Toward residential upgrade savings guarantees: An AMI-based diagnostic interface

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Abstract

Residential weatherization and HVAC programs often struggle to deliver 100 % realization rates, but Inclusive Utility Investment programs such as Pay As You Save® (PAYS®) face a steeper challenge: to ensure that, barring changes in behaviour or new load, participants will all enjoy net bill cost savings. There are five primary reasons that expected savings are not fully realized even after weather-normalizing and adjusting for fuel cost changes: 1) changes in usage behaviour, 2) installation of appliances, 3) overestimated savings, 4) upgrades were not properly installed, 5) unrelated equipment failure. Even programs that deliver high energy savings realization rates will, due to the unavoidable occurrence of causes 1 and 2, will include projects where post-upgrade net energy savings are less than estimated and do not fully cover the fixed cost-recovery payments that are a feature of these programs. Although PAYS programs do not offer a savings guarantee, future Inclusive Utility Investment programs that wish to do so will need a means to manage that risk or at a minimum quantify the associated monetary risk so that it can be accounted for in program budgets.

In their quest to ensure that all participants are saving money, a rural electric cooperative is testing a new diagnostic tool designed for residential upgrade programs. The system is built on top of the open standard CalTRACK methods and provides physically meaningful model outputs such as changes in heating and cooling loads and balance points. This paper opens the hood of this new tool, showing how it analyses the hourly electric AMI data to generate charts and metrics that can automatically flag projects for review and help to identify what types of issues could be impacting performance. This paper also explains how the diagnostic system can identify early signs of potential deficiencies, such as misconfigured HVAC controls, determine if a fix is needed, and verify that any such issues are effectively remediated.

Introduction

Inclusive Utility Investment with strong consumer protections was invented by the Energy Efficiency Institute based in Colchester Vermont, USA in 1999 and trademarked as Pay As You Save® (PAYS®) (Cillo and Lachman 1999). The model has been further refined and improved by program operators through a series of program operation innovations, many developed by EEtility, a public benefit corporation based in Arkansas and the only multistate operator of PAYS programs. Together the PAYS system elements and program operation innovations create a no risk offer for a deep energy efficiency upgrade delivered via a frictionless turnkey process that eliminates all traditional barriers to customer adoption of clean energy upgrades (Bickel and Ferguson 2020). Inclusive utility investment is the US EPA's non-proprietary descriptor for programs with designs incorporating at least all of the key features of the PAYS system (Jantz-Sell et al. 2021). All current Inclusive Utility Investment programs are using some form of the PAYS system.

Inclusive Utility Investment as currently implemented is, in practice, a type of Managed Energy Services Agreements (Kim et al., 2012) like Energiesprong, except that the utility and its program operator are standing in for the energy service company. In avoids the pitfalls that hobbled programs like the U.K.

Green Deal such as charging upfront audit fees, offering capital at high cost, creating complexity and uncertainty among participants in benefits and quality (Badi et al., 2017). With Inclusive Utility Investment, the utility assesses the energy savings potential of the home, rather than the owner's liquidity or creditworthiness, to make investment decisions. As such, PAYS makes home energy upgrades accessible to all customers without credit checks, upfront cost, or debt obligation. The utility pays the upfront cost and is paid back with the energy savings over time through a monthly charge on the customer's bill. The monthly charge is less than the estimated savings from the upgrade so that the customer enjoys a lower energy bill from day one and a more comfortable and healthy home (Cillo and Lachman 1999). Since the utility is making the upfront investment and depends on an expected return, it is motivated to manage the entire process to ensure upgrades are installed correctly and deliver the projected savings. This transforms the home upgrade process from one where customers' coordinate contractors and pay for upgrades to one where they simply choose to receive a proposed package of home improvements (Bickel and Ferguson 2020). As a result, customers accept Inclusive Utility Investment upgrade offers 70–90 % of the time (Energy Efficiency Institute and LibertyHomes 2021) compared to less than 10 % for loan programs.

Two companion papers in these proceedings describe Inclusive Utility Investment in more detail and document the establishment and growth of the system from a utility perspective (Ferguson et al., 2022) and policy perspective (Hummel et al., 2022).

Cooperatives are embracing because upgrades have positive net present value (Bickel et al. 2020), while investor-owned utilities appear to be embracing them in the expectation that regulators will allow them to treat IUI investments as grid assets and earn their regulated rate of return (split between participants and ratepayers) (Ameren, Missouri et al. 2021).

