2.77, giving some credence to our estimate – one would think the value from the thermostat would be a little lower than the heating system – although of course, their operation is inextricably linked. The incidences are probably higher than would be estimated from a true pre/post/control group study.

ADVANCED LEDS

In a recent study, the authors adapted two NEIs estimation approaches and applied them to a non-NEI problem in a non-traditional way. Because the study was discussing equipment that was not yet available, the study used two estimation methods to try to minimize risk that one approach might not be successful. It also allows us to examine differences between the results from the two methods.

The problem of interest was to assign a dollar value to indicate the extra amount that purchasers might be willing to pay for LEDs with specific advanced features. The dollar estimation of the “value” might indicate a maximum for a price that could be associated with that technology when it becomes available in the product. Our monetized values (or prices) were the first step in a larger project that then added to the cost of base technologies as inputs into a long-term lighting market adoption / projection model to determine changes in market share for new technologies and resulting changes in energy efficiency and energy use and savings potential in lighting from the adoption of advanced LEDs in the future. The two NEI estimation approaches are briefly described below.

- Labeled Scaling, or labeled magnitude scaling (LS/LMS): The labeled scaling approach used for NEI work asks respondents to answer how much more or less valuable a NEI effect is – using specific relative word phases - than a factor of known dollar value (usually energy savings). The authors adapted an approach described in journal articles on labeled scaling (e.g., Lim 2011) to apply this easier questioning method to NEIs. The published literature notes that the inherent multipliers associated with those specific phrases are consistent across large population groups. This can allow dollar values to be calculated using easy-to-answer (and non-numeric) questions.
- Ranking & Willingness to Pay (R+WTP): The second method used was rank ordering of sets of technology choices, followed by asking respondents to state the willingness to pay (and percentage extra willing to pay) for top and last-ranked options with advanced features compared to a baseline technology.

The authors included advances in common lighting types used in three different sectors: commercial 4-foot overhead luminaires; residential bulbs, and street/roadway lighting fixture technologies. The advanced LED features under consideration related to visual, non-visual, and environmental advantages, and the technologies (and their energy use) were expected to change over time. The features included advancements in glare, flicker, color, adjustability, and sky / scatter effects for various bulb applications. Some of these new features improve sleep cycles, better match our “circadian” rhythms and daylighting simulation, improve mood, alertness, and improve health and productivity. Two points in time were benchmarked, so the study estimated incremental dollars for both near-term advanced LEDs, and later-term equipment with additional advancements. The technology specifications were provided from lighting engineers, and are outlined in Figure 5 below. The three market sub-sectors that were examined as part of this research (in bold), and the associated “baseline technologies” are listed below.

- **Commercial 4-ft linear**: A mix of typical commercial overhead office lighting, specifically four-foot linear LED luminaires. The baseline technology is assumed to include no design emphasis on the specific advanced features examined in this study.
- **Residential general service**: A mix of residential LED light bulbs (general service),
- **Street/Roadway**: Mix of outdoor LED fixtures, optimized for first cost minimization.

	Feature	Near term, vs. baseline	Longer Term vs. baseline
Com'l	Glare	15% lower EE, no price change	No EE or price changes
	Flicker	10% price increase, no EE change	No change in price or EE
	Color	10% better EE, no price change	20% better EE, no price change
	Adjustable	10% lower EE, no price change	10% better EE, no price change
Resid.	Flicker	10% price increase, no EE change	No change in price or EE
	Color	10% better EE, no price change	20% better EE, no price change
	Adjustable	10% lower EE, no price change	10% better EE, no price change
PW^	Color and effects*	No change in EE or price (50% higher LER)	10% better EE, no price change (80% higher LER)

Table Notes: ^PW=Public Works. (*)Streetlighting color & effects: color: warmer, no blue and accompanying improved human visibility, reduced wildlife effects, night sky advantages. LER is Luminaire Efficacy Rating and is a measure of how efficient a luminaire is (how much light does it put out based on how much energy it consumes).

Figure 5: Feature / Tradeoff Scenarios Studied by Sector

Sector / Respondent Group	Source / Administration Method to Web survey	Number of Responses
Commercial – Lighting Designers	Purchased sample/ emails; emailed link	184
Commercial – Business Owners	Purchased panel survey responses, statistically representative nationwide	400
Commercial – Business Owner Follow-up sample	Purchased panel survey responses, statistically representative nationwide	104
Residential – Builders	Purchased sample / emails; emailed link	104
Residential – Households	Purchased panel survey responses, statistically representative nationwide	400
Street/roadway – Public Works and Utilities	Purchased sample / emails; emailed link	79

Figure 6: Response Counts by Survey Group

The estimation work for this project required a deviation from the traditional NEI survey design because energy savings was not always available as the relatively-known dollar value comparison factor. In basic terms, the questions took the following forms. The LS questions were posed by describing the base case, describing key elements of the new technology with the array of feature changes, and asking how much they would say the *reduction in visual discomfort* from flicker was relative to the 10% higher purchase price, or where available, the x% energy savings, and so on. For the R+WTP option, respondents were provided four scenarios of new technologies, and asked to rank them. Then they were asked the maximum they'd be willing to pay for their top-ranked option, 2nd ranked, and last-ranked options.

