A Toolkit for Affordability Driven Home Energy Efficiency Retrofits Through Local Improvement Charge Programs

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A Toolkit Case Study: Retrofit Package Optimization, Analysis and Recommendations for the City of Toronto

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Notice

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Table of Contents

Introduction

This report is part of a series of reports and studies produced as part of Volta Research's CMHC-funded "Affordable home energy retrofit toolkit" project, together constituting the "Toolkit," which aims to inform the way that municipalities and other entities define and create their single-family home energy efficiency LIC/PACE programs.

The analytical processes presented within this report serve as a template for policymakers and program administrators to help them explore and define retrofit package optimizations for their programs to reduce total user annual costs, GHG emissions, and energy usage within their regional context.

Specifically, this report presents a brief background of the problem it aims to address. A general methodology is defined to analyze solutions to this problem. It is then presented and applied to homes in Toronto as an example demonstration case study. The results of this case study are presented and discussed, followed by a conclusion that speaks to the recommendations put forward regarding retrofit package design and future work.

Background

Single-family homes are impacted by and contribute to Canada's climate and affordability crises. Energy-efficient retrofit incentive packages are needed to not only optimize energy (GJ) reductions but help mitigate these issues by reducing emissions and lowering costs To help Canadians face these crises.

With the broad deployment of LIC/PACE programs across Canada, there exists a potential to drive positive change on a large scale through informed, user-needs-centric program design. Surveys conducted as part of this and other research projects have indicated that housing retrofit programs must address capital and operational costs associated with housing retrofits – the Total Cost of Ownership (TCO) - to meet their participants' needs. Guidance for program administrators to assess housing retrofit programs and retrofit packages under the lens of TCO has the potential to benefit municipal program design and the affordability of existing homes in Canada.

For more information on the current state of practices across the single-family home energy efficiency landscape, selected programs are summarized below and explored in greater detail in other reports within the Toolkit.

Current Program Practices

In general, these programs have historically aimed to reduce *energy* consumption first. There has also been an awareness of the need to reduce greenhouse gas (GHG) emissions as part of program designs. To date, though, little has been done to address the TCO associated with these upgrades, apart from a few affordability-focused service providers - this despite the notes on TCO in the FCM toolkit document (Clean Air Partnership, 2020), the leading program design resource for LIC/PACE program administrators in Canada.

Within the municipal LIC/PACE loan programs already deployed across Canada, the performance-based (energy assessment) approach was the most common. In contrast, both performance and prescriptive-based approaches were commonly used for utility programs.

Selected programs relevant to the Toronto case study example are discussed in this report and are presented below. Still, the “A Review of LIC and PACE Programs in Canada” document within the Toolkit provides a more verbose assessment of programs across Canada.

Example

FCM Guidelines

The FCM LIC/PACE loan program guidelines are generally based on section 2.3 of FCM’s LIC toolkit (Clean Air Partnership, 2020). It is a widely adopted framework for retrofit program design used by municipalities in Canada and the direction most LIC/PACE programs are taking, based on our stakeholder engagement. The FCM toolkit provides a variety of approaches that a municipality can pursue to design and implement a LIC/PACE program for energy efficiency loans. The guidelines generally focus on the program’s administration from a municipality’s perspective. The Toolkit also covers some ways that retrofits can be chosen. Still, it leaves much up to the discretion of the program administrator.

Toronto Home Energy Loan Program (HELP)

Toronto’s HELP, the example case study with this Toolkit, adopts the FCM program guidelines with a focus on the homeowner-led approach from the FCM toolkit (Section 6.6.1). It is energy evaluation-driven, and the homeowner leads most of the retrofit choices and management. The main home-specific guidance resource the homeowner has access to is the Renovation Upgrade Report (RUR), delivered by the energy advisor after the first energy assessment. It explains the energy (GJ) reduction measures the homeowner can undertake to improve energy efficiency. Still, there is no mention of cost and minimal discussion of GHG reductions. Toronto also has a website resource, BetterHomesTO, for homeowners to get information on potential retrofit package types and to help interpret the results of the initial energy assessment (and RUR).

Canada Greener Homes Grant

The Canada Greener Homes grant funds a selection of retrofit measures with purchase and energy assessment incentives as high as $5600 per home. It is more GHG emission reduction-focused than other programs and does not fund fossil fuel-based measures for space or water heating. The grant is based on the EnerGuide Rating System energy evaluation process and requires preliminary and post-retrofit energy assessment conducted by an energy advisor. It is very highly subscribed and “received applications for over 25 percent of its intended grants in just the first seven months of its seven-year lifespan.. (and received) as of September 6, 2022, a total of over 196,000 grant applications” (NRCan, 2022). The significant uptake, Canada-wide reach, and its timing coinciding with the program design and deployment of LIC/PACE loan programs by many municipalities across Canada have led to a move towards loan programs being based around the EnerGuide Rating System.

Utility Programs

In terms of programs available for Toronto, those offered by Enbridge Gas (now the delivery agent of the Canada Greener Homes Grant in Ontario) use the preliminary and post-retrofit energy assessment process and prescriptive programs for income-qualifying applicants for their programs. Ontario's Independent Electricity System Operator offers a grant-based performance program with a free energy assessment and a selection of free upgrades based on the applicant's income bracket (IESO, 2022).

General Analytical Process

Introduction

Given the need to advise LIC/PACE program administrators on the impacts of implementing the available and commonly suggested energy efficiency upgrade measures for single-family homes, an experimental methodology is presented that defines a process by which this advice can be derived. The methodology aims to guide how to conduct a regionally aware analysis regarding optimizing post-retrofit energy (GJ), GHG emissions, and total annual upgrade cost variance (TCO reductions) for different single-family home upgrade packages and to ultimately meet the stated needs of program users.

The methodology uses publicly available, government-verified housing archetype data and industry-accepted energy modelling software and processes. It serves as a blueprint for program administrators, enabling them to conduct analyses that optimize results for their program users. Program administrators can leverage the results produced by the regional archetype and upgrade analyses to build informed technical upgrade requirements within programs that help inform the design of effective user-centric performance/prescriptive hybrid or prescriptive LIC/PACE programs that maintain or increase housing affordability. If required, the methodology can also be used to inform a procurement document flow for program administrators to procure the services of an energy-focused firm to perform this retrofit analysis methodology for them.

The following methodology describes a process flow to determine which retrofit packages best achieve a good regional optimization of the abovementioned needs (energy, emissions, cost) for LIC/PACE program users. The methodology is also demonstrated practically throughout the report using the Toronto case study examples.

Energy Modelling Method Determination

Within LIC/PACE loan programs in Canada that follow the Toolkit provided by FCM, our literature review and survey results from municipalities indicated that most programs have chosen a model that requires energy assessments (e.g. performance-based) to assess the participant's home before and after a retrofit. Many programs use an energy assessment process within their program that follows or uses the EnerGuide Rating System as a template, given that the timing of many LIC/PACE program rollouts coincided with the Canada Greener Homes Grant's launch. This rating system uses NRCan's HOT2000 software to simulate and determine the annual energy consumed by a single-family home. The inputs to the simulation are based on information collected during a site visit by an energy advisor. HOT2000 produces a variety of metrics to assess the performance of residential buildings. Of most significant importance in this analysis are the following metrics:

- Total annual energy consumption (GJ)
- Total annual natural gas consumption (m3)
- Total annual electricity consumption (kWh)
- Total annual propane consumption (L)
- Total annual oil consumption (L)
- Total annual wood consumption (kg)

HOT2000 is the most widely used energy modelling software in Canada's Part 9 (low-rise) building industry. It has been used for decades to deliver the EnerGuide Rating System for more than a million homes and is part of the compliance paths in the Canadian building and energy codes for new - and soon-to-be-existing buildings. It can also provide a detailed snapshot of a home's current and predicted energy performance. And though not always needed for a single retrofit action, it helps paint a "bigger picture" for the program user by defining a roadmap to help plan future retrofit measures.

Example

Given the above considerations and the need for this analytical methodology to be easily replicated by program administrators and/or their agents, HOT2000 was chosen to perform the energy modelling for the Toronto case study. For this work, the command line interface of HOT2000 version 11.11 (the most recent version at the time of this writing) was chosen to perform the energy modelling.

Housing Archetype Data Collection

To enable a robust set of input data for the retrofit analysis modelling exercise and to enable usage of HOT2000, the analytical methodology needs a set of HOT2000-compatible input files – housing archetypes - that are statistically representative of the wider housing stock for the metrics and regions of interest (demographically, geographically, building topologically, or other). Using these files ensures that the analysis results will reflect those obtained by energy advisors conducting fieldwork and be relevant to the targeted metrics within the analyzed program design. For example, a program targeting low-income seniors could use the Canadian census, property roll, and/or other datasets to determine the type of houses to be targeted by the program. Then, the representative HOT2000 archetype files could be constructed. This would be considered an advanced analysis, though. Using a special dataset of statistically representative HOT2000 files is much simpler in the case of regionally targeted programs and still maintains good applicability.

NRCan's CanmetENERGY has generated a set of approximately 6,800 archetype HOT2000 files from the EnerGuide for existing homes database (database of all EnerGuide assessments in Canada) representing multiple, statistically relevant archetypes for regions across Canada. These archetypes were collected between the years 2016 to 2019. The dataset was developed for use with NRCan's Housing Technology Assessment Platform (HTAP). NRCan provided it for usage within the Toronto case study example. Program administrators can directly contact NRCan's CanmetENERGY staff for access to the dataset. The dataset was assembled based on the methodology from the publicly available Canadian Single-Detached and Double/Row Housing Database (CSDDRD) but was optimized to reduce the number of files. The CSDDRD came from combining the data sources of the EnerGuide for housing database, SHEU2015, National Energy Use Database, and census data, and was documented in a research paper (Swan, Ugursal, & Beausoleil-Morrison, 2008).

Example

For the Toronto case study within this document, all HOT2000 energy simulations for the analysis were conducted on the subset of archetype HOT2000 files whose:

- Forward Sortation Area (FSA) code began with "M," and
- whose building types excluded mobile homes and multi-unit residential buildings (low and high rise).

Cross Tabulation Data Collection

When using HOT2000 archetype files that are statistically relevant over a specific region but not for other metrics of interest, significant additional value can be obtained from this analytical methodology by cross-tabulating the results obtained by running HOT2000 simulations with other datasets containing metrics of interest. FSA parameters accompany the archetypes files discussed above. They can be cross-tabulated with other data containing FSA geolocators – such as the Canadian Census of Population from Statistics Canada. Importantly, cross-tabulating energy results with demographic data allows program administrators to understand the effects of retrofit programs on the user groups that the program hopes to serve. For example, the impacts of different retrofit packages could be evaluated for regions experiencing energy poverty, or program communications could be targeted to the most prevalent languages for that region. Similarly, the same could be accomplished for regions exhibiting exceptionally high GHG emissions levels that a program might hope to address at an FSA scale. This cross-tabulation technique makes this analytical methodology an effective tool for creating more efficient and effective programs.

Example

For the Toronto case study within this document, the results of the HOT2000 archetype files were cross-tabulated with the 2016 Census of Population FSA data.

Retrofit Package Determination

It is helpful to construct a set of retrofit packages to be tested on each of the selected HOT2000 archetype house files to perform the analytical methodology detailed within this report. They can be constructed as a set of *individual* upgrades to be tested in all their permutations on every file with a tool such as HTAP; however, this can be an onerous and resource-intensive endeavour. Another way to perform the analysis is to create retrofit packages that consist of predefined sets of retrofit upgrades that make sense to group together. This can be done by looking at common retrofit upgrade groupings from existing program data or consulting with an energy efficiency specialist to design the appropriate packages.