Unpublished data from the cooperative utility sponsoring development of the diagnostic tool described below indicate that the accuracy of program operator estimates, and the quality of installations have steadily and in some cases dramatically increased as sources of consistent bias are removed. Initial features such as delegating responsibility for gather home performance data, prepare savings estimates, define scopes of work were delegated to installation contractors, accepting job costs bid on a home-by-home basis, and conducting only post-upgrade quality assurance and quality control (QA/QC) on a statistical sample of homes have been progressively eliminated and replaced by use of expert program implementer staff to gather on-site data, conduct assessments, and create PAYS compliant scopes of work using pre-negotiated contractor price sheets reflecting volume pricing, as well as implementing pre and post QA/QC on 100 % of jobs. (Bickel and Ferguson 2020). Post upgrade portfolio level results have increased from average savings of 18 % savings, 3,300 kWh/yr and 0.75 kW peak load reduction per home and to 25 % savings, 6500 kWh/yr, and 0.9 kW peak load reduction per home per year with 95 % of homes with reduced weather normalized electricity consumption.

For IUI programs energy savings performance is only half of the story, as customers must also be largely cash flow positive after considering the annual cost recovery fees. For the program referenced above, despite 74 % of participants having positive energy savings in the early program period, 71 % of those did not pass the Annual Cash Flow Test, while in the later program period of the 95 % of homes had positive energy savings 44 % of these did not pass the Annual Cash Flow Test. Since IUI program participants are permitted to increase their energy use, negative cash flow is not an indicator of any defect in program performance.

Besides harming participants, IUI momentum could also be harmed if this key reputational risk is not rapidly addressed. Were the public, utility regulators, consumer advocates, and/or class action law firms to determine that a significant proportion of IUI participants energy bills have increased, and the program sponsor cannot quickly and cogently explain why that is the case, the ensuing controversy could easily halt or reverse the adoption of IUI, even if 90 % of participants are experiencing positive cash flow for energy costs.

One solution to this risk is for programs to provide financial compensation and adjustments to participant cost-recovery fees so customers are bill neutral, however, even in this case, to do so without creating a moral hazard, the utility must be able to accurately determine when the program bears some responsibility for a customer's negative cash flow and to be able to quantify economically the degree of that responsibility.

Such calculations demand that the utility be able to differentiate the relative contributions of five causes of costs exceeding savings, which are

1. changes in occupancy or occupant behaviour that increase energy usage (e.g., new occupants, different occupancy schedule, different thermostat setpoints, etc)
2. installation of appliances
3. overestimated savings
4. upgrades were not properly installed
5. unrelated equipment failure.

This paper describes the first set of diagnostic tools developed to enable sponsoring utilities to distinguish behavioural from program related causes and ultimately enable them to determine when program errors justify compensating customers, by how much they should be compensated, and ultimately how much the utility should budget to cover such expenses as the program grows and expands.

The Problem

To ensure that all participants achieve a positive annual cash flow except in cases where non-program-driven changes have increased energy use, program operators must follow two steps: First, energy savings must be calculated for each home; and second, any projects whose weather normalized savings do not fully offset their annual payments must be investigated to determine the cause. Note that the subject of this paper is limited to automated analysis techniques that can facilitate this process. It does not include a discussion of the other aspects of implementing a savings guarantee, managing the customer interactions and remediation workflow, or financing such a guarantee. While these are valid concerns, our primary focus is on creating a transparent and scalable process that would both reduce the administrative burden of monitoring actual savings and build trust in the determination of responsibility for under-performing projects.

The first necessary condition is to automate the savings calculation for each individual project. This contrasts with how many whole-home energy upgrade programs are evaluated: every few years, the energy use data from a sample of homes is "pooled" so that the average savings can be calculated and divided by the "ex ante" (or forecasted) energy savings to generate a "realization rate." Realization rates for non-PAYS energy efficiency upgrade programs can range from less than 25 % (DNV-GL 2017) to over 80 % (Cadmus 2020); reported portfolio level realization rates for PAYS programs, are at the high end or above this range 77 % (Bickel et al 2020) to 102 % (Midwest Energy 2021). Portfolio level realization rates may be adequate for determining if the program as a whole is effective, but even a program that achieves a 100 % realization rate can include a large percentage of projects that save less than predicted, so long as others overperform. Since the goal of evaluating an IUI program is to determine if all participants benefitted financially, and not simply if the program is achieving a net benefit overall, this sort of pooled analysis is not adequate.

The second necessary condition is that any project that is found to be saving less than the annual on-bill repayment amount will be investigated to determine if the increased net cost is due to an under-performing project or a change in the occupants' energy use choices. On the one hand, the program staff might have overestimated the savings that could be achieved from the project, or the contractor might have failed to deliver on the expected quality of HVAC upgrade or insulation and air-sealing or both. In these cases, the program bears the responsibility for under-performance and thus should either perform additional work on the home at their own expense or compensate the participant for the portion of past overpayment attributable to the program and reduce the monthly cost-recovery fee so that their annual cost is at or below the actual value of the energy savings. On the other hand, the home's energy use could have increased due to additional appliances that were installed, additional occupants or longer occupancy hours, or changes to occupant behaviour such as different thermostat set-points, or some combination thereof. Such changes are allowed by the program, but any energy savings assurance would be exclusive of these discretionary energy use increases. It is typically not feasible, however, to conduct open-ended investigations for every project that fails to meet the savings goals, as this may include one third of all projects. Further, such determinations should be as objective as possible, since customer satisfaction and trust is an important factor in scaling the program, but paying for increased energy use outside of its control will jeopardise the program's financial viability.