Figures 7-9 show the dollar-value results for the lighting with different features. The study developed quantitative results in two forms – annual stream, and present value, akin to a price increment. The dollar valuation results shown graphically in the following figures, identify the results for both the near- and longer-term technologies for each sector. Only the present value / price increment value is shown for simplicity.

When results from multiple respondents were available, the results presented are the weighted average of groups of respondents. The results for the scenarios that have paired results are "near term" scenarios, and the others are the "longer-term" scenarios described in Figure 7 above. These were the values provided to the market share forecasting model.

The reader will note the percentage extra value for the advanced features is shown, along with the base price for the LED without the advanced features in the upper right of each figure.

Clearly, the advanced models – with variations in both feature performance and accompanying changes in energy efficiency– are valuable to potential purchasers, and the individual features add about 12-33% to the value of a base fixture or lamp.

A last result, not presented in the figures, is that the priced increment for the combination of all features is about 55% of the total of individual features for advanced commercial and about 43% of the total for residential lighting. The incremental value falls as more features are added.

Table Key: Glr-glare; Flk-flicker, Clr Rnd=color rendition, Adj Clr=adjustable color spectrum, EE-energy efficiency, Feat.-features.

Figure 7: Commercial Results for Advanced LEDs

Table Key: Glr-glare; Flk-flicker, Clr Rnd=color rendition, Adj Clr=adjustable color spectrum, EE-energy efficiency, Feat.-features

Figure 8: Residential Results for Advanced LEDs

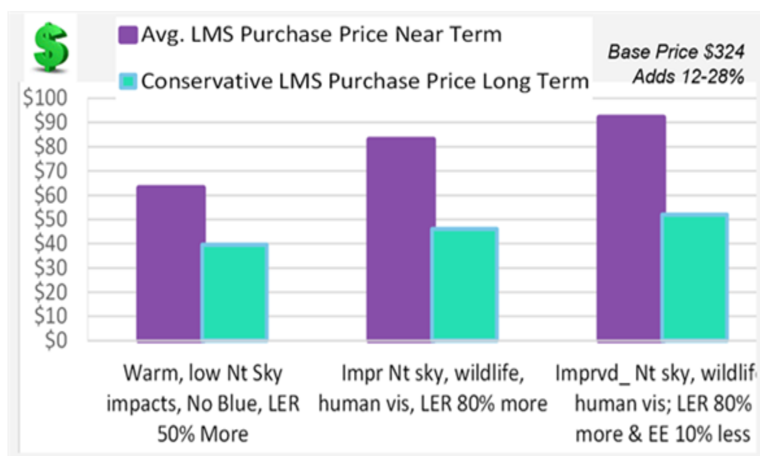
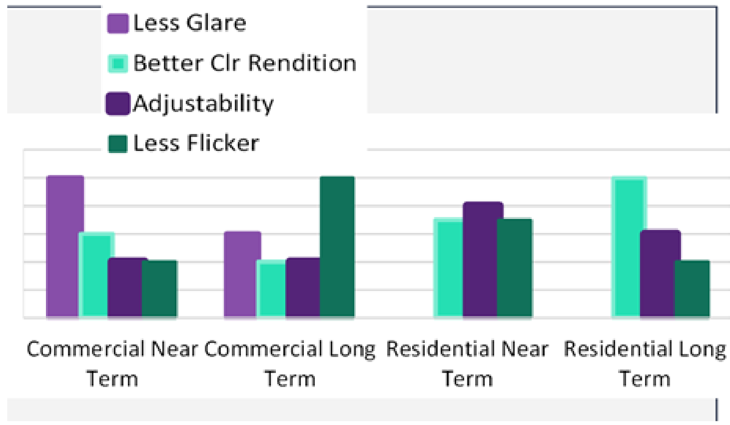


Figure 9: Street / Road Lighting Results

After the study was completed, the authors re-analyzed the data to identify which features were most valued. This calculation would provide information that can be compared to the cost to identify which are most worth the focus of future R&D work. Figure 10 shows the value of the various advanced features from the results above. However, these data mingle the value of the feature plus the accompanying changes in energy efficiency, etc. It reflects "bundled" values. Figure 11 extracts the value of the energy efficiency change and shows the relative value of the advanced features themselves for each group.

There is more consistency in Figure 11. Glare is most valuable in offices, and color rendition is less valuable to both businesses and residents than adjustable intensity / color and reduced flicker. If bulbs with each of the features cost the same to develop and produce (and if it is less than the value), the results indicate that manufacturers could make greater profit by developing LEDs with the reduced glare feature, which has a higher willingness to pay by potential purchasers. These rankings and adders, based on an NEIs analysis, have implications for manufacturers for R&D, payback/ROI, and pricing.



