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How to cut emissions from the residential sector in the Waterloo Region

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11-1-2020

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Executive Summary

Here in the Region of Waterloo, we have 30 years in which to fulfill our commitment to cutting GHG (greenhouse gas) emissions by 80% below 2010 levels[1]. For the residential sector, this will mean energy efficiency upgrades that add insulation and seal leaks in homes, and it will also mean shifting away from heating systems that use fossil fuels and toward electrified systems. Highly efficient heat pump systems powered by electricity are already capable of making our homes comfortable year round in our climate and heating our water.

Much of our local housing was built before 1981, before energy efficiency became a priority in the building industry. Convincing the owners of these and newer homes to carry out home energy efficiency improvements has historically been challenging. We analyzed a database of local home energy audit data from 1999-2020 sourced from NRCan (Natural Resources Canada) to explore home upgrade activity and potential.

Home energy efficiency upgrade activity has most commonly occurred when attractive incentives were present, but even then, the average energy efficiency gain and GHG emission reduction was approximately 20%. Our models suggest that ambitious energy efficiency upgrades to the building envelope are insufficient to meet our targets, achieving an average total emissions reduction of ~50%. Meanwhile, our models suggest that a switch to heat pumps for space and water heating would achieve an average ~70% reduction in emissions. When combined, greater than an average 80% reduction in energy use and GHG emissions is possible.

To help streamline energy efficiency upgrades, an A-D rating system was developed for each element of a home (insulation levels in attics, walls, foundations; performance of windows and doors; efficiency of space heaters and water heaters). Homes can also be rated based on how easy and cost-effective it is to upgrade (using values 1-3).

The relative potential for energy efficiency upgrades and electrification of heating systems was analyzed using homes that had a uniform A-D rating for all building envelope elements. Homes with the lowest ratings for the building envelope performance showed the greatest GHG emissions reductions with envelope improvements, while electrification was most effective in newer and better performing homes.

Cutting GHG emissions from the building sector sufficient to meet our climate targets will be a massive undertaking. It will require both energy efficiency improvements and electrification of space and water heating in the vast majority of homes. We have 30 years and over 200,000 homes: we have work to do!

Introduction

The Region of Waterloo, recognizing that climate change is a threat to our current and future well-being, has committed to reducing emissions by 80% below 2010 levels by 2050[2]. Residential buildings account for 18% of our community's emissions. With over 200,000 residential buildings in our region and only thirty years until our target, this will require a huge effort, ideally one that is streamlined to maximize emissions reductions while minimizing costs and efforts on the homeowners' part. This report focuses on low rise residential buildings: predominantly single family homes, semi-detached, and row housing and uses local home energy audit data sourced from NRCan.

The majority of a home's emissions come from the fossil fuels used for space and water heating. Energy efficiency upgrades are the traditional approach to reducing emissions. These involve air sealing; upgrading windows and doors; and adding insulation to a building's envelope (its exterior walls, foundations, attics) to reduce the energy needed to keep indoor temperatures in a comfortable range.

Convincing homeowners to invest in energy efficiency upgrades has been challenging[3]. Most homeowners are unaware of the multi-dimensional benefits of such upgrades, including more comfortable homes with better indoor air quality. The investments in energy efficiency upgrades can have long paybacks, often exceeding the homeowner's anticipated ownership of a home. The large variability in fuel prices over time means that energy savings are hard to predict. Accessing quality advice and trusted tradespeople can also be a challenge. For renters that pay for utilities, the landlord may be reluctant to invest in upgrades for which they do not benefit (split incentives). And in all cases, renovations can be stressful, time-consuming, and disruptive for the occupants.

If we are to achieve the deep emissions reductions that are required by our climate commitments, we must nearly eliminate the use of fossil fuels in the home. Since Ontario's electricity supply is largely decarbonized, electrification of space and water heating using high efficiency heat pump systems will almost certainly be required. While many homes will need to reduce their total energy use through building envelope upgrades to make electrification affordable, some homes are sufficiently energy efficient that it may already be more cost-effective to electrify their space and water heating.

Heat pump systems with built-in backup electric heat can meet all of a home's space and water heating needs. The technology has a long and reliable history, being used in fridges, air conditioners, and dehumidifiers. Heat pump systems that can heat water for domestic use and provide all of a home's heating and cooling needs are available. Because they move heat rather than generating heat, heat pumps can use three to five times less energy than conventional heating systems[4].

Many communities are working to develop streamlined energy efficiency upgrade programs to overcome barriers to homeowner engagement and achieve deep emissions cuts. These programs aim to reduce the costs, time-commitments, and hassles associated with home renovations and may also offer financing and access to incentives. This report provides a classification tool that can be used to quickly rate elements of a home and help a homeowner assess which upgrades are the most accessible and cost effective to perform. We also model the energy and emission impacts of such upgrades with the help of housing archetypes. Data from home energy audits conducted on 44,463 Waterloo Region single-family, semi-detached, and row housing between 1998 and 2020 was used in this report to estimate the energy efficiency and emission impacts of home upgrades.

General profile of homes in the Waterloo Region

The Waterloo Region is a growing community with over 200,000 homes. While some of the oldest homes date back to the eighteenth century, 2016 census data show that more than half of existing homes were built since 1981[5]. Older homes are more likely to have inadequate insulation, a leaky building envelope, and inefficient heating systems.