Automated Savings Calculations

We are using the CalTRACK methods (Young and Best, 2018) to calculate each project's weather-normalized energy savings from utility meter data. These standard, transparent methods are implemented in the open-source OpenEEmeter software (LF Energy, n.d.). CalTRACK includes both piecewise linear regression methods that can be applied to either monthly meter readings or to interval data from AMI (Advanced Metering Infrastructure) or AMR (Automated Meter Reading) systems, which can be aggregated to a daily frequency time series. CalTRACK also includes hourly methods, which are derived from the time-of-week and temperature methods developed at Lawrence Berkeley National Laboratory (LBNL) (Mathieu et. al. 2011) that are suitable for calculating peak kW demand reductions. While residential customers are not typically on a demand-sensitive electricity rate, such peak demand reduction can represent a significant savings in the utility's cost of service and help to justify the investment in administrative support that is necessary to operate the program.

We calculate the weather-normalized savings because much of the energy use in residential buildings—and the savings from these projects—is due to heating and cooling. Therefore, simply measuring the difference between annual energy use before and after the efficiency project could give an inaccurate result if the weather was different during the pre- and post-project time periods. This process, which is typical in efficiency program evaluation, involves constructing an outdoor temperature-regression model of the building's energy use before the project so that we can estimate what the building *would have used* on a given day if it had not been upgraded. Since we want to measure not only how much each participant has actually saved in the time since the project was completed, but how much we expect they will save over the project's lifetime, we also model the post-project energy consumption of each building in the same way and then compute both the original and upgraded building's expected energy use during a "typical meteorological year" (Wilcox and Marion, 2008), which captures not only the average heating and cooling loads, but also the peak heating and cooling conditions for the local climate.

It is worth noting that not only do these standardized software methods allow us to calculate savings for every project in a consistent fashion, but they also allow us to automate that process so that these results can be rapidly generated on a regular basis (quarterly or even monthly). This ensures that participants will not suffer undue economic impacts for longer than necessary, but it also helps the program to identify any systemic issues, such as upward bias in savings estimates or under-performance of upgrades delivered by particular contractors, so that they can be corrected before they affect more projects. While astute readers will recognize that such problems cannot be fully identified and diagnosed until a full year after project completion, it is often possible to detect early signs of such under-performance with only a month or two of peak heating or cooling season energy data, at least in the most severe cases.

Diagnostic Interface

Ultimately, the determination of whether a project is underperforming or if there are additional energy uses that have caused the net bill to increase will be made by some human member of program staff who can weigh the full range of factors. That person's job will be easier –and their conclusions more consistent – if they have some metrics to consider beyond simply the amount of energy that the project actually saved and what it was predicted to save. In this section, we describe some of the metrics and data visualizations we are presenting to program staff to help them understand the potential causes of individual projects' performance. These metrics are primarily derived from the regression model coefficients calculated by the CalTRACK methods, such as a building's base load, thermal balance points and kWh/degree-day heating and cooling demand. Some of the diagnostic tools rely on hourly data and are only available for buildings that have hourly AMI data, and all of them will provide more precise results when daily or better data is available, but a core set of interfaces can be produced with only monthly billing data.

Before diving into the specifics of these model-based diagnostic interfaces, consider one the most simplistic metrics: the ratio of the forecasted savings to the pre-upgrade energy use. If a project is predicted to save more than 50 % of the home's total energy use, it's likely that savings estimate was overly optimistic, which could be the reason that the annual payment exceeds the actual savings. For example, in one such program we evaluated, actual savings only exceeded 50 % of pre-upgrade energy use in just a few (roughly 3 %) of the projects. However, over a third of the projects had forecasted savings in excess of 50 %; a few even predicted they would save more than 100 %! This is obviously a trivial metric to calculate, even before billing data analysis results are available. Program operators can and should use such metrics as part of a screening process before the projects are implemented, and some operators already do so.

Note that, while most of the following diagnostic tools are described from the perspective of completed projects, their goal is also to help program operators proactively avoid underperforming projects and quickly address any that do occur.