Example

The Toronto case study analysis used a variety of sources to help develop the set of energy efficiency retrofit packages to be tested. Retrofit packages were selected to represent the following:

- Home improvements conducted under Toronto's Home Energy Loan Program, as well as recommendations listed on Toronto's BetterHomesTO website (betterhomesto.ca);
- Typical recommendations provided by energy advisors and those listed in the FCM toolkit (equivalent to an energy efficiency specialist-designed set of packages); and
- A custom set of packages designed with affordability in mind based on Volta's research experience.

A more detailed discussion of each set of packages selected within each category is presented in the following sections.

Toronto HELP Retrofit Packages

From the data provided by Toronto, the most common retrofit packages implemented by program users were used to define several upgrade packages for modelling purposes. Individual retrofit upgrades detailed in Toronto's data provided the information needed to build the retrofit packages into modelling files. In addition, other packages were added that represented components suggested in HELP documents but did not appear in the data as top retrofit packages.

The following packages were designed with the above influence in mind:

- Help1
- Help2
- Help3
- HelpAirSealWindowDoor
- HelpHVAC
- HelpSolarPV5kW

Energy Advisor and Toolkit Packages

Another set of packages was created that represented a pathway to Net-zero. These packages started with simple envelope upgrades and increased in complexity to packages with deep envelope changes that were fully electrified with renewable energy to reflect a federal policy pathway approach (though not specific to tiered codes or CHBA Net Zero compliant). This pathway also followed the energy assessment industry approach, where the theory is that staging of retrofits is essential. The packages first aimed to reduce the total energy used by the building. Then systems were sized correctly and changed to a low-emission fuel source. In this way, the low-emission fuel source costs were mitigated. The following packages were designed with this influence in mind:

- BasicEnvelope

- MediumEnvelope
- DeepEnvelope
- NetzeroEnvelope

Affordable Test Packages

From Section 6.4.1 of Clean Air Partnership's Toolkit (Clean Air Partnership, 2020), the project aimed to perform the "cost-effectiveness analysis" to improve or maintain the affordability of the participant's home. Based on the data provided by Toronto and Volta's previous sensitivity analyses of HOT2000 energy models, the team compiled a set of packages that would likely have low capital costs yet produce relatively significant reductions in energy consumption. The intent was to select packages that, even when accounting for the annual loan repayment cost with interest, would yield a lower total annual cost than the baseline archetype house. Two other packages were added to the list as well. One package represented a completed affordable retrofit project that Toronto highlighted to community groups in webinars (AffordableK). The other package (acSystemBaseline) was built to compare the incremental cost of adding an air conditioner versus the Affordable3 package. This special package was used as a baseline comparison for the Affordable3 package to highlight a more affordable means of adding cooling to a home.

The following packages were designed with the above influence in mind:

- Affordable1
- Affordable2
- Affordable3
- AffordableK
- acSystemBaseline

Build Automation Tools for Analysis

With this analytical process, automation tools can be created and used that help speed up the process to handle the extensive data analysis needed to produce retrofit package conclusions. Though this is not a necessary step, it can provide value to the program administrator or their agents in quickly going back and performing further analyses much faster. For example, the analysis can be easily repeated for a larger or different set of FSAs or investigate other relationships between cost, GHG, and GJ predictions concerning upgrade packages.

Example

For the Toronto case study example, the project team leveraged custom-built, cloud and locally-hosted JavaScript and Python toolsets to perform the required analyses and HOT2000 file creation. Brief descriptions of these toolsets follow for the reader's interest and reference.

File Generation Engine

To help create an agile platform for various analyses based on HOT2000 energy simulations, the team created a set of Python and JavaScript tools to read HOT2000 files and apply retrofits to them based on a set of rules or in a "smart" manner. The tools handled building the wall assemblies for the upgrade packages, choosing upgrades to HVAC systems as appropriate, and generally building upgrade files in HOT2000 format for all retrofit packages selected to be tested. This helped the team to create batches of retrofit files ready for simulation.

Cloud-Based Energy Simulation

To speed up the energy modelling required to complete the retrofit analysis, a set of Python scripts were developed in conjunction with a database of HOT2000 modelling files and a virtual machine-hosted command-line interface (CLI) for version 11.11 of NRCan's HOT2000 software. This enabled the project team to produce thousands of modelling files and have them automatically run through the CLI, and the results returned to the database for analysis.

Other Automation Scripts for Project Tasks

When possible, the project team maintained Python notebooks that aggregated the types of analyses needed to provide insights for the case study. These Python-based Jupyter notebooks were easy to read for non-coders. They were used to present calculations and results in a word document-like format (code with markup). This analysis used these scripts to consolidate and compare results from the thousands of simulated energy models.

Emission Data Collection

If the program administrator intends to evaluate emissions as part of the analytical methodology, emissions data will need to be obtained for each type of energy consumed by each archetype house model being evaluated with HOT2000. In many cases, this can be obtained directly from the outputs of HOT2000, and no further input is needed. However, more regionally relevant or more detailed sources of emission factors can be substituted in the analysis if desired.

Example

In the case of the Toronto case study, annually averaged emissions data was collected from Canada's most recent National Inventory Report at the time of this report (published in 2021, reporting 2019 data). These emission factors were used along with the annual fuel consumption data output by HOT2000 for every simulation to compute the annual emissions for each archetype's baseline house and respective upgrade packages. The data collected from the report only included CO_2 emissions. This analysis did not consider other factors, such as the health implications associated with particulate emissions from wood-burning appliances.

Hourly generator data was also collected from the IESO. This data enables the future assessment of emissions based on the variability of electricity generation sources and informs more detailed emissions analyses when used with more granular electricity consumption data and upgrade-specific load profiles. This data could provide insights into technologies such as solar PV or space cooling systems, whose electricity generation and consumption coincide with times of the year and days when more fossil fuels are used to produce electricity for the grid.

Financial Data Collection

A key data collection need for the analysis outlined in this methodology is estimating the capital costs associated with the types of individual retrofit upgrades and assembled retrofit packages chosen to be evaluated. Combing the annual fuel consumption results from the HOT2000 simulations with utility cost data (which also should be collected for the region or metric being analyzed) allows the annual change in the TCO for the user to be evaluated. This information enables the change in affordability to be assessed. With the addition of emissions information in the analysis, the methodology addresses the core components driving the need for retrofits in Canada (cost, emissions, and energy reductions).

To fully complete the analysis, the capital cost of each retrofit package is needed, but the ability to obtain regionally accurate retrofit costing is often limited. Public datasets are in development by NRCan and its partners, while some other public and private datasets exist but have limited availability. Program administrators are advised to contact NRCan's CanmetENERGY for updates on these initiatives and access to cost data. Some program administrators will already have access to past invoices submitted to their LIC/PACE program and the type of upgrades included for each invoice. This methodology allows this data to be processed to determine the median price for each upgrade being analyzed and then used as "best-guess" estimates for this process. If the program administrator is working on a new program without any previously submitted invoice data, it is recommended to reach out to geographically close regions and their administrators who have already deployed programs to ask for access to their retrofit upgrade pricing analyses.

Future cost projections have not yet been considered within this methodology. Still, they could be incorporated into analyses if the appropriate data is available. The depth to which to pursue the cost analysis is left to each program administrator to determine. Within the context of creating affordable retrofits, the most benefit to users is achieved by performing even the most basic TCO assessment.

Example

For the Toronto case study of this methodology, the invoice data Toronto collected from each HELP-funded project was used. This process used the actual costs incurred by completed HELP loan recipients, which were compiled and verified by Toronto HELP program administrators. The distribution of costs for each component in the HELP packages was analyzed where sufficient data was available. The median value for each component's available price was selected for the analysis based on the data distribution. The cost data used for each package is provided in the modelling input section of this report.

Parameters for the LIC/PACE loan were determined using the City of Toronto's HELP program requirements and the recent council approval for changes to the program, including the use of a 0% interest rate. The full set of loan parameters used is listed in the modelling input section of this report.

Utility financial details were collected for the Toronto case study through the Ontario Energy Board, Toronto Hydro, Enbridge Gas, NRCan's online fuel cost information portal for fuel oil and propane, and a Toronto supplier of cured hardwood. Utility data collection included the cost per unit of energy and the fixed costs associated with obtaining that energy.

Energy Simulation Process

HOT2000 files must be created to represent every possible combination of archetype and upgrade package needed to conduct the energy simulation process within this methodology and create the energy metrics used to benchmark retrofit package affordability (or other metrics) against. Program administrators can procure the services of an energy firm to accomplish this task through the tools already available from NRCan or by other means that provide good value to the administrator. The firm procured should be familiar with the use of HTAP and how to structure upgrade packages for large batches of energy simulations.

The program administrator using this methodology might also choose to perform a more complex simulation scenario involving future weather files. For example, by using future weather files such as those produced by the Pacific Climate Impacts Consortium (Pacific Climate Impacts Consortium, 2022), a program administrator could evaluate the climate change resilience potential of different retrofit packages and the effects on affordability.

Example

A more custom solution was developed within the Toronto case study discussed in this report. HOT2000 archetypes and upgrade packages were selected using the automation tools discussed, and compliant HOT2000 files were built for every permutation of archetypes and upgrades. Then, using the most recent HOT2000 command-line interface (version 11.11), simulations were run for all baseline and upgrade files. This resulted in the creation of approximately 5,100 unique files, where a file contains either baseline or upgrade information. T this task was performed in small batches in case errors were encountered with HOT2000.

To keep the simulations produced for each retrofit package comparable, consistency of inputs was prioritized for HOT2000 simulation runs when possible. For example, a single heat pump type was chosen and then automatically sized by HOT2000 with the cutoff temperature (temperature to switch to backup heating) determined by the device specifications. Items such as PV systems were not matched to the house’s orientation since the roofing details of the structure were not contained within the HOT2000 file. Instead, the same PV parameters were used for all houses.

Another constraint on the modelling was that for upgrade packages with a high-efficiency water heater and furnace, only archetype baselines that used natural gas as a heating/hot water fuel received the upgrade. It was also assumed that the weather conditions would stay the same for the entire loan term. As such, annual metrics for a single year could be extrapolated across all years of the analysis. It is also important to note that the type of baseline systems and geometric characteristics of each archetype was not broken out in this analysis. The archetype models were assessed as aggregated data containing all house geometries and system types.

Financial Calculations

For this analytical methodology, the specifics of cost calculations are left to the preference of the program administrator, given that the type of calculations needed within the analysis will vary with the metrics being evaluated. Regardless, any analysis to assess affordability should focus on the total annual cost for utilities and servicing the capital loan required for the retrofit packages. The analyses that follow the simulations will seek to identify potential energy-efficient retrofit upgrade packages that lead to a lower total annual cost versus the baseline home operation. The remainder of the report section presents an example of the methodology applied to the Toronto case study and the calculations used therein.

Example

Capex Upgrade and Loan Cost

Within the context of the Toronto case study of the analytical methodology, to build the individual capital costs for each retrofit package, the costs of each component in each of the packages were summed to create a total upgrade cost. Items that could be analyzed by cost per unit of implementation (e.g. cost per door or window) had their total value determined by multiplying the number of units in the HOT2000 simulation file by the median unit cost from HELP invoice data. As a result of this summation, the costs derived were conservative since they do not factor in the efficiency of simultaneously completing multiple components of retrofits.