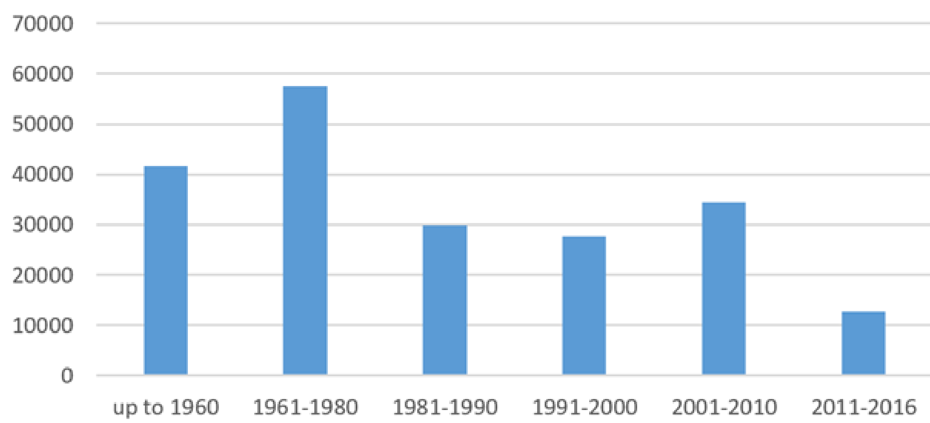

FIGURE 1: NUMBER OF HOMES BY DATE OF CONSTRUCTION IN THE WATERLOO REGION (CENSUS 2016)

A breakdown of the 2011 census housing data by forward sortation areas (first three digits of the postal code) shows that much of the housing is found in what we classified as suburban neighbourhoods of Cambridge, Kitchener, and Waterloo. Suburban neighbourhoods were characterized as consisting predominantly of housing, parks, and schools, with commercial activity generally concentrated at high traffic intersections. This is in contrast to urban neighbourhoods that have mixed uses and more dispersed commercial buildings. Table 1 shows the number of homes in urban, suburban, and rural neighbourhoods.

TABLE 1 TOTAL NUMBER OF SINGLE FAMILY HOMES (SINGLE DETACHED, SEMI-DETACHED AND ROW HOMES) IN RURAL, SUBURBAN, AND URBAN NEIGHBOURHOODS (CENSUS 2011).

	Cambridge	Kitchener	Waterloo	total
rural				32,235
suburban	26,755	39,005	19,430	85,190
urban	11,745	17,955	10,455	40,155

Residential fuel use

The majority of homes in Waterloo Region use natural gas for space and water heating (see Figure 2 below). These heating systems are responsible for most residential GHG emissions. While energy efficiency upgrades reduce the total energy needed to heat our homes and hot water, these homes must ultimately decarbonize their heating systems to achieve the large emissions reductions embedded in our climate goals.

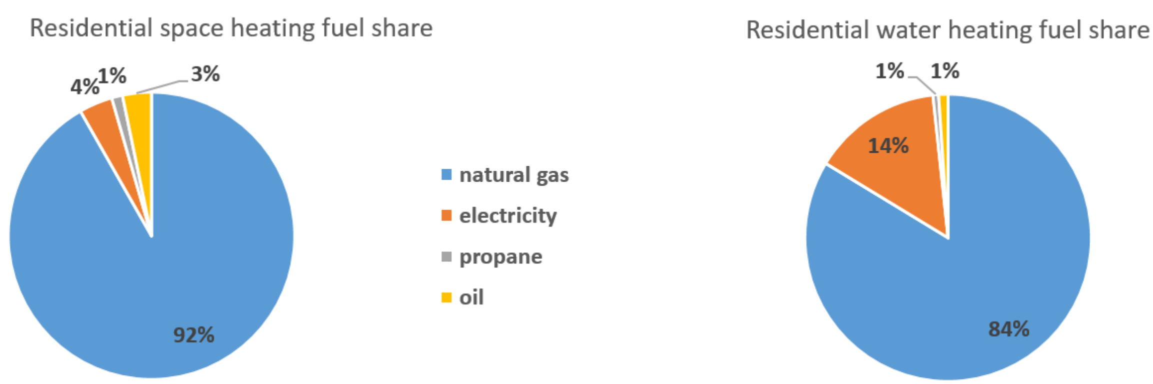

FIGURE 2 RESIDENTIAL SPACE AND WATER HEATING FUEL SHARES FOR THE WATERLOO REGION.

Historical energy efficiency upgrade activity

Historically, residential energy efficiency upgrade activity has closely matched the availability of incentives (see Figure 3 below). Peak upgrade activity occurred during the EcoENERGY era when the federal government offered up to $5,000 in rebates for energy efficiency measures such as installing an energy-efficient furnace; adding insulation; air sealing; replacing window and doors; and adding water conservation measures. Grants from the provincial government for retrofits were also available during much of this time. At its peak (in 2009), 1.6% of homes in the Waterloo Region performed post-upgrade home audits. The availability of future incentives is therefore likely to impact homeowner interest in upgrades.