METRICS USED BY THE DIAGNOSTIC CHARTS

- **Heating balance point:** the outdoor temperature above which the house no longer uses additional heating energy, in degrees Fahrenheit. The thermostat set-point is typically around 5–15 degrees above the balance point.
- **Cooling balance point:** the outdoor temperature below which the house no longer uses additional cooling energy, in degrees Fahrenheit. The thermostat set-point is typically around 5–15 degrees above the balance point. Note that many thermostats can accommodate separate heating and cooling set-points (or occupants will manually set them differently as the season shifts) so these two balance points are typically several degrees apart.
- **Heating degree-days:** the sum of average degrees below the heating balance point for every day when it is colder than that balance point temperature. This number increases as the heating balance point increases. Note that this is shown in negative numbers on the X-axis, but that is just an artifact of how heating is plotted to the left of the origin.
- **Cooling degree-days:** the sum of average degrees above the cooling balance point for every day when it is warmer than that balance point temperature. This number increases as the cooling balance point decreases.
- **Heating demand:** the amount of additional energy the house uses every day for every degree below the heating balance point, in units of kWh/heating degree-day. This value is typically in the range of 2–4 kWh/HDD, but larger houses will use more, all else being equal.
- **Cooling demand:** the amount of additional energy the house uses every day for every degree above the cooling balance point, in units of kWh/cooling degree-day. This value is typically in the range of 2–6 kWh/CDD, but larger houses will use more, all else being equal.
- **Base Load:** The amount of energy used by the house that is not dependent on outdoor temperature, in units of kWh/day.
- **R-squared:** an indication of how well the model fits the year of training data. Higher numbers (closer to 1.0) are better, and all models must by >0.5 to qualify.
- **CVRMSE (coefficient of root mean squared error):** an indication of how much "error" exists between the model prediction and the actual energy use for that period. It's a percentage; lower numbers are better and 0.0 is perfect.

BREAKDOWN BY LOAD TYPES

These charts illustrate how much of the impact on electricity use came from cooling (black stacked bars) and heating (light grey), versus base loads (i.e., everything else, dark grey).

How it's used:

- Changes to base load: it should decrease a bit. An increase in base load could indicate new electrical end-uses.
- Heating or cooling use should both decrease, except in fuel switch projects, where heating load should increase. If one of them was expected to decrease based on the project components but did not, the project might be under-performing. Check the balance points and regression model comparison charts to see if thermostat setpoint changes might have occurred. Alternatively, the participant may have added load or changed their occupancy patterns.
- Abnormal balance points: if either balance point is outside of the normal range (10–20 degrees C for heating, 15–25 degrees C for cooling), it may indicate the model is not reliable, possibly due to multiple HVAC systems with different efficiencies.

MODEL PREDICTIONS VS. ACTUAL DAILY ENERGY USE

This chart compares the baseline (pre-project) and reporting (post-project) models' predicted daily energy use to the actual daily energy use. All trends use a 7-day rolling average. This visualization can identify a point in time when the performance of a building changed.

In the above example on the left, this building's actual AMI data was at first showing savings in the winter, as it was tracking below the "Baseline" line, which indicates how much energy the pre-upgrade model estimates the building would have used. The "Reporting" line tracks close to the "AMI" line shows that the post-upgrade model effectively describes the actual behaviour. The chart on the right shows that, in the same time period, the building exhibited a consistent pattern of energy use relative to outside temperature up until about 10/2019 (the chart allows zooming to identify a more exact date). Then the post-upgrade "reporting" model estimates that the upgraded building should have used much less energy (the line in the chart on the right is well and consistently below the X-axis) during the

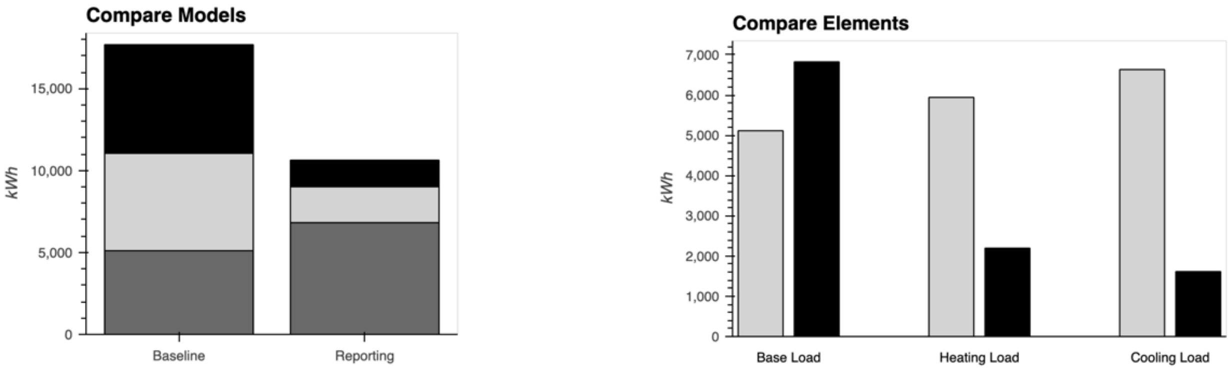

Figure 1. Model components compared before and after efficiency project.