After the costs of retrofit packages were calculated, a loan calculator was applied to that cost. The loan calculation used the same terms, interest rate and administrative costs for all upgrades. This included using a 0% interest rate and 2% administration fee, and a 15-year term from HELP. These conditions were chosen because they represented the measures with the shortest anticipated lifespan (HVAC equipment) and were also long enough to have the smallest potential increase on the annual/monthly cost of the homeowner. The loan from Toronto was spread into equal annual payments. The annual loan cost was estimated by adding the interest on the principal over the loan term plus the principal times the admin fee, all divided by the years of the loan term. The loan input parameters were also summarized in the model inputs section.

Utility Costs

For the Toronto case study, the cost of utilities or energy provided for each simulation depended on the collected utility cost data. For utilities or energy providers that charged a per-unit energy fee (including per-unit fees not related to the fuel supply) plus the annual sum of the fixed cost, the cost of the energy for that source was determined by multiplying the energy usage for that source by the cost of each unit of energy plus the fixed cost multiplied by HST. In the more complex case where two electricity fee structures exist, both time-of-use (TOU) and tiered rate structures were calculated in addition to the regular fixed costs. Since HOT2000 outputs annual energy data, both TOU and tiered electricity rate structures could not accurately be calculated. To account for this, the OEB's bill calculator distributions of off-, mid- and on-peak TOU electricity rates were used to determine the final rate applied to the kWh usage output from the simulation. In the case of tiered rates, the average of the rate was applied to the kWh produced by the simulation. This was to account for the potential higher use of electricity by electric heating for many of the proposed packages. After calculating the variable, fixed, and HST costs, the Ontario Electricity Rebate of 11.7% was applied to reach the final annual electricity cost. For energy sources with a fixed cost that experienced zero use of that source annually, it was assumed that the source was not connected to the home, and fixed costs were not tabulated for that energy source. It was not assumed that utility cost escalation was escalated throughout the analysis period. Details for each utility or fuel cost are in the model input section.

Total Annual Cost

For the Toronto case study, to obtain the total annual costs incurred for each upgrade package simulated, the annual loan and utility/fuel costs were summed. Given the focus on annual costs and not the net present value of the equipment, the lifetime of the equipment was not considered outside of selecting a term of the loan that was shorter than the lifetime of all components comprising the upgrade packages. No discount rate was applied to the cost calculation since the analysis did not rely on future savings beyond the loan payment duration to calculate the annual costs. Other programs or incentives, such as Enbridge's rebates, CMHC/NRCan's loan or NRCan's Greener Homes grant, were not factored into the total annual costs. This intentional omission aimed to isolate the analysis from the risks associated with program changes outside of the LIC/PACE program being evaluated.

Emission Calculation

Generally, annual emissions calculations can be performed by taking the annual fuel/energy consumption from the HOT2000 results for every file produced and multiplying each fuel type usage by its respective emission factor obtained from the program administrator's chosen source. These results are then summed to determine the total annual emissions for each archetype's baseline and upgrade packages. Although the data used to perform this analysis would ideally include hourly electricity emission factors, the annual energy consumption output is a limitation of the HOT2000 energy simulation software used in the EnerGuide process and, therefore, many LIC/PACE programs. Of note, in previous analyses of HOT2000 annual emissions outputs versus hourly consumption data, the emissions from electricity generation can vary significantly based on the time of day and year due to significant variations in the electricity generation mix over time. However, most jurisdictions prefer annual analysis, and HOT2000 cannot output hourly consumption.

Example

For the Toronto case study example, the calculation took the annual fuel/energy consumption from the HOT2000 results for every file produced and multiplied it by its respective emission factor obtained from the National Inventory Report.

Example: Toronto Case Study Input Data

Census Data

The 2016 Census of Canada was downloaded in its entirety based on forward sortation area (FSA) (Statistics Canada, 2017). It was subsequently loaded into a cloud database. It was then queried by FSA beginning with "M" to obtain the data for "Average total income of households in 2015 ($)", "Prevalence of low income based on the Low-income measure, after-tax (LIM-AT) (%)," and the subcategory of that, "65 years and over (%)" for the City of Toronto. Language data was also obtained for each FSA.

Regional Housing Archetypes

The HTAP Archetypes, a HOT2000 input files database, was obtained from CanmetENERGY for use in the analysis of this project. A total of 5970 files were loaded into the project database for existing Part 9 homes in Canada, excluding MURBs and mobile homes. Each file had an FSA location associated which allowed it to be linked with census data. Approximately 200 archetype files representing the Toronto area were used in this analysis.

Retrofit Components, Packages and Costs

The individual components contained within the retrofit packages analyzed are summarized below. A given retrofit package is composed of one or more of these components.

Retrofits Components with Costs

- Air Sealing
  - Retrofit Component: Improve the existing air sealing performance by 20%
  - Cost: $1145
- Air Source Heat Pump (Existing heating backup)
  - Retrofit Component: Add an EnergyStar air source heat pump, add or replace the cooling system, and use the existing heating system as backup heat
  - Cost: $6337
- Air Source Heat Pump (Electric heating backup)
  - Retrofit Component: Add an EnergyStar air source heat pump, add or replace the cooling system, and use an electric heating system as backup heat
  - Cost: $7837 ($4756 for AffordableK package)
- Attic Insulation
  - Retrofit Component: Upgrade existing attic insulation to R50 (R60 for AffordableK package)
  - Cost: $2034 ($352 for AffordableK package)
- Foundation Insulation
  - Retrofit Component: the foundation insulation to R30
  - Cost: $2620
- Heat Pump Water Heater
  - Retrofit Component: Upgrade the existing water heating system to an electric heat pump water heater with an energy factor rating of 3.55
  - Cost: $4000
- High-efficiency Furnace
  - Retrofit Component: Replace the existing heating system with a 97% efficiency natural gas furnace
  - Cost: $7910
- Slab Insulation
  - Retrofit Component: Increase the foundation slab insulation to R10
  - Cost: $2401

- Solar Photovoltaics - 2kW
    - Retrofit Component: Install a 2kW solar photovoltaic system using modules with an efficiency of 18%
    - Cost: $5700
- Solar Photovoltaics - 5kW
    - Retrofit Component: Install a 5kW solar photovoltaic system using modules with an efficiency of 18%
    - Cost: $14250
- Wall Insulation (Add R12)
    - Retrofit Component: Add R12 of insulation to the exterior of the building
    - Cost: $7910
- Wall Insulation (Add R20)
    - Retrofit Component: Add R20 of insulation to the exterior of the building
    - Cost: $12997
- Window/Door Upgrade
    - Retrofit Component: Replace all of the existing windows with ones that have a U-value of 1.04 and all doors with ones having an RSI of 0.85
    - Cost: $1107 per unit
- Gas Water Heater
    - Retrofit Component: Replace the existing water heater with a gas water heater tank having an efficiency of 67%
    - Cost: $3170
- Air Conditioner
    - Retrofit Component: Add a cooling system where none exists or replace an existing cooling system with one having a 20 SEER rating
    - Cost: $5337
- EcoSolaris Mini-split Heat Pump
    - Retrofit Component: Supplement the existing heating system and add or replace the cooling system with an EcoSolaris 18kBTU/h DC heat pump
    - Cost: $3616
- Solar Photovoltaics - 2kW (No Inverter)
    - Retrofit Component: Install a 2kW solar photovoltaic system using modules with an efficiency of 18%, but no DC/AC inverter (for use with DC heat pump)

    - Cost: $4520
- Electric Water Heater
    - Retrofit Component: Replace the existing water heater with an electric water heater tank having and an efficiency of 92%
    - Cost: $2387

Retrofit Packages

Table 1. Packages based on HELP implementations.

Package Name	Components	Notes
HELP 1	● High-efficiency furnace (97%) ● High-efficiency AC (20 SEER) ● High-efficiency gas water heater (0.67 EF) ● Attic insulated to R50 (effective) ● Foundation walls insulated to R30 (effective) ● R12 insulation added to walls	Only applied to natural-gas heated homes with basements
HELP 2	● High-efficiency furnace (97%) ● High-efficiency AC (20 SEER) ● High-efficiency gas water heater (0.67 EF) ● Air sealing (20% ACH improvement) ● ENERGY STAR windows ● ENERGY STAR doors	Only applied to natural-gas heated homes
HELP 3	● High-efficiency furnace (97%) ● High-efficiency AC (20 SEER) ● High-efficiency gas water heater (0.67 EF) ● Air sealing (20% ACH improvement) ● ENERGY STAR windows ● ENERGY STAR doors ● Attic insulated to R50 (effective) ● Foundation walls insulated to R30 (effective) ● R12 insulation added to walls	Only applied to natural-gas heated homes with basements
HelpAirSeal-WindowDoor	● Air sealing (20% ACH improvement) ● ENERGY STAR windows ● ENERGY STAR doors	
HelpHVAC	● High-efficiency furnace (97%) ● High-efficiency AC (20 SEER) ● High-efficiency gas water heater (0.67 EF)	
HelpSolarPV5kW	● 5 kW solar photovoltaics	

Table 2. Packages based on a "pathway to net-zero" approach

Package Name	Components	Notes
BasicEnvelope	• Air sealing (20% ACH improvement) • ENERGY STAR windows • ENERGY STAR doors • Attic insulated to R50 (effective)	
MediumEnvelope	• Air sealing (20% ACH improvement) • ENERGY STAR windows • ENERGY STAR doors • Attic insulated to R50 (effective) • Foundation walls insulated to R30 (effective) • R12 insulation added to walls • Air Source Heat Pump (9.57 HSPF, 21.5 SEER) • *Existing heating system remains as backup*	Backup heating system only comes online when ASHP cannot meet the heating load.
DeepEnvelope	• Air sealing (20% ACH improvement) • ENERGY STAR windows • ENERGY STAR doors • Attic insulated to R50 (effective) • Foundation walls insulated to R30 (effective) • Foundation slab insulated to R10 (effective) • R20 insulation added to walls • Air Source Heat Pump (9.57 HSPF, 21.5 SEER) • Electric heating backup	Backup heating system assumed to be electric, either baseboards or backup built into heat pump.
NetzeroEnvelope	• Air sealing (20% ACH improvement) • ENERGY STAR windows • ENERGY STAR doors • Attic insulated to R50 (effective) • Foundation walls insulated to R30 (effective) • Foundation slab insulated to R10 (effective) • R20 insulation added to walls • Air Source Heat Pump (9.57 HSPF, 21.5 SEER) • Electric heating backup • 5 kW solar photovoltaics • Heat pump water heater (3.55 EF)	5 kW of solar was applied to all homes for consistency and was not sized to precisely meet the net-zero energy requirement.