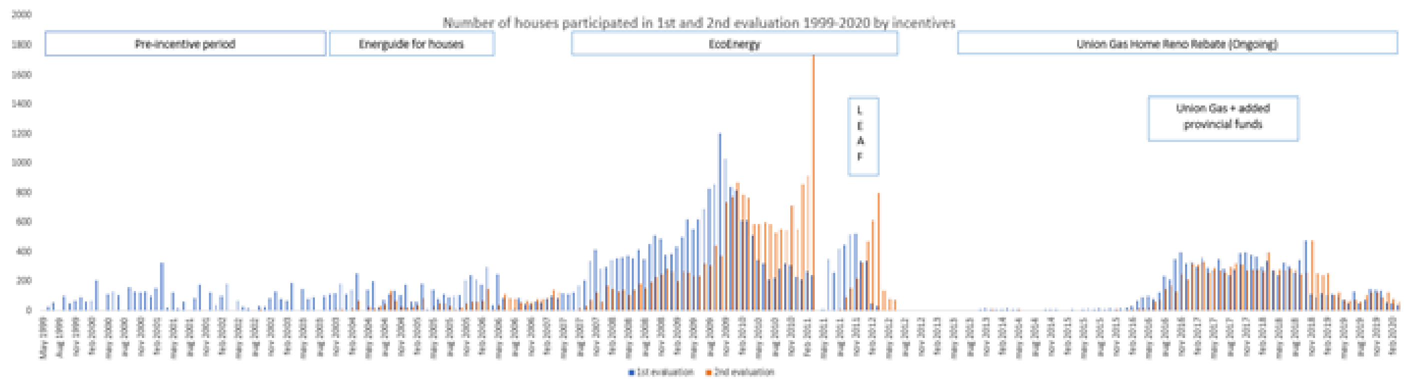

FIGURE 3 HOME ENERGY AUDIT ACTIVITY OVER TIME IN WATERLOO REGION. (FIGURE BY PHUONG LINH LE[6])

The majority of homeowners in the Waterloo Region did not participate in major energy efficiency upgrade incentive programs over the last two decades (81%). Even when homeowners did participate, 79% did not achieve their recommended potential. In conclusion, nearly all homes can make significant improvements to their energy efficiency.

Energy efficiency upgrade activity has not occurred at the same rate in all neighbourhoods. Figure 4 shows the cumulative percentage of all homes that performed post-upgrade home energy audits. It is notable that urban, often older, neighbourhoods generally showed a higher percentage of homes performing post-upgrade audits (green bars).

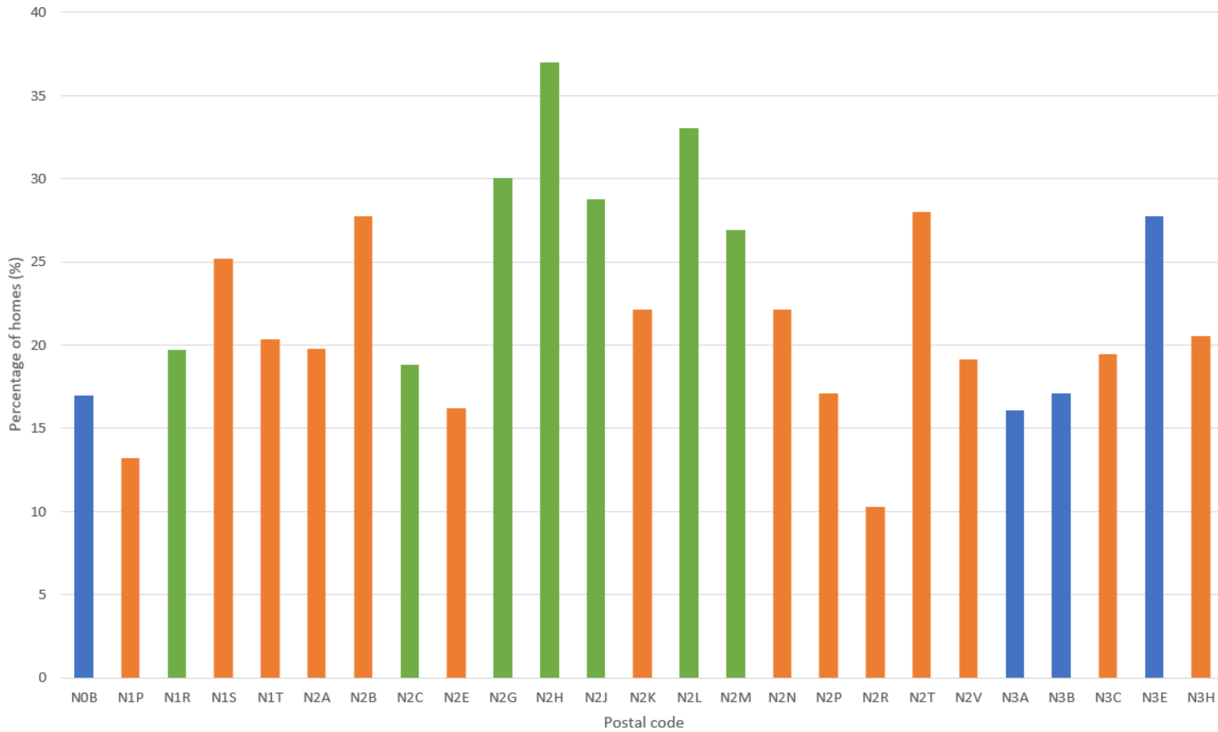

FIGURE 4 PERCENTAGE OF HOMES THAT HAD POST-UPGRADE HOME AUDITS BY NEIGHBOURHOOD IN THE WATERLOO REGION. BLUE BARS ARE RURAL, ORANGE BARS ARE SUBURBAN, AND GREEN BARS ARE URBAN NEIGHBOURHOODS. (FIGURE BY PHUONG LINH LE[7])

As Figure 5 shows, most homes achieved energy efficiency improvements in three areas of the home's building envelope or mechanical systems. Figure 6 shows the percentage of households that undertook each type of upgrade measure.

The most common upgrade was to heating systems: 75% of homes that performed post-upgrade audits had upgraded their heating system. Incentives to upgrade the furnace have been generous and anecdotal evidence suggests that many homeowners saw economic and environmental advantages to upgrading their furnace before the end of its lifespan.