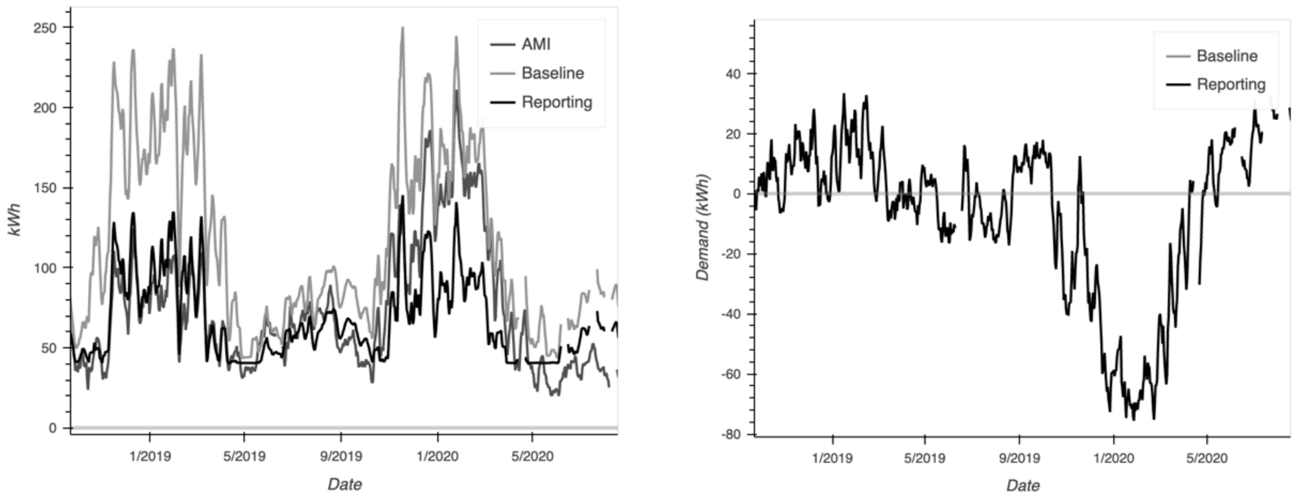

Figure 2. Time-series trends of kWh for modelled, actual, and difference in energy use.

2019–2020 winter. Specifically, it appears that the building is now starting to use energy more like it did pre-upgrade (AMI in the left chart tracks closer to the Baseline).

How it's used:

- A toolbar at the top right of the chart (not shown) provides pan and zoom functions.
- The chart on the right shows the difference between the baseline model forecast and the actual daily consumption and the difference between the actual reporting model Positive values means that the model expected higher energy use; negative values mean the model expected lower energy use.
- Zoom in to look at time periods when the chart on the right shows the model is expecting much higher or lower energy use to see when (or what season) it occurred in. Both charts will display the same date range regardless of which one you pan and zoom with.
- If there is a consistently positive or negative model difference (chart on the right) immediately before or after the project date, it might mean that a piece of equipment broke, was fixed, or was added or removed from the home, or occupancy/use patterns changed. It could also mean that the model date was recorded incorrectly.

CHANGES IN SEASONAL LOAD PROFILES

These charts compare the daily load profiles in the 12 months before and after the project was completed. The solid lines indicate the median use in each hour, while the shaded bands show the range of typical use (excluding the 25 % highest and 25 % lowest readings).

In the example above, it appears that the home is using much less energy during summer days, although it didn't improve the night-time energy use much compared to the pre-upgrade home. And the winter use has become much higher, plus it is no longer exhibiting set-back behaviour. This might not be a warning sign if this home switched from a fossil-fuel heating system (which still uses electricity for fans, pumps, and ignition) to a variable-speed heat pump that is most efficient when operated at a constant temperature, but if it had the same kind of heating system before and after the upgrade, this might be a warning sign.