Table 3. Packages designed for affordability

Package Name	Components	Notes
affordable1	• Air sealing (20% ACH improvement) • Attic insulated to R50 (effective)	
affordable2	• Air sealing (20% ACH improvement) • Attic insulated to R50 (effective) • Air Source Heat Pump (9.57 HSPF, 21.5 SEER) • *Existing heating system remains as backup* • 2 kW solar photovoltaics	Backup heating system only comes online when ASHP cannot meet the heating load.
affordable3	• Air Source Heat Pump (9.57 HSPF, 21.5 SEER) • *Existing heating system remains as backup* • 2 kW solar photovoltaics	Backup heating system only comes online when ASHP cannot meet the heating load.
affordableK	• Air sealing (20% ACH improvement) • Attic insulated to R60 (effective) • Air Source Heat Pump (9.57 HSPF, 21.5 SEER) • Electric heating backup • High-efficiency electric hot water tank (0.92 EF)	Attic insulated to R60 in this case to match real-world example.
acSystemBaseline	• High-efficiency AC (20 SEER)	Used as a baseline to evaluate affordable3

Utility Cost Information

Electricity Cost

- Delivery and other charges from Toronto Hydro rates (Toronto Hydro, 2022)
  - Fixed cost: $39.91 per month
  - Variable cost: $0.01739 per kWh
- Time of use electricity rates for Ontario
  - Off Peak Rate: $0.074 per kWh
  - Mid Peak Rate: $0.102 per kWh
  - On Peak Rate: $0.151 per kWh
  - Applied Ratio (Off Peak %, Mid Peak %, On Peak %): 18, 18, 64
- Tiered electricity rates for Ontario
  - Tier 1 Rate: $0.087 per kWh
  - Tier 2 Rate: $0.103 per kWh
  - Applied Ratio (Tier 1 %, Tier 2 %): 50, 50
- Tax applied to electricity
  - HST: 13%
- Rebate applied to the entire electricity bill for the Ontario Electricity Rebate
  - Rebate: 11.7%

Natural Gas Cost

- Delivery and other fixed costs from Enbridge (Enbridge, 2022)
  - Fixed cost: $22.12 per month
  - Variable/usage cost: $0.5526 per m^3 (using an average of the delivery plus the rest of the m^3 charges)
- Tax applied to natural gas
  - HST: 13%

Propane Gas Cost

- Delivery and other fixed costs from NRcan (NRCan, 2021)
  - Fixed cost: $0 per month
  - Variable cost: $0 per L
- Propane Gas Rates
  - Rate: $1.399 per L
- Tax applied to propane gas

    - HST: 13%

Fuel Oil Cost

- Delivery and other fixed costs from NRcan (NRCan, 2022)
    - Fixed cost: $0 per month
    - Variable cost: $0 per L
- Fuel Oil Rates
    - Rate: $2.389 per L
- Tax applied to fuel oil
    - HST: 13%

Cord Wood Fuel

- Delivery and other fixed costs
    - Variable cost: $0.1677 per kg
- Cord Wood Rates
    - Rate: $0.311 per kg
- Tax applied to wood
    - HST: 13%
- Notes: The prices of seasoned cord wood in Toronto were obtained from Tree Doctors Inc (Tree Doctors, 2022) at their current prices. They charge $150 delivery per cord and a $130 stacking cost per cord. With each seasoned cord of maple hardwood estimated to weigh 1670 kg (Utah State University, 2022) and firewood being obtained by the cord when ordering, a value of $0.1677/kg was calculated for variable costs. Tree Doctors charges $520 for a seasoned cord of mixed hardwood and when using 1670 kg for the cord weight, a price of $0.311/kg of seasoned cord wood is achieved.

Loan Information

Annual HELP Payment Calculation

Annual Loan Payment = (Loan Principal x Administrative Fee + Loan Principal + Loan Principal x Loan Term Length x Loan Interest Rate) / Loan Term Length

Loan Conditions

- Loan Term Length: 15 years
- Loan Interest Rate: 0% annually
- Administrative Fee: 2% of principal
- Loan Principal: Sum of the cost of all of the upgrades contained with the upgrade package being simulated

Emissions Information

- Electricity emission factor
  - Value: 30 g per kWh
  - Source: NIR, 2021. Part 3. Table A13–7 Electricity Generation and GHG Emission Details for Ontario
- Natural Gas emission factor
  - Value: 1888 g per m^3
  - Source: NIR, 2021. Part 2. Table A6.1–1 CO2 Emission Factors for Natural Gas
- Residential Light Fuel Oil
  - Value: 2753 g per L
  - Source: NIR 2021. Part 2. Table A6.1–5 Emission Factors for Refined Petroleum Products
- Residential Propane
  - Value: 1515 g per L
  - Source: NIR 2021. Part 2. Table A6.1–4 Emission Factors for Natural Gas Liquids
- Stoves and Fireplaces Residential Combustion
  - Value: 1539 g per kg fuel
  - Source: NIR 2021. Part 2. Table A6.6–1 Emission Factors for Biomass

Example: Toronto Case Study Results and Analyses

Results

Energy Modelling Results Summary

A total of 2583 energy simulations were performed on 204 archetype house files within 74 FSA regions, starting with "M" using the current version (11.11) command-line interface for NRCan's HOT2000 simulation software. The Python automation scripts were used to read and interpret the fully simulated HOT2000 files, and a selection of parameters from the HOT2000 files was parsed into a large CSV file for post-processing. The CSV data was indexed by simulation file name and upgrade type with the data was sorted into columns:

- The H2K filename of the archetype house used
- The forward service area portion of the postal code of the archetype H2K file
- The upgrade package type that was modelled on the archetype filename

- The total gigajoules (GJ) of annual energy consumption for that package type
- The total kilowatt-hours (kWh) of annual electricity consumption for that package
- The total cubic meters (m^3) of annual natural gas consumption for that package
- The total liters (L) of annual propane consumption for that package
- The total liters (L) of annual fuel oil consumption for that package
- The total kilograms (kg) of annual hardwood consumption for that package
- The total kilowatt-hours (kWh) of annual solar energy utilized for that package
- The total kilowatt-hours (kWh) of annual solar energy available for that package
- The peak design heating load (W) for that package
- The peak design cooling load (W) for that package
- Heating system type
- Capacity of the heating system (kW)
- Cooling system type
- Capacity of the cooling system (kW)
- Number of windows upgraded in the model
- Number of doors upgraded in the model
- Square footage of the attic insulation upgrade
- Square footage of the exterior wall upgrade

The simulation results from the HOT2000 runs on the archetype files supplied by NRCan were assumed to be appropriate for the region for which they were obtained since both the input file parameters and simulation energy were verified and quality checked by NRCan. However, the base housing topology in Canada has changed over time. The baseline files will have to continually be updated to enable future simulation runs to accurately reflect current building stock and ensure this type of analysis continues to be useful. In the case of this analysis, data in the archetype files were collected from recent audits, recorded no earlier than 2016.

Results Post Processing

The aggregated simulation results were post-processed to produce a set of appropriate metrics to inform the type of upgrade packages that could offer the potential of increased annual affordability. The metrics calculated were intended to demonstrate easily digestible results for program administrators. The metrics aimed to indicate the trends that different retrofits produced on a wide and varied set of housing archetypes likely to represent a good portion of the regional housing stock. The metrics highlighted were energy consumption, GHG emissions, annual costs, income level, and language.

Energy modelling and census data were combined in post-processing and indexed together by FSA, filename and upgrade type. New columns for each of the respective fuel costs, the annual total fuel cost, the annual loan cost, the annual total cost, as well as the census “MemberID” data for average income, the percentage of low income, all ages, percentage low income over 65 per FSA, spoken language, and mother tongue language were calculated or connected. Additional columns were also computed to determine the percentage change for each fuel type, GHG emissions, the GJ and loan cost versus the baseline, and the percentage of each fuel and loan cost’s contribution to the total energy cost for each archetype file and respective upgrade type.

Distribution of Results for Energy, Emissions, and Annual Cost Breakdown

The statistical distributions for percent changes (upgrade case relative to baseline for a given archetype) in energy consumption, total annual cost, and emissions were also produced with the aggregation of all Toronto FSAs data for each upgrade type to understand the variability of the modelled upgrade’s effectiveness across a variety of Toronto building archetypes. This can be seen in Figure 1, Figure 2, and Figure 3. Note that a negative percent change indicates savings.