Nearly half of homes achieved a greater than 10% improvement in their blower door test results: a measure of a home's air tightness. Not all of these homes may have taken direct air sealing measures however, as improvements to a home's insulation and heating system can also improve the air tightness.

Window upgrades were the third most common upgrade, followed by addition of insulation to the attic space. Window replacements may be attractive because they can improve comfort when sitting near the window as well as the visual appeal of a home.

The least common upgrades were improvements to exposed floor insulation (exposed floors include floors over unheated crawlspaces and garages), water heater upgrades, and improvements to the insulation of main walls.

Figure 6 confirms that even in homes that have performed energy efficiency upgrades, the majority addressed only a part of the building envelope. Attics were the most common place to add insulation. They are also typically the easiest and cheapest place to add insulation. Adding insulation to the main walls, however, often requires making holes in the interior or exterior walls to add insulation to an existing empty wall cavity, or adding a new layer of insulation to the wall with the replacement of the exterior cladding or drywall. Such measures can be difficult, disruptive and costly.

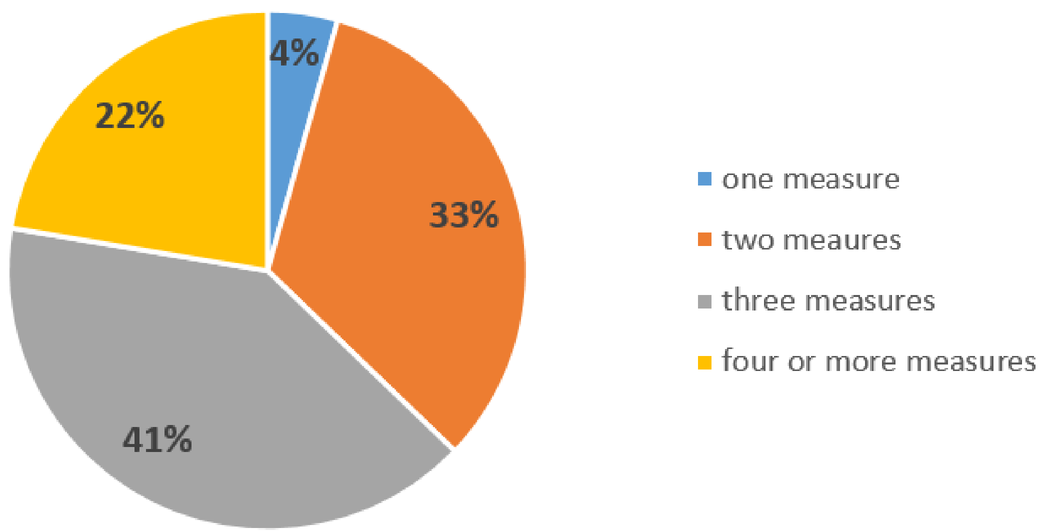

FIGURE 5 THE TOTAL NUMBER OF ENERGY EFFICIENCY IMPROVEMENTS ACHIEVED IN HOMES THAT HAD POST-UPGRADE AUDITS IN THE WATERLOO REGION