Key: I&C- intensity and color. PW-public Works

Figure 10: Apparent Preferences for Features

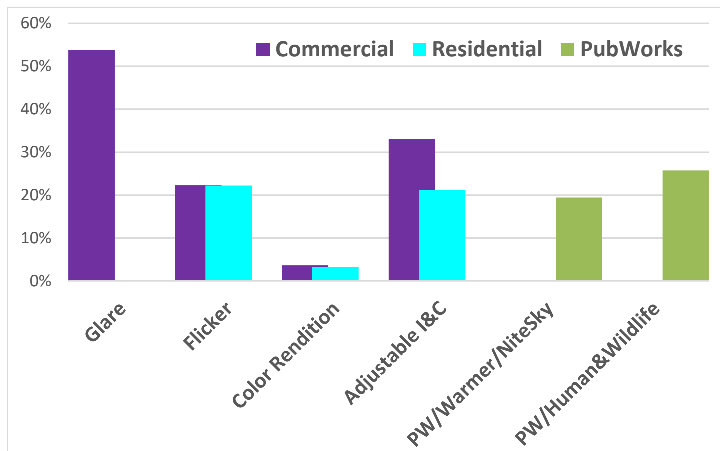


Figure 11: NEI price adder extracting Price & EE differences

The NEI value and their hierarchies can be used for its intended purpose – as inputs for an LED / lighting market share forecasting model and inputs to estimating the incremental energy savings potential from development of the technologies. The study also concluded that the values from multiple features are not additive; there are decreasing incremental returns from adding multiple features. The results from the two methods were fairly consistent and allowed for some triangulation and checking of results. However, based on the project's experience, the results from the labeled scaling approach were easier to gather and calculate, and bring relatively stronger academic underpinnings (and in addition, Skumatz and Gardner (2002) shows WTP provides more volatility).

CONCLUSIONS

This research suggests that estimating measure-based NEIs can provide robust and transferable results in many applications. The key advantages over program-wide NEI estimates are that the NEI results can be re-weighted as the program evolves, and measure-based results may be more transferable between programs and utilities. However, as the paper points out, not all measures lend themselves to measure-based NEIs, so there are roles for both measure- and program-based NEIs.

The paper used results from a comprehensive database of 44,000 lines of NEI data to summarize the NEI values available in the literature on thermostats, which focus on traditional programmable thermostat values. The research then used a large survey of non-utility-sourced data to develop NEI estimates for Wi-Fi and smart thermostats, and analyzed the results and provided comparisons to some of the programmable results. The study found several high net population-wide NEIs (with seven valued at more than 20% of the energy savings).

NEIs for greater comfort, doing good for the environment, safety, aesthetics, and fewer missed days from work or school were all valued highly. Although the effects were overall positive from the population of participants, a few respondents realized negative NEIs, or barriers associated with the measure. The sum of the ten wifi thermostat NEIs presented in this paper (which include only participant-side NEBs and only a subset of those possible) sum to $83, or 1.89 times the assumed energy savings.

Newly estimated values for thermostat NEBs that overlap with those in the SERA "NEB-It" database show the new values are similar or somewhat higher magnitudes for some NEIs (missed work and comfort) and a little lower for the comfort NEI. However, it is difficult to compare the values for any individual NEIs across studies because the literature has largely focused on providing NEI values across all participants. This figure is highly influenced by the characteristics (and locales, etc.) of the population participating in the program.

This weakness could and should be addressed in future NEI studies. The comparability, transferability, and longevity of NEIs estimates would be greatly enhanced if every NEI study presented the results in terms of the size of the effect for those participants experiencing an effect, as well as weighted to program-wide numbers based on the percentages of participants that do and don't receive certain measures or treatments. Then NEI studies could compare values for those experiencing a measure or experiencing an effect, could be reweighted to allow transfer between programs, and would allow a utility program's NEI estimates to predictably evolve over time as the measure mix changes over time. This applies to both percentages and to dollar NEI results.

The paper also attempted to show how a focus on measure-based NEIs can go beyond the traditional. The last section also demonstrates that NEI approaches may be useful in valuing "hard to measure" effects (here, for LEDs), and that NEI-type measurement approaches may even be useful in applications beyond NEIs (D'Souza and Skumatz 2021). This section used two measurement methods (Labeled Scaling and ranking-plus-valuation approaches) and showed they show promise in NEI estimation but also as applied to more expanded uses. the research showed strong market value associated with various "next-gen" LED improvements, and that NEIs can be used to demonstrate the market is willing to pay higher costs for specific EE measure features. The NEI results were used for the following applications: payback and ROI to better understand decision making and uptake, and refine incentive-setting; identifying attractive features for marketing; and R&D and pricing intelligence.

The research again showed that NEIs are significant, relative to the energy savings associated with the measures examined (thermostats and LEDs). As the NEIs field advances, and as programs evolve, it is important to include measure-based NEIs where possible to maximize portability / transferability of NEI results, and to continue to innovate and enhance NEI estimation methods and applications.

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