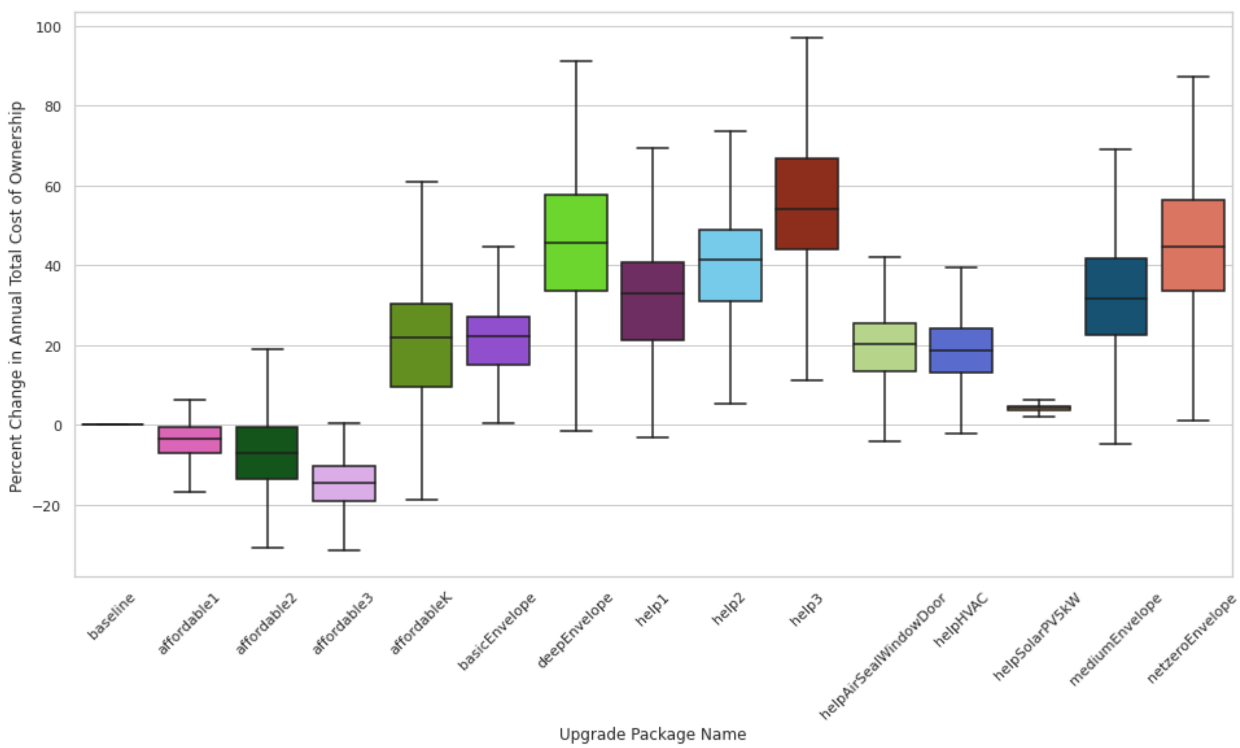

Figure 1. Annual cost change by upgrade package

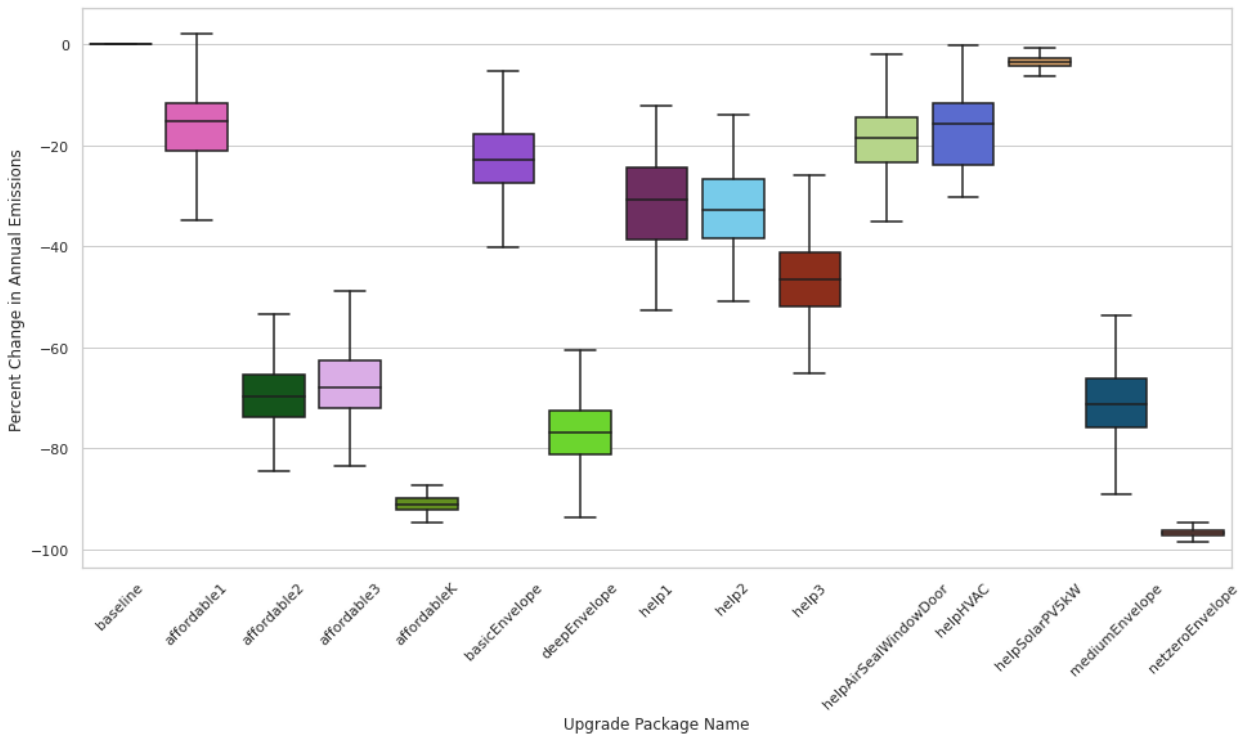

Figure 2. Annual emissions change by upgrade package

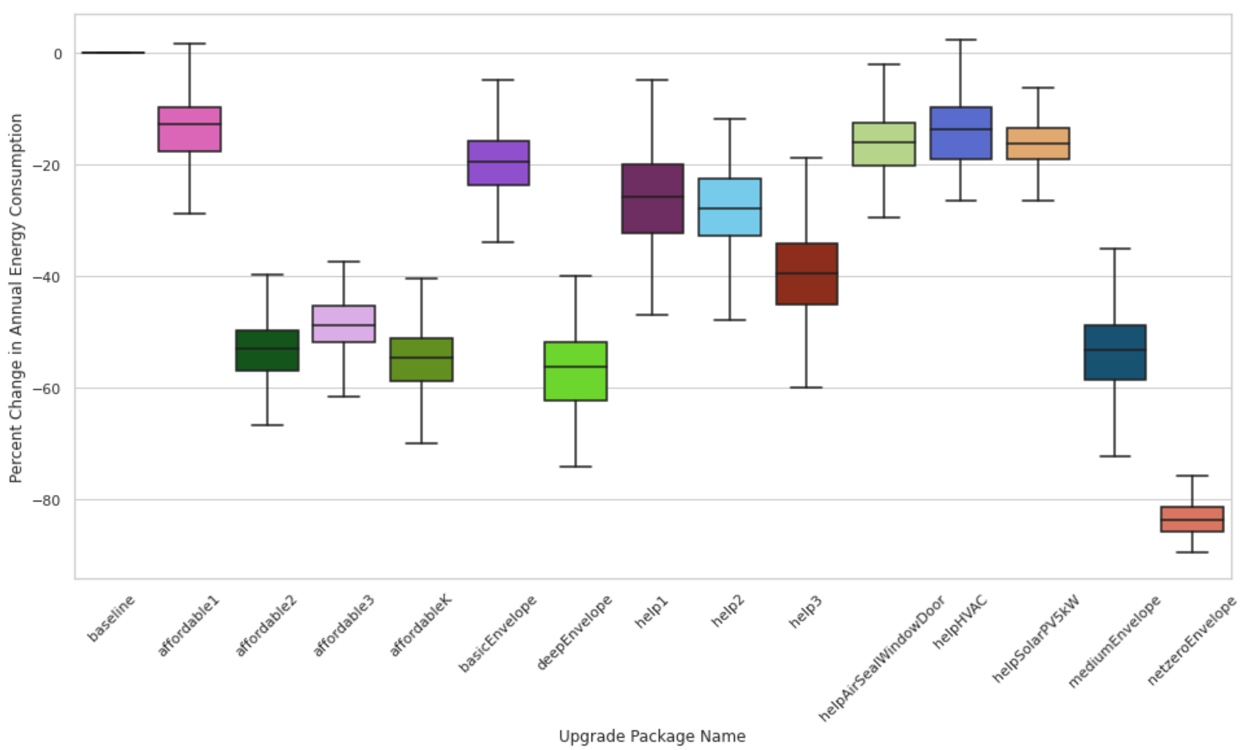

Figure 3. Annual total energy consumption change by upgrade package

Each fuel cost and LIC/PACE loan contribution to the total annual cost was also statistically analyzed for each upgrade type to understand the breakdown of components of the annual cost incurred and the potential sensitivity of the cost to fuel and loan cost changes. This can be seen in Figure 4.

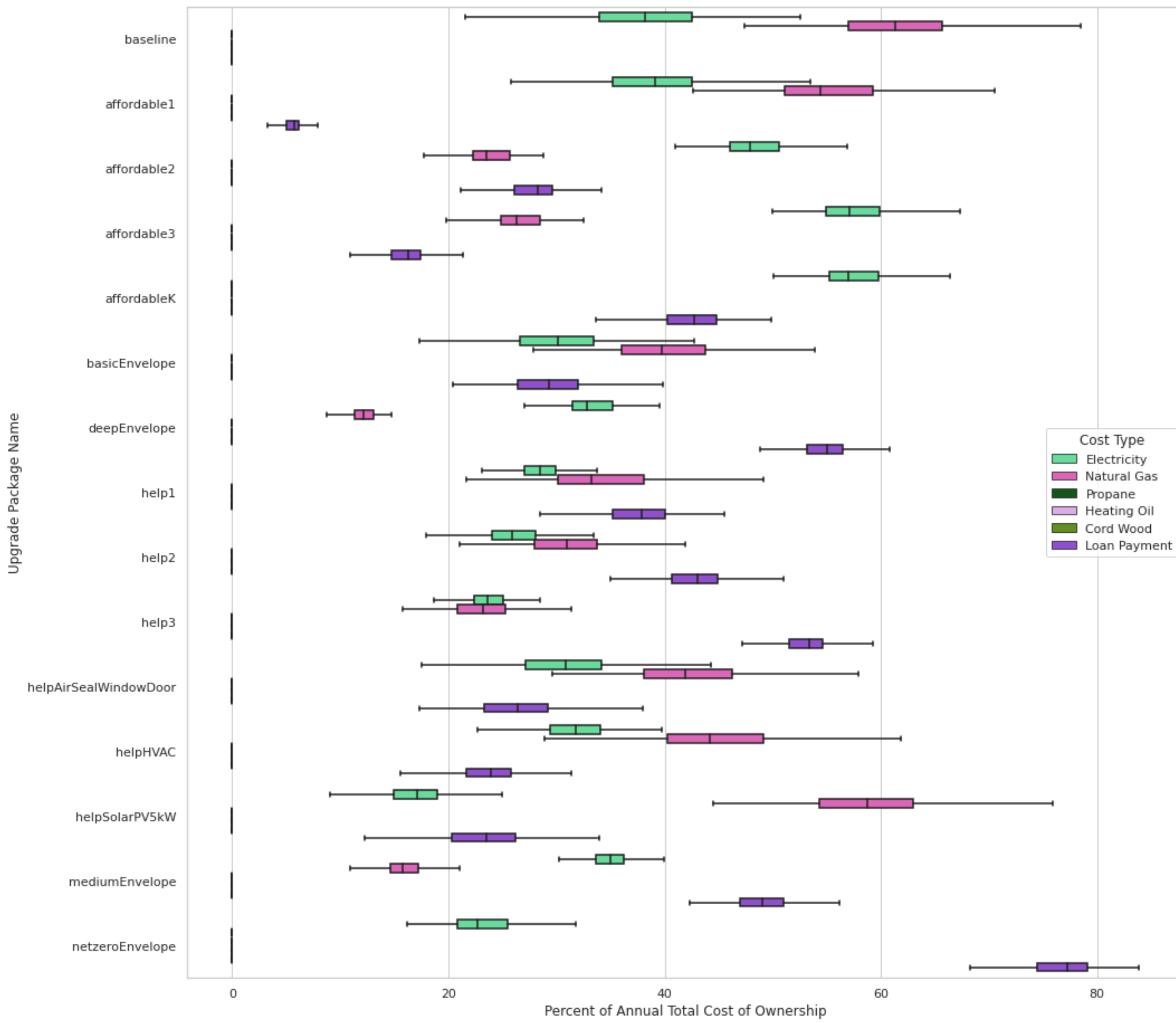

Figure 4. Cost breakdown by fuel type and upgrade package

Retrofit Annual Costs in Relation to Energy and Emissions

To visualize relationships between results, point cloud comparisons were made between the percentage changes of energy consumption versus total annual cost and GHG emissions versus total annual cost for each upgrade package. This was intended to highlight the upgrades that led to energy and emissions reduction while obtaining baseline annual cost equity or cost reductions. The results are shown in Figure 5 and Figure 6. Each point represents one simulated archetype, and each colour group represents one upgrade package tested on all archetypes.