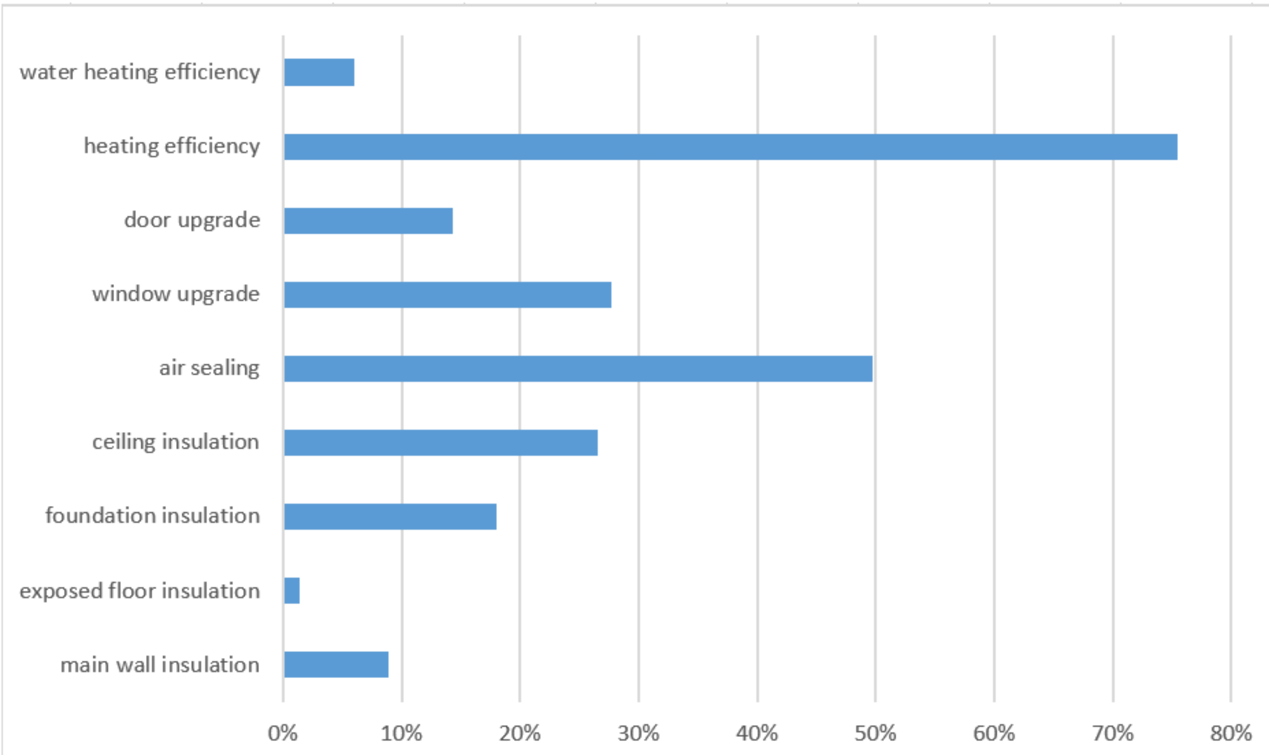

Figure 6 Percentage of Waterloo Region homes performing post-upgrade audits that showed different types of energy efficiency improvements

What residential upgrades will be needed to achieve our climate targets?

The Region of Waterloo aims to achieve an 80% reduction in community GHG emissions below 2010 levels by 2050. The energy efficiency and GHG emissions reductions achieved from historical upgrades can help us develop an approach to achieving our future targets. The average modeled energy efficiency improvement and GHG emissions reduction for the homes that performed post-upgrade audits was ~20% (see Table 2). Even if homeowners performed all of the upgrades recommended by the home auditors, only a ~27% improvement in energy efficiency and GHG emissions would be achieved: far lower than the 80% reduction in GHG emissions required to meet our climate targets. More could be achieved with retrofits as the audit recommendations were not always aiming for deep retrofits. Nevertheless, it seems clear that fuel switching from fossil fuels to clean electricity for space and water heating and other appliances will be essential for any successful residential decarbonization plan.

Modeled energy efficiency upgrades

We explored the energy efficiency and GHG emissions reduction potential of three upgrade approaches. In the first, homes undergo comprehensive deep energy upgrades to the building envelope. This includes adding insulation to the attic, walls and foundation; upgrading windows to triple pane low E argon (doors were treated like windows in this analysis); and achieving 1.0 air exchange per hour (ACH50) in a 50Pa blower door test (the Passive House standard for upgrades). In the second approach, the space and water heating systems are upgraded to heat pump systems that rely exclusively on energy from electricity. In the final approach both deep energy upgrades to the building envelope and electrification of the space and water heating systems were considered.

The effects of these upgrades could not be assessed using the original software used to model the post-upgrade outcomes (Hot2000) because we did not have access to the original Hot2000 files for all homes. Creating an archetype home that represented all homes to be used in Hot2000 also presented challenges (too many variables for which we do not have average values). We consequently calculated an estimated savings based on the heat loss values from the data.

We estimated the effects of different upgrades on the total home energy use and GHG emissions. In this estimation, the heat loss was assumed to decrease in direct proportion to the ratio of the before and after values for R (resistance to heat flow: a measure of insulation effectiveness), ACH50 or mechanical system efficiency. The total space energy use was assumed to be the sum of the heat loss values for all elements while the total energy use of the home also includes electrical energy use and energy used for water heating. These assumptions are likely different and simpler than those used in the Hot2000 modeling, yet they are expected to give a reasonable estimation for what is achievable with upgrades to Waterloo Region homes. As can be seen for the calculated total energy use per home for post-upgrade and recommended values, this approach yields larger total energy use per home and tends to slightly underestimate the total impacts of upgrades.

TABLE 2 AVERAGE HOME CHARACTERISTICS AND MODELED VALUES FOR AUDITED WATERLOO REGION HOMES BEFORE AND AFTER DIFFERENT TYPES OF ENERGY EFFICIENCY UPGRADES (STANDARD DEVIATION VALUES ARE IN BRACKETS)

	Units	Pre-upgrade	Post-upgrade	Recommended	Deep energy efficiency upgrades	Electrification	Deep upgrades + electrification
Building envelope							
Attic	R	21.05 (8.36)	25.79 (9.69)	31.69 (10.07)	60.00	21.05	60.00
Wall	R	11.28 (3.35)	11.71 (3.26)	12.13 (3.16)	40.00	11.28	40.00
Foundation	R	6.03 (4.52)	7.53 (5.47)	11.27 (6.07)	25.00	6.03	25.00
Windows	# ENERGY STAR	0.15 (1.41)	4.87 (7.04)	2.16 (4.72	All: 15.73 (6.50)*	0.15	15.73*
Doors	# ENERGY STAR	0.02 (0.24)	0.82 (1.26)	0.24 (0.67)	All: 2.80 (1.19)*	0.02	2.80*
Air sealing	ACH50	6.45 (3.41)	5.54 (2.71)	5.69 (2.39)	1.00	6.45	1.00
Mechanicals							
Furnace efficiency		84.1% (7.6%)	94.4% (5.6%)	94.9% (4.2%)	300%	84.1%	300%
Water heater efficiency		59.9% (10.0%)	60.8% (12.6%)	68.2% (26.4%)	350%	59.9%	350%
Energy use							
Total energy use/home	MJ from all fuels	174,140 (65,341)	139,830 (46,847)	125,259 (40,028)			
Energy efficiency gain			20%	28%			
Modeled total energy use/home	MJ	187,459	152,767	137,261	95,577	58,526	33,096
Modeled energy efficiency gain			19%	27%	49%	69%	82%
GHG emissions reduction							
Modeled GHGe/home/yr	tCO2/home/yr	9.1	7.3	6.6	4.5	2.5	1.4
Modeled GHGe reduction			20%	27%	51%	73%	85%

*in modelling, it was assumed that these all upgraded from R2 to R3

Modelling shows that even with ambitious deep energy efficiency upgrades, the homes in the Waterloo Region cannot achieve the 80% reduction in GHG emissions that is set out in our climate target.