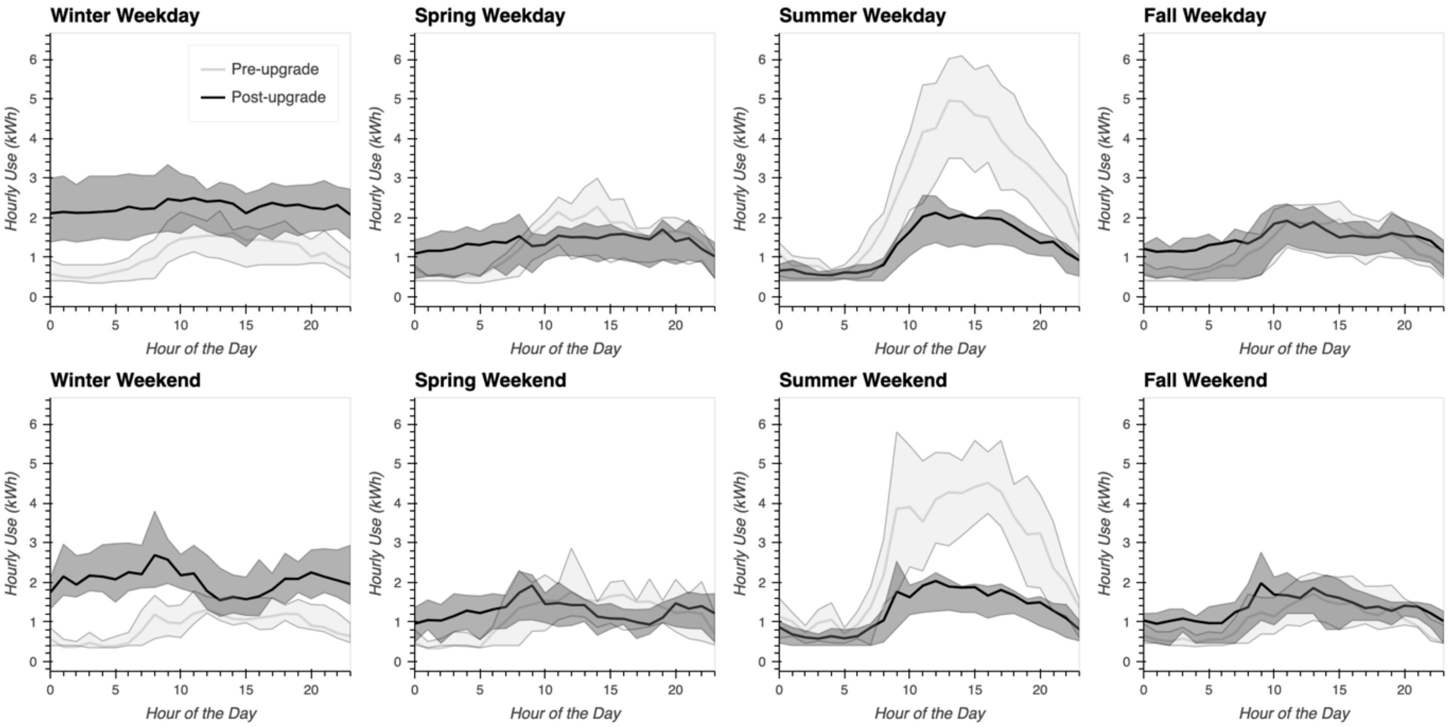

Figure 3. Seasonal weekday/weekend hourly profiles comparing pre and post load shapes.

How it's used:

- Look for time periods where there is little or no overlap between the shaded bands. That indicates that the energy consumption during that period changed significantly when the project was completed.
- Most projects should result in a reduction during summer afternoons (cooling load) and all-electric homes should see a reduction in winter, particularly overnight (heating load). Spring and fall are typically driven more by occupancy than heating and cooling loads.
- Look for any periods that increased significantly in the spring and fall if there is an increase in base load as shown on the Typical Meteorological Year charts.

REGRESSION MODEL COMPARISON

This chart shows the change in heating, cooling, and base loads as a combination of changes to the degree-days (driven by balance point) and demand (driven by insulation and HVAC efficiency). Note that the base load does not respond to either of these factors but is shown to scale so that each unit of area represents an equivalent amount of annual energy use. In this case, the heating balance point changed from 56F to 61F (from 13C to 16C), resulting in nearly 50 % more heating-degree days (light grey box is wider), though the heating demand decreased by nearly 25 %; on balance (that box is shorter), this appears to have increased overall heating energy use. The full interface has a table of model coefficients and values. Cooling, on the other hand, saw a slight decrease in degree-days (due to a small increase in set-point) and also a modest improvement in the cooling demand. Base load also decreased.

How it's used:

- Reductions in heating and cooling demand can be due to improvements in insulation and air sealing, and they can also be due to better HVAC efficiency.
- Heating demand will typically increase in a fuel-switching project. It should decrease a little or stay flat in a fuel-heated project and should decrease significantly in an all-electric project.
- If a project has improved the building envelope through insulation and air-sealing, the heating balance point should decrease slightly (the house can stay comfortable without heat until it gets colder outside) and the cooling balance point may increase slightly as well.
- If either balance point has gotten "worse" (higher for heating, lower for cooling) then it may mean that the occupants have adjusted their thermostat to improve comfort.
- If either the baseline or reporting model has a balance point outside of the normal range (10–20 degrees C for heating, 15–25 degrees C for cooling), it may mean that the model is not fully representing the weather-based drivers of energy use, perhaps due to multiple heating or cooling systems, non-thermostatic operations, or simply a larger variation in non-weather-driven energy end-uses. In these cases, use caution in drawing conclusions from the model outputs.