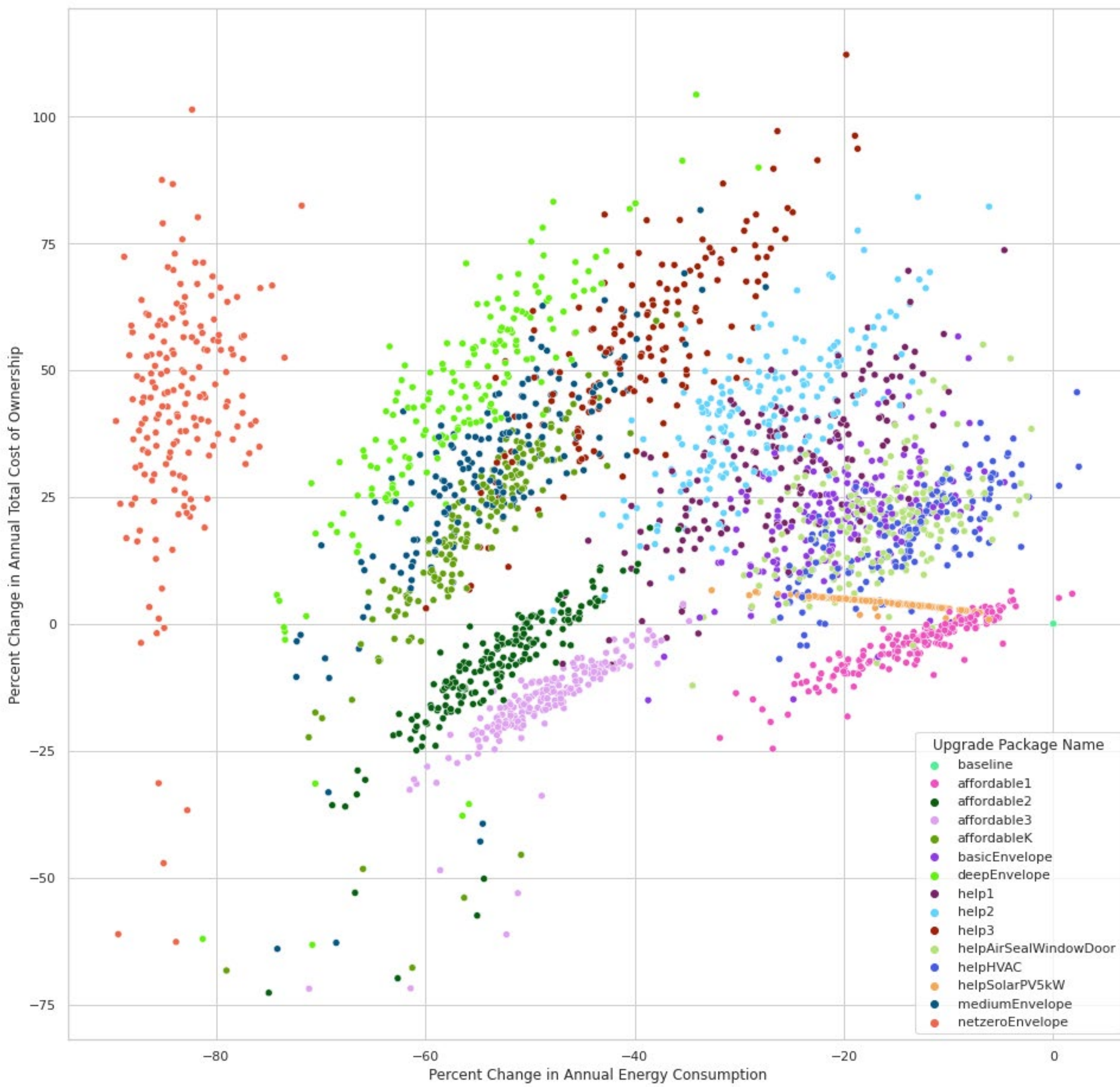

Figure 5. Change in annual costs versus change in total annual energy consumption

Figure 6. Change in annual costs versus change in total annual emissions

Geographic Considerations

A statistical analysis was also performed on the results to show the distributions of the percent cost reduction per first two letters of FSA by each upgrade type to understand if certain areas in Toronto had housing types that responded to certain upgrades better than others from an affordability standpoint. The results are shown in Figure 7.

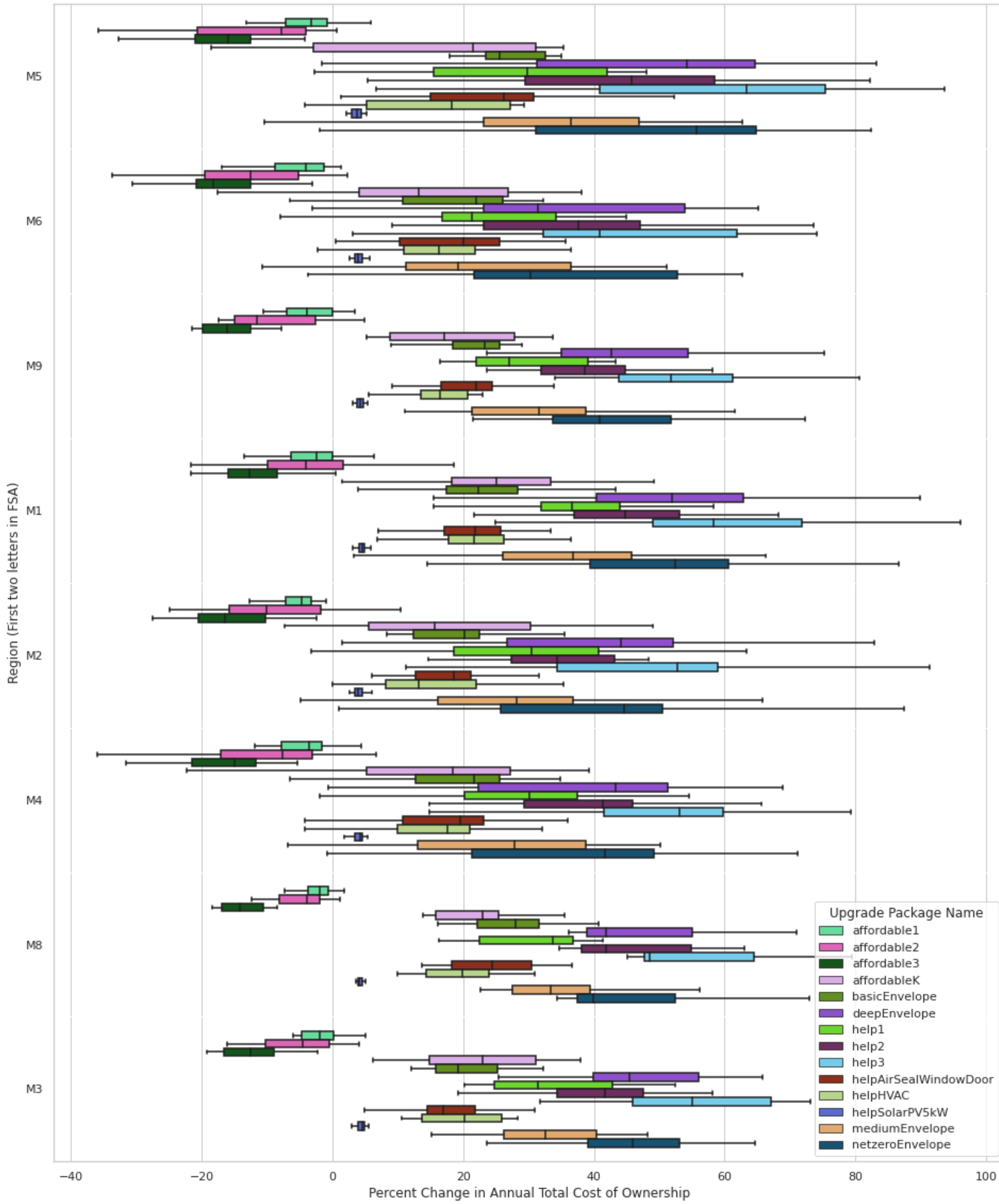

Figure 7. Change in annual operating costs by upgrade package and FSA grouping

The census income data points were analyzed with the total annual cost (TCO) for each upgrade measure for all Toronto FSAs to assess if certain upgrades created unsustainable total annual energy (and upgrade cost) to income ratios in Toronto geographic areas. Total annual costs of the baseline and all upgrades were compared to average incomes for all the modelled FSAs and expressed as a percentage of average income. They were also compared to the percentage of non-English speakers in each FSA. These results are sorted from the highest to lowest TCO as a percentage of Average Total Income for the baseline package, as shown in Figure 8 and Figure 9.

Postal	Annual Total Upgrade Cost / Average Total Income (%)														Census Data				
			<2.5	2.5-5	5-7.5	7.5-10	>10												
FSA	baseline (%)	affordable1 (%)	affordable2 (%)	affordable3 (%)	affordableK (%)	basicEnvelope (%)	deepEnvelope (%)	help1 (%)	help2 (%)	help3 (%)	helpAirSealWindowDoor (%)	helpHVAC (%)	helpSolarPV5kW (%)	mediumEnvelope (%)	netzeroEnvelope (%)	Average total income of households in 2015 ($)	Prevalence of low income based on the Low-income measure, after tax (LIM-AT) (%)	65 years and over (LIM-AT) (%)	Non-English First Language (%)	Non-English Mother Tongue (%)
M4X	16.0	12.1	7.6	8.2	8.4	13.6	11.1				14.1		16.1	10.8	11.0	65064	35.3	39	6.3	47
M4Y	8.3	6.9	6.6	6.9	8.6	9.4	10.6	9.0	9.8	10.6	9.4	8.2	8.4	9.8	10.8	70100	28.3	19	5.7	39
M5T	6.2	5.6	5.7	5.5	7.9	7.2	9.0	7.8	8.2	9.0	7.2	7.0	6.3	8.0	9.1	67852	32.9	45	17	49
M1W	6.0	5.5	4.5	4.0	6.0	6.8	7.3	5.9	6.5	7.4	6.9	5.1	6.2	6.6	7.3	80752	20.9	18	17	68
M4J	5.9	5.6	3.9	3.4	4.9	6.3	5.8	5.0	5.3	6.0	6.3	4.3	6.0	5.3	5.6	99966	17	24	6.8	32
M6K	5.5	6.4	6.5	5.1	8.9	8.7	9.9	8.3	7.7	9.9	6.5	6.6	5.6	8.9	10.0	70034	24.5	38	7.1	35
M6E	5.2	4.8	5.0	4.6	6.7	6.2	7.5	6.5	6.9	7.6	6.1	5.8	5.3	6.8	7.5	74558	16.4	18	10	52
M3N	5.1	5.1	5.7	4.9	8.0	6.4	9.3	8.1	8.0	9.4	6.3	6.8	5.3	8.1	9.3	57606	31.8	23	9.2	46
M9N	5.1	5.1	5.4	4.8	7.4	7.0	9.0	7.3	8.2	9.1	6.8	6.4	5.3	8.1	9.0	65571	26.2	25	5.5	38
M1T	5.1	4.7	5.2	4.8	7.4	6.3	8.5	7.3	7.7	8.5	6.2	6.4	5.2	7.5	8.6	69616	26.3	27	13	60
M3J	5.0	5.0	5.5	4.7	7.7	6.6	9.0	7.4	7.9	9.0	6.5	6.3	5.2	7.9	9.1	65841	24.6	15	6.7	54
M1P	4.9	4.9	5.3	4.5	7.4	6.6	8.8	7.1	7.8	8.8	6.4	6.1	5.1	7.7	8.9	67265	24.7	20	7.3	55
M6M	4.8	4.9	5.4	4.7	7.5	6.6	8.7	7.2	7.8	8.8	6.3	6.2	5.0	7.7	8.8	66702	23.5	19	7.3	47
M6N	4.8	4.6	5.1	4.6	7.2	6.2	8.1	6.8	7.4	8.2	6.0	6.1	5.0	7.2	8.2	70016	21.2	21	8.6	48
M9R	4.8	4.7	4.8	4.3	6.4	6.0	7.5	6.3	6.7	7.5	5.9	5.4	4.9	6.8	7.5	80507	21	13	6.2	47
M1E	4.7	4.2	4.6	4.1	6.4	5.6	7.5	6.3	6.8	7.6	5.7	5.5	4.8	6.7	7.5	78494	22.1	14	4.3	33
M1R	4.7	4.7	5.0	4.3	6.8	6.3	8.3	6.6	7.3	8.2	6.2	5.7	4.8	7.3	8.3	74777	21.3	15	6.2	46
M2N	4.7	4.5	4.6	4.2	6.3	5.8	6.9	5.8	6.5	7.0	5.8	5.3	4.8	6.3	7.0	87061	28.9	24	8.4	65
M1L	4.6	4.8	5.3	4.4	7.4	5.3	7.3	7.1	6.6	7.4	5.2	5.9	4.7	6.3	7.3	70159	27.7	19	6.2	48
M4A	4.5	4.3	4.7	4.2	6.7	5.5	7.7	6.8	6.7	7.8	5.3	5.7	4.7	6.7	7.7	70865	22.2	23	7.1	45
M3K	4.5	4.4	4.6	4.2	5.8	6.4	7.6				6.3		4.6	7.3	7.7	85016	15.1	8.5	7.3	55
M6S	4.5	4.4	3.0	2.7	4.0	5.2	4.5	3.6	4.0	4.3	5.2	3.2	4.6	4.1	4.6	134207	12.1	12	4.5	29
M2J	4.5	4.2	4.6	4.2	6.4	5.4	7.3	6.2	6.5	7.3	5.5	5.4	4.6	6.4	7.3	79919	23.7	16	8.8	63
M1K	4.5	4.4	5.1	4.3	7.0	5.8	8.1	6.9	7.2	8.3	5.8	5.9	4.6	7.2	8.1	64868	24.6	19	5.5	46
M1G	4.4	4.4	5.0	4.4	7.0	5.6	7.9	7.0	7.0	8.0	5.4	5.9	4.6	7.0	8.0	66536	28.7	23	6.3	49
M2R	4.4	4.4	4.7	4.1	6.4	6.1	7.7	6.1	7.0	7.8	6.0	5.4	4.6	7.0	7.7	76640	23.2	27	7.9	63
M9M	4.4	4.6	4.8	4.1	6.7	5.8	7.5	6.2	6.9	7.6	5.8	5.6	4.6	6.6	7.5	73319	20.4	14	7.7	53
M3L	4.4	4.3	4.6	4.0	6.2	5.5	7.1	6.0	6.5	7.3	5.5	5.2	4.5	6.5	7.1	73805	17.9	18	9.4	54
M1V	4.3	4.2	4.6	4.1	6.4	5.4	7.3	6.3	6.5	7.4	5.3	5.4	4.5	6.5	7.4	76850	21.8	20	25	74
M9V	4.3	4.2	4.7	4.1	6.5	5.4	7.4	6.4	6.6	7.6	5.3	5.5	4.5	6.6	7.5	70475	23.5	16	8	53
M8W	4.2			4.0							5.2		4.3			94004	12.1	11	3.9	34
M3M	4.2			4.0					6.5		5.1	5.6	4.4			68432	20.2	14	7	51
M2M	4.2	4.1	4.3	3.9	6.0	5.6	7.2	5.8	6.4	7.1	5.5	5.0	4.3	6.4	7.3	88709	26.3	20	8.8	69
M4C	4.2	4.1	4.4	3.9	6.3	5.6	7.5	6.1	7.2	7.5	6.0	5.2	4.3	6.6	7.6	79132	22	21	6	37
M6J	4.1	3.7	3.8	3.7	5.2	4.7	5.8	4.9	5.5	5.8	4.9	4.7	4.2	5.1	5.8	107587	14.9	14	11	35
M1S	4.0	3.9	4.4	3.9	6.2	5.3	7.4	6.1	6.6	7.4	5.2	5.3	4.1	6.5	7.4	78915	22.1	21	18	68
M3A	3.9	3.5	3.8	3.6	5.2	4.4	5.9	5.4	5.3	6.0	4.4	4.7	4.1	5.3	5.9	86403	20.5	15	6.4	44