Waterloo Region homes could achieve estimated GHG emissions reductions close to the climate target with two measures: converting all homes to heat pumps for space and water heating. (For further analysis of the electrification potential for Waterloo Region, please see "*Analysis of residential electrification potential for Waterloo Region*[8].) This is possible because Ontario's electricity supply is already largely decarbonized.

Ideally, however, a home would perform deep energy efficiency upgrades before electrifying its space and water heating. This would not only ensure the home is more comfortable and economical to operate for the homeowner, it would also reduce the strain on the electricity grid. If all homes combined a deep energy efficiency upgrade with electrification, there would be a total 83% reduction in a home's total energy use: the electrical grid demands of a fully electrified home with deep energy efficiency upgrades becomes easier to manage.

In addition, many homes that achieve the deep energy efficiency targets used here could achieve net zero energy by adding enough onsite solar panels to offset the home's total energy demands averaged out over a year.

Yet many homeowners will not have the funds, time, or interest to do a full deep energy efficiency upgrade all in one go. Homeowners have historically preferred to target one area at a time, sometimes in conjunction with other renovations. When replacing vinyl siding, for example, it makes sense to add insulation to the exposed walls but it would be cost-prohibitive otherwise. Therefore, we have developed housing archetypes by element to help planners and homeowners efficiently identify which upgrade measures to prioritize in their home.

Climate targets and the electrical grid

The electricity grid is largely decarbonized in Ontario. Yet the electricity supply will have to grow to meet the increased demand associated with electrification of buildings and transportation. As new generation is added the GHG emissions associated with electricity use will also change, depending on the source of energy. If this new generation uses fossil fuels, it may be nearly impossible to meet our climate targets. Alternatively, if the electricity supply is completely decarbonized, electrification of homes could result in a 100% reduction in GHG emissions.

Our calculations show that total annual electricity demand for low rise homes in the Waterloo Region would increase by 74% if they were to electrify their space and water heating without first improving their energy efficiency, most of it in the winter months[6]. Energy efficiency is therefore key to help manage increasing demand on the grid. Also important is accelerating the addition of renewable energy.

Rating homes by element

All homes in the Waterloo Region will need to do some form of energy efficiency upgrade before 2050 if we are to meet our climate targets and do our part to prevent catastrophic climate change. Theoretically, that means over 3% of homes must upgrade for energy efficiency per year. In practice, this is likely to occur in waves associated with the availability of incentives and financing, utility costs, and other home maintenance or upgrade plans.

Not all upgrades will look the same. For some, this will mean replacing a fossil fuel heating system with an electrified (or otherwise decarbonized) system when it reaches the end of its lifespan. For others, this measure will be accompanied with the addition of insulation to the basement. And for others, a home will require a complete overhaul to make the home comfortable and affordable.

This section aims to identify a streamlined pathway for identifying what each home's energy efficiency upgrade plan should look like. For each measure, a home can be ranked based on how well it performs and how easy it would be to improve the performance. Easy to improve measures are prioritized over hard to perform measures as are those that provide the greatest benefits and cost savings.

A home is more than the sum of its parts. Ideally all parts of a home should be upgraded at once, with particular attention paid to areas where different parts of a home meet (walls and foundations for example) and to features that pass through the building's envelope (e.g. vents). In practice, most upgrades occur piecemeal as issues are addressed, funds become available, renovations are made etc. Although we address different elements of a home separately here, homeowners and contractors should take care to ensure the effects of upgrades in one area do not adversely affect other areas of the home and that each upgrade brings a home closer to its ideal for efficiency, for comfort, and for health.

Because house ratings depend, at least in part, on details of the building structure that are not included in the NRCan dataset, this section is based on principles and not precise EnerGuide for Houses (EGH) scores. As more data are collected from local homes, these ratings can be improved and the impacts of energy efficiency upgrades to each rating can be quantified.

The rating system

Each element of the homes will be rated on an A-D scale for its modeled energy efficiency performance. In addition, each insulation and air tightness element will be rated based on how easy it would be to improve the performance (1 is easy to improve, 2 is more challenging to improve but worth the investment, and 3 indicated that improvements would be very challenging or not cost-effective to make).

For the A-D performance scale (see Tables 3-5), the A designation was based on the performance values typically achieved in net zero energy ready homes[9]. Net zero energy homes generate enough on-site energy (typically with solar panels) that is fed into the electrical grid in a year to offset their total energy consumption from all energy sources in a year. The Ontario building code is moving toward this standard. The B rating was largely based on the current standards in the Ontario building code[10]. This is considered a good rating that could be improved. The C rating is based on the general performance of existing homes in our region that could see major improvements. The D rating is for homes that are severely underperforming and should be a priority for upgrades.

TABLE 3 RATING DEFINITIONS FOR THE INSULATION (R VALUES) AND AIR TIGHTNESS (ACH50) OF A HOME.

Rating	attic	walls	foundation	air tightness
A	55+	30+	25+	3 and lower
B	40-54	16-29	16-24	3.1-6.0
C	20-39	11-15	11-15	6.1-10.0
D	0-19	0-10	0-10	10.1+

TABLE 4 RATING DEFINITIONS FOR WINDOWS AND DOORS.