OCCUPANCY FACTOR BY MONTH

This chart shows the number of hours in each calendar month that were categorized by the model as "occupied," meaning simply that they typically exhibit higher energy use than the weather

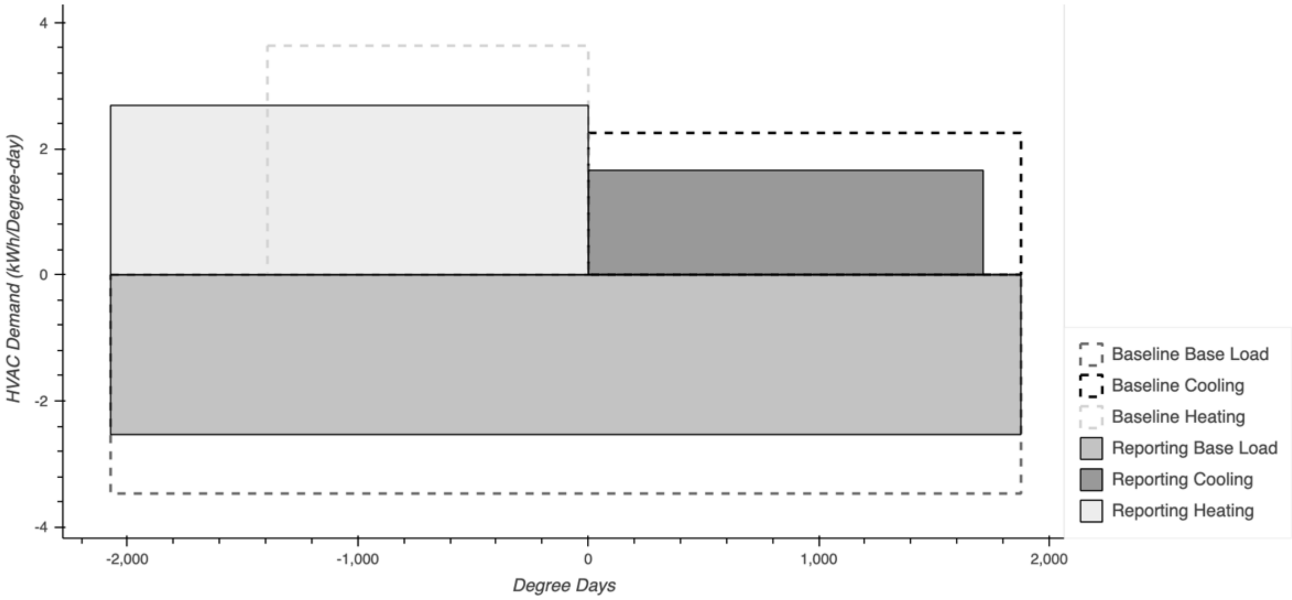

Figure 4. Plot of weather-regression model components comparing pre and post use.

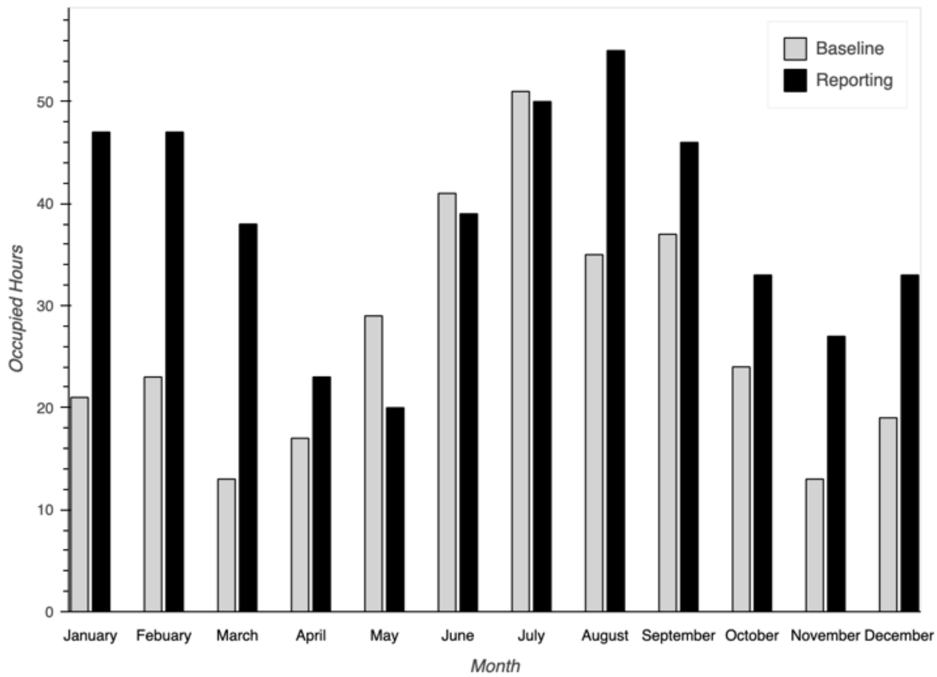

Figure 5. Plot of occupancy factor by month of year, comparing pre and post upgrade.

model would predict. If this changes dramatically between the pre- and post-upgrade years, that may indicate that the home is being occupied differently. In the case shown in Figure 5, there appears to be an increase in occupancy during the winter months. Checking the seasonal load profiles for this home (shown in Figure 6), we see a pronounced morning spike in energy use during the post-upgrade period as compared with the pre-upgrade period. As it happens, this house was still getting significant heating energy savings, but the project proposal had forecast ~50 % savings relative to the baseline usage, and this project only saved about 30 % overall, as shown in the second plot in Figure 6. If this occupancy were to be an important factor for calculating utility compensation it would need to be corroborated by direct unbiased communication with the customer.