Figure 8. Comparison of upgrade cost to average income level by FSA (Part 1)

Postal FSA	baseline (%)	affordable1 (%)	affordable2 (%)	affordable3 (%)	affordableK (%)	basicEnvelope (%)	deepEnvelope (%)	help1 (%)	help2 (%)	help3 (%)	helpAirSealWindowDoor (%)	helpHVAC (%)	helpSolarPV5kW (%)	mediumEnvelope (%)	netzeroEnvelope (%)	Average total income of households in 2015 ($)	Prevalence of low income based on the Low-income measure, after tax (LIM-AT) (%)	65 years and over (LIM-AT) (%)	Non-English First Language (%)	Non-English Mother Tongue (%)
	Annual Total Upgrade Cost / Average Total Income (%)															Census Data				
			<2.5	2.5-5	5-7.5	7.5-10	>10													
M2H	3.9	3.6	3.9	3.6	5.3	4.7	6.2	5.2	5.8	6.2	4.9	4.8	4.0	5.6	6.2	90314	20.8	18	11	67
M3C	3.8	4.0	4.4	3.7	6.2	4.9	6.5	5.7	6.1	6.7	4.7	5.1	4.0	5.7	6.5	75884	27.7	20	8.2	56
M8V	3.8	3.8	4.1	3.6	5.8	5.2	6.9	5.6	6.2	6.9	5.1	4.8	3.9	6.1	7.0	84412	20.9	23	5.4	35
M2K	3.8	3.8	3.9	3.4	5.3	4.9	6.1	5.1	5.4	6.1	4.7	4.4	3.9	5.5	6.1	98256	23.7	14	7.7	61
M9W	3.7	3.7	4.1	3.5	5.6	5.2	7.1	5.6	6.1	7.2	5.1	4.7	3.9	6.4	7.1	77220	18.1	11	5.1	46
M1B	3.7	3.7	4.1	3.5	5.7	4.8	6.6	5.7	5.9	6.7	4.7	4.8	3.8	5.9	6.7	80137	17.4	14	5.6	43
M5S	3.7	3.6	3.8	3.5	5.2	5.0	6.5	4.9	5.4	6.1	5.0	4.2	3.8	5.9	6.6	99353	30.4	13	5.4	42
M6P	3.7	3.7	4.0	3.5	5.5	4.9	6.3	5.2	5.8	6.4	4.8	4.6	3.8	5.7	6.3	93088	15.9	20	5.9	32
M4B	3.6	3.6	3.9	3.3	5.5	4.8	6.5	5.4	5.6	6.6	4.6	4.5	3.7	5.8	6.6	86241	20.9	14	4.9	34
M1M	3.5	3.5	3.9	3.3	5.4	4.7	6.2	5.2	5.6	6.3	4.5	4.5	3.6	5.5	6.2	91286	18.7	18	3.8	33
M6B	3.4	3.4	3.6	3.2	4.9	4.3	5.6	4.7	5.0	5.6	4.3	4.1	3.5	5.0	5.6	106225	15.5	16	5.9	46
M1N	3.3	3.3	3.5	3.1	4.8	4.8	6.0	4.7	5.6	6.1	4.7	4.1	3.5	5.4	6.0	102338	14.6	12	3.5	21
M9C	3.3	3.3	3.5	3.1	4.8	4.2	5.6	4.8	5.0	5.7	4.1	4.1	3.4	5.0	5.6	98891	12.1	8.5	5.1	45
M8Y	3.3	3.4	3.5	3.0	4.8	4.5	5.4	4.4	5.1	5.5	4.4	4.0	3.4	4.9	5.4	105713	15.8	18	5.3	38
M4K	3.3	3.1	3.3	3.0	4.6	3.9	5.2	4.5	4.7	5.3	4.0	4.0	3.4	4.6	5.2	108472	16.1	20	5.3	28
M9B	3.2	3.1	3.3	2.9	4.4	4.2	5.3	4.3	4.8	5.3	4.2	3.8	3.3	4.7	5.3	122433	11.7	8.1	5	43
M6C	3.2	3.1	3.2	2.8	4.2	4.2	5.1	4.1	4.7	5.1	4.1	3.6	3.3	4.7	5.1	125138	14.4	18	4.6	29
M1C	2.7	2.7	2.9	2.6	4.0	3.9	5.1	4.0	4.6	5.2	3.9	3.4	2.8	4.6	5.1	126192	8.2	4.6	3	32
M1X	2.7	2.8	3.1	2.6	4.3	3.6	5.1	4.3	4.4	5.2	3.5	3.6	2.8	4.5	5.1	105913	9.1	5	6.7	57
M4L	2.7	2.6	2.9	2.6	4.0	3.3	4.7	4.1	4.1	4.8	3.3	3.4	2.8	4.2	4.7	115346	16	17	6	21
M6G	2.6	2.6	3.1	2.7	4.3	3.7	5.1	4.2	4.6	5.2	3.6	3.6	2.7	4.5	5.1	112203	13.7	17	8.2	31
M8Z	2.6	2.6	2.9	2.5	4.0	3.3	4.4	3.8	4.0	4.5	3.2	3.4	2.7	4.0	4.4	120453	7.5	9	5.4	39
M4E	2.5	2.4	2.6	2.4	3.6	3.1	4.3	3.7	3.7	4.2	3.0	3.2	2.6	3.7	4.3	142761	11.1	16	3.2	13
M9A	2.5	2.5	2.6	2.3	3.5	3.4	4.2	3.3	3.9	4.2	3.4	3.0	2.6	3.8	4.2	160481	14.5	15	5.4	42
M4S	2.4	2.4	2.8	2.4	3.9	3.1	4.6	4.0	4.0	4.6	3.0	3.3	2.5	4.0	4.6	112210	14.5	17	4.7	30
M5P	2.3	1.8	2.0	2.2	2.6	2.8	3.4	2.6	3.3	3.4	3.0	2.5	2.3	3.2	3.5	243566	11.5	8	3.4	23
M3B	2.1	2.1	2.2	2.0	3.0	2.8	3.5	3.0	3.6	3.9	2.7	2.6	2.1	3.2	3.5	189736	11.9	6.9	6.2	45
M5R	2.0	2.2	2.3	1.9	3.1	3.4	4.2	2.8	3.2	4.1	2.8	2.4	2.1	3.8	4.2	188123	19.6	13	4.3	25
M5N	1.9	1.9	2.0	1.7	2.6	2.6	3.2	2.5	3.0	3.2	2.6	2.2	1.9	2.9	3.2	214698	12.3	13	3.3	25
M4V	1.9	1.8	1.7	1.6	2.3	2.5	2.8	2.1	2.7	2.8	2.5	2.0	1.9	2.6	2.8	258550	12.3	7	3.6	21
M4G	1.5	1.5	1.6	1.4	2.2	2.1	2.6	2.1	2.4	2.6	2.0	1.8	1.6	2.4	2.6	227398	7.8	6	2.9	19
M4R	1.4	1.4	1.5	1.3	2.1	1.9	2.5	2.1	2.2	2.5	1.8	1.8	1.5	2.2	2.5	220031	9.9	8.9	3.8	22
M4N	1.4	1.3	1.2	1.2	1.6	1.8	1.9	1.4	1.9	1.9	1.8	1.4	1.4	1.7	1.9	407478	9.5	8.7	4.1	21
M8X	1.3	1.4	1.4	1.2	1.9	1.9	2.3	1.8	2.2	2.3	1.9	1.6	1.4	2.1	2.3	251737	6.3	4.7	3.1	25
M5M	1.3	1.4	1.5	1.3	2.1	2.1	2.7	2.0	2.4	2.7	2.0	1.7	1.4	2.4	2.7	252123	7.6	9.3	3	22
M2L	0.9			0.9					1.4		1.1	1.2	0.9			306301	14.7	7.1	7.2	49

Figure 9. Comparison of upgrade cost to average income level by FSA (Part 2)

Cooling Considerations

A special analysis was performed to compare the addition of a high-efficiency air conditioner as the baseline case versus the addition of the Affordable3 package to evaluate the selection of a heat pump-based package over an air conditioner alone. The results presented in Figure 10 show the incremental change in the total annual cost, energy consumption, and GHG emissions for the Affordable3 versus the acSystemBaseline case.