Rating	Window characteristics	Door characteristics
A	All triple glazed, low E argon filled, high performance frames	All R10 insulating or better with 2-3 seals along each edge[11]
B	All ENERGYSTAR or better	All ENERGYSTAR or better
C	Some ENERGYSTAR or better	Some ENERGYSTAR or better
D	No high performance windows	No high performance windows

TABLE 5 RATING DEFINITIONS FOR SPACE AND WATER HEATER EFFICIENCIES.

Rating	Space heater efficiency (%)	Water heater efficiency (%)
A	>100	>100
B	90-100	85-100
C	80-89	70-84
D	0-79	0-69

How easy it is to improve the performance of an element of the home depends largely on how the home was built and how the space is used. Table 6 shows the major considerations that affect how easy and cost-effective it would be to upgrade the energy efficiency of the element. A "1" rating indicates that an upgrade is easy and cost-effective to perform: these upgrades should be high priorities. A "2" rating indicates that an upgrade is more challenging to perform but still recommended. These renovations might be performed alongside other renovations. For example, insulation could be cost-effectively added to an exterior wall when the vinyl siding is replaced but not as a stand-alone measure. A "3" rating generally suggests that investing in upgrading this element is unlikely to be cost-effective and investments are therefore better spent elsewhere (such as electrifying space and water heating).

TABLE 6 RATING DEFINITIONS FOR HOW EASY AND COST-EFFECTIVE IT WOULD BE TO IMPROVE THE PERFORMANCE OF A HOME'S INSULATION AND AIR TIGHTNESS.

Rating	attic	walls	foundation	air tightness
1	Open attic space	Empty wall cavity	Unfinished basement	Obvious leaking of the building envelope
2	Cathedral ceilings	Exterior siding coming due for replacement or major renovations planned	Finished basement with empty wall cavity	No professional air sealing to date and/or renovations planned
3		Brick exterior and no interior renovations planned	Finished basement	Professional air sealing has already been done and no renovations planned

Attics

As Figure 7 demonstrates, the majority of NRCan evaluated Waterloo Region homes would rate a C for attic insulation. In many cases, this rating can easily be improved through the addition of added insulation.

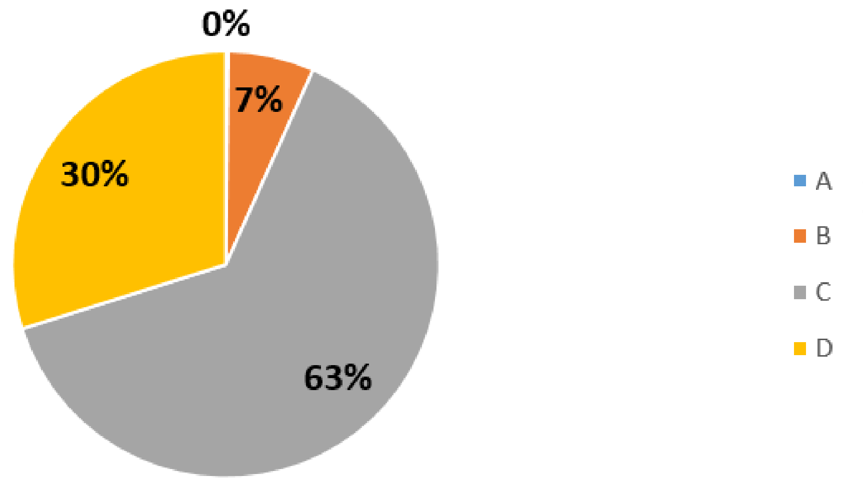

FIGURE 7 PERCENTAGE OF AUDITED WATERLOO REGION HOMES WITH EACH ATTIC INSULATION RATING.

Generally, attic insulation performance decreases with the age of the home. Attic insulation levels in the NRCan data rose successively over three periods: during the 1950s, during the 1980s, and since 2005 (see Figure 8).

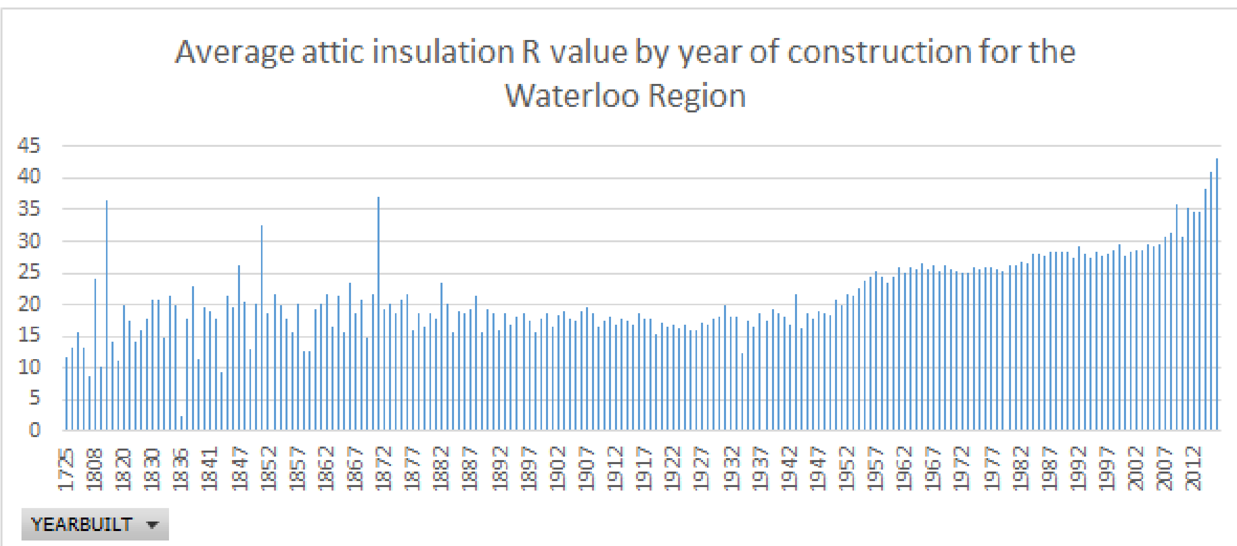

FIGURE 8 AVERAGE ATTIC INSULATION R VALUE BY YEAR OF CONSTRUCTION, WATERLOO REGION. SOURCE: NRCAN DATASET.