Tips:

- If one or more months shows a significant increase in occupied hours from the baseline to the reporting years, review the Season Usage charts to look for trends in that season.

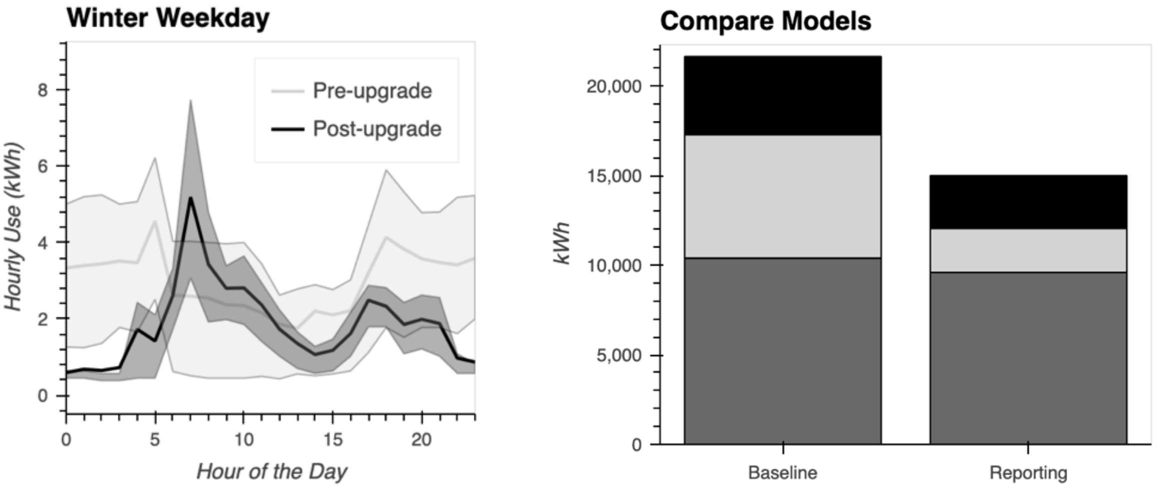

Figure 6. Additional plots from the project shown in Figure 5, showing corroborating evidence.

- Note that this data visualization is still experimental, and any theories based on these trends should be corroborated with occupants or project contractors to confirm that the relationship between this metric and occupant behaviour is valid.

Conclusion

In order to meet our current science-based decarbonization goals, Inclusive Utility Investment (IUI) is an effective tool for scaling up whole-home efficiency projects. One of the key value propositions for IUI programs is that these projects should not cause any individual participant's annual bills to go up, though occupants' choices to install new appliances, increase comfort through different thermostat settings, or spend more time in the home may cause the net bills (energy plus project repayment costs) to increase. Determining the likely cause of specific projects' increased bills is a necessary condition for program operators to progress from "soft" commitments of bill stability, based only on ex ante model estimates, to more firm commitments that include program-funded remedies such as correcting faulty work or reducing payments.

An open-source modelling approach called CalTRACK can be used to calculate savings for each project and quickly identify those at risk. Novel visualizations of some physically-meaningful model outputs may help program staff to determine whether the project implementer under-delivered or if the occupant's energy use patterns changed. In this paper, we have demonstrated how particular patterns that are easily recognizable in these visualizations can help program staff to troubleshoot the root causes for under-performing projects. We are currently testing the application of these visualizations by working with the sponsoring program administrator and implementer to validate the meaning of indicators in these visualizations against ground-truth information about actual conditions in these homes.

Based on our experience, we recommend that programs should use standard, transparent tools to monitor the actual success of every project. Even if they are not offering explicit performance guarantees, it can help with customer satisfaction and can also identify systemic problems that should be addressed in order to ensure that programs meet their goals and maximize climate impact. Programs will likely need to supplement automated calculations, visualizations, and decision rules with interviews and on occasion on-site investigations to resolve ambiguities. The results of such investigations can be compiled into a knowledge base of ground-truth examples that will help us to improve the accuracy and saliency of our tools in the future. We plan to validate these diagnostic tools using both phone interviews and site visits. The cooperative utility's program for whom this tool was developed is generating a large net present value per participant that is likely to substantially exceed any liabilities that might result from compensating participants for overestimation of savings.

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