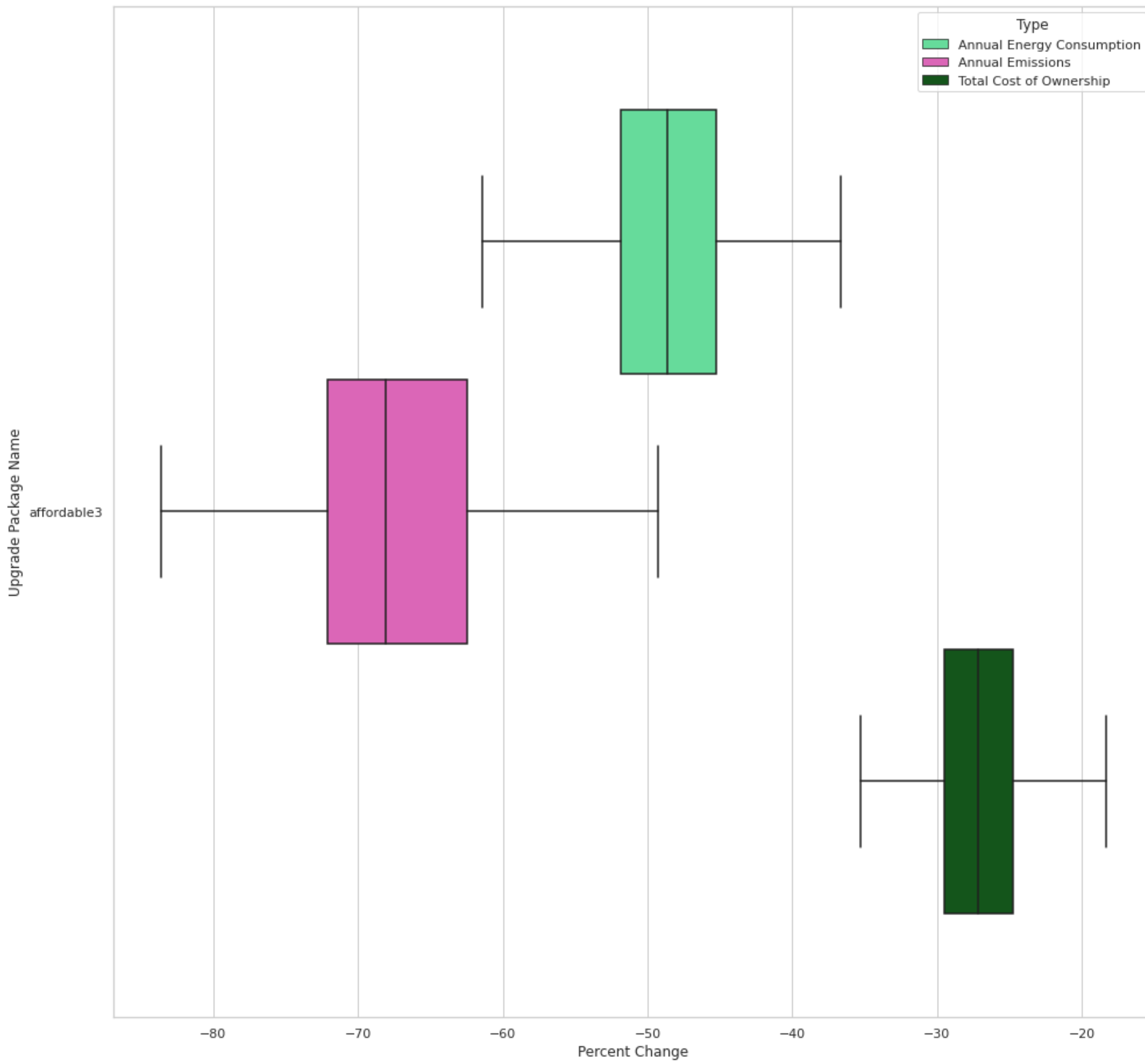

Figure 10. Cost, emissions, and energy savings of the Affordable3 package relative to the addition of a standard air conditioner.

Discussion

Affordable Packages

From the results, it can be concluded that the packages Affordable1, Affordable2, and Affordable3 deliver good emissions and energy reductions while having a likelihood of remaining cost neutral annually. When those three packages were applied to typical Toronto houses, Affordable3 showed the greatest statistically-likely chance of providing an annual cost reduction versus the baseline case when the cost of the loan and utilities were summed.

Adding solar photovoltaics was an important component in achieving deep energy and emissions reductions along with cost parity. Though the 5kW solar package was not included in the affordable cases, it showed a strong likelihood that it came close to cost parity on a 15-year timescale. Therefore, its addition to affordable packages was unlikely to burden the users on this time scale overtly. That being said, though both Affordable2 and Affordable3 packages included heat pumps, the addition of solar helped mitigate the increase in electricity usage and associated costs.

It was also shown that basic improvements to the attic insulation and air sealing of a building, as suggested by Affordable1, achieved cost parity while delivering important improvements to the building envelope. Affordable3 delivered better results than Affordable2 because it used a heat pump system that directly accepted a solar input, therefore reducing the capital cost for the package by the cost of a solar inverter - enough to drive the savings seen in the results. These results were expected because the package components were chosen to provide the largest reductions in energy consumption for the lowest capital cost. If fuel switching was implemented, solar photovoltaics (PV) offset the additional electricity cost. Notably, the Affordable2 and Affordable3 packages achieve greater than 40% energy savings and greater than 50% emission savings, exceeding the typical threshold for “deep” retrofits.

The results for the AffordableK package did not reach annual total cost parity in simulation. This package’s input parameters were based on a retrofit completed by a Toronto resident that disconnected from Natural Gas for a capital cost below $10,000. This contradicted the participant’s reported achievement of annual cost parity when they analyzed current versus past utility bills. This discrepancy could be attributed to several factors, including that the participant did not detail loan payments as part of the financial presentation. It can be seen that loan servicing for the AffordableK package made up around 40% of annual costs - enough to bring utilities alone to cost parity. Also, the participant’s home had previously received window and wall insulation upgrades that may have left it in a position to use less energy than comparable archetypes in the NRCan dataset.

The results from the incremental cost comparison between the acSystemBaseline as a baseline case versus the Affordable3 package as the analysis subject were telling. Although the Affordable3 package had a slightly higher absolute capital cost than the air conditioning system in the acSystemBaseline package, the incremental changes told a different story. The GHG emissions and energy consumed for the Affordable3 package were reduced by 70% and 50%, respectively. This was achieved with a total annual cost of around 25% less than the baseline air conditioning case. Importantly, this showed that if cooling is needed for a household in

Toronto for climate change resiliency or comfort reasons, much better overall results can be achieved by adding the Affordable3 package rather than a conventional air conditioning system.

HELP and Industry Standard Packages

Aside from the affordable packages results, a general conclusion that can be made is that packages that (i) prioritized deeper building envelope improvements, and (ii)partial or full electrification of heating with heat pump space and water heating, achieved impressive energy usage and GHG emissions. Fuel switching off fossil fuels led to deep emissions reductions, seen in the results for the packages that contained components that switch fuels, namely the mediumEnvelope, deepEnvelope and netzeroEnvelope packages. In those cases, we saw emission reductions greater than 60% and energy reductions greater than 50% (80% in the netzeroEnvelope case), similar to those observed in the case of three of the affordable packages. The other package cluster resulted in a 20-40% reduction in energy and emissions. These results were essentially tied to how much fossil fuel use was reduced versus baseline.

In terms of cost implications, apart from the helpSolarPV5kW package, all tested packages increased the annual costs by at least 20% on average. Apart from the basicEnvelope, helpAirSealWindowDoor, helpHVAC, and the aforementioned solar package, all of those packages increased annual costs by more than 30% - including the three most popular help1, help2 and help3 packages from the provided Toronto HELP data.

Through this analysis, we determined that when deep envelope improvements are implemented with existing fossil fuels, the program user could likely experience higher annual costs with lower emissions reductions. We also concluded that deeper envelope retrofits and fuel switching, even when paired with solar PV to offset costs - as in the case of the netzeroEnvelope retrofit package - resulted in significant increases in total costs using a 15-year loan term. This finding was as expected and indicated that loan terms need to approach the retrofit package payback periods or will result in greater annual costs than the baseline case.

Geographic Considerations

It can be seen from the cross-tabulated geographic and energy results that across the first two letters of FSA aggregations for Toronto in Figure 7, the results for the total annual costs in relation to the baseline results were similar and often within the statistical bounds of each other. This was a good indicator that if programs were deployed across Toronto that featured the simulated retrofit packages, there would be a likelihood of similar results across all regions in Toronto. However, the results did show that the likelihood of certain retrofits achieving cost reductions, based on the distributions, was more likely in certain areas. This was likely due to the type of housing and its prevalence in certain regions. In practice, it could present an opportunity for regionally-targeted initiatives. This was even more prevalent when the results in Figure 8 and Figure 9 were examined. Most postal code FSAs analyzed followed the same pattern regarding the relationship between the percentage of retrofit total cost out of income, but there were outliers. Those outliers could also be identified as candidates for special programs targeting affordability increases for residents.

Conclusions

The Toronto case study example and the proposed analytical methodology demonstrate that it is possible to perform an extensive analysis of different energy efficiency upgrades against a set of statistically representative housing archetypes for a geographic area. We have shown that the geographic granularity of this analysis can be varied to examine city-wide or regional needs. Results were generated using the industry-standard energy modelling software HOT2000 to ensure their relevance to program stakeholders. The analysis collected and utilized available costing information to calculate the required data to assess the total annual cost.

In this analysis, the methodology identified types of energy efficiency upgrade packages that yield total annual cost parity and reductions in GHG emissions and energy use. Statistical distributions indicated a strong likelihood that the analysis results would be achieved when conducted for each program user, ensuring relevance to program field results.

Key Recommendations

Use Data-Driven Affordability Indicators

Program administrators for LIC/PACE loans should use the proposed general analytical methodology to calculate the participant-focused percent changes of total annual cost, GHG emissions, and energy consumed for proposed retrofit packages versus existing baseline archetypes and use them as metrics to be referenced when examining retrofit packages and planning programs. This analysis can be performed internally or outsourced to an appropriately capable firm. This can also be used to develop datasets to be cross-tabulated with sociodemographic, geospatial, or other datasets to evaluate additional metrics.

Utilize Existing Cost Data

Program administrators should look at their existing retrofit invoice data from existing LIC/PACE programs and/or nearby or equivalent regions' invoice data to help build a retrofit component and package cost database for this analysis. The regional comparison can be completed using StatsCan or EnerGuide data to determine the likely partner regions to contact who have similar housing stock and demographics. This analysis can be performed internally or outsourced to an appropriately capable firm.

Provide Clear Cost Guidance

The guidance provided in educational and marketing materials directed to potential program users should address their need to have cost data presented to them. Though not included in the Toronto case study presented within this report, which only focused on the PACE/LIC retrofit-only scenario, program administrators should also consider the other incentive programs available to their users in their analyses to provide a more accurate regional TCO estimate. Analyses of the completed TCO should include the offset from these other incentive programs, where applicable, and differently from the LIC/PACE TCO for the user accessing the educational content.

Provide Multiple Pathways to Success

This analysis identified that the capital expenditure required to complete energy efficiency retrofits can vary significantly in value. The FCM toolkit previously posited that hybrid prescriptive/performance-based retrofit approaches could be taken to balance municipal administrative efforts with ease of use for program users. Based on the results of this analysis, it is recommended that a selection of packages with a statistically significant likelihood of achieving annual cost parity or reductions compared to baseline archetypes have detailed costing conducted. These packages should then be deployed as prescriptive LIC/PACE retrofit packages with set cost rebates for completion of that upgrade package type within dedicated affordable retrofit programs.

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