It is often easy and cost-effective to add insulation to open attic spaces, these homes would get a "1" rating recommending improvements. This can also be an opportunity to check for moisture build-up; proper ventilation of bathroom and kitchen fans; and air seals around attic hatches, pipes, light fixtures and other penetrations into the attic space[12]. Improving these can boost the home's overall energy efficiency performance.

A home with attic-less construction (e.g. flat roof, cathedral ceiling) will be harder to upgrade the insulation and are classified as “2”. A professional may be required to perform the work in a way that does not create moisture problems and thermal bridging. Solutions may involve dropping the ceiling height to accommodate extra insulation or adding a new insulated roof over the old one[13].

Walls

As Figure 9 shows, the predominant wall rating for NRCan-evaluated homes in the region is a C for wall insulation. Adding insulation to walls is generally more difficult than attics and foundations.

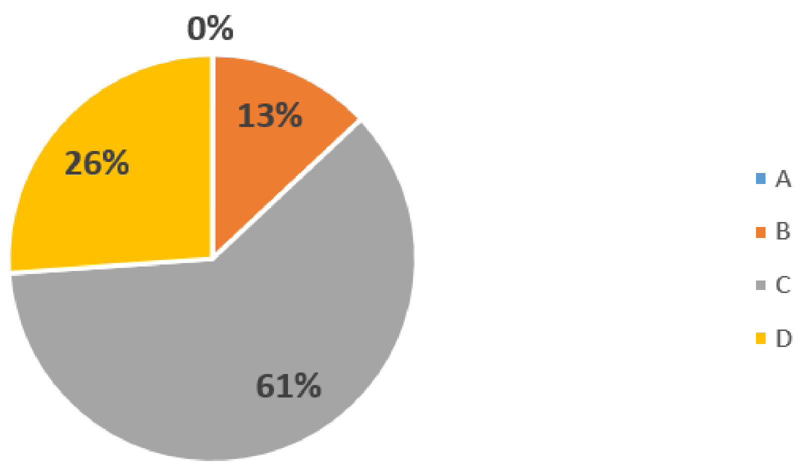

FIGURE 9 PERCENTAGE OF AUDITED WATERLOO REGION HOMES WITH EACH WALL INSULATION RATING.

Wall insulation performance has also increased over time, with improvements occurring in the 1950s, the 1990s and since 2010 (see Figure 10).

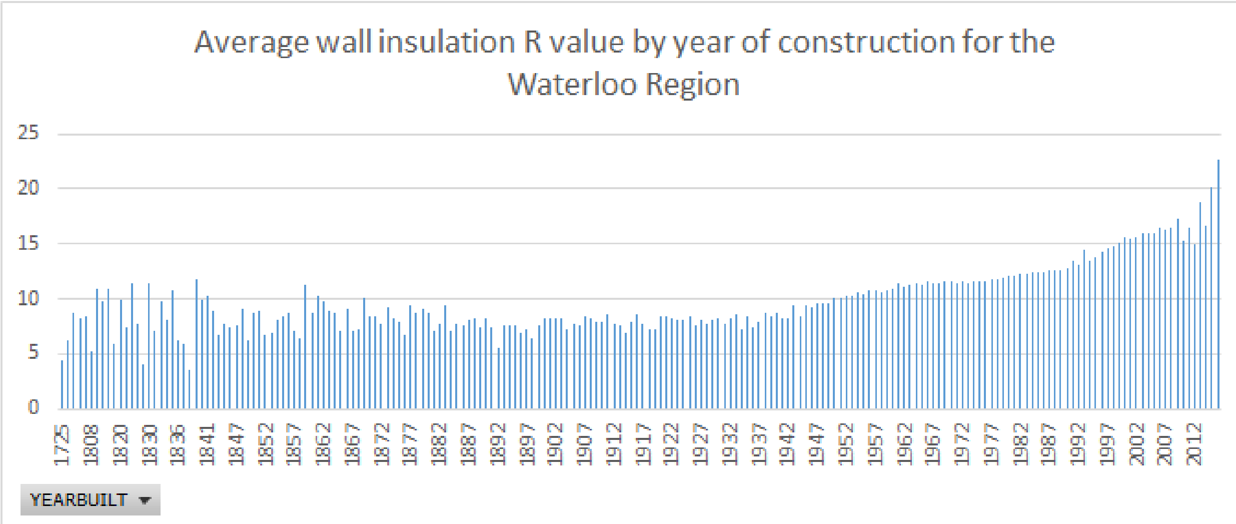

FIGURE 10 AVERAGE WALL INSULATION R VALUE BY YEAR OF CONSTRUCTION, WATERLOO REGION. SOURCE: NRCAN DATASET.

Some older homes may have walls with empty cavities. Insulation can be blown or sprayed into these cavities through small holes in the wall that are relatively easy to repair. These homes would be rated “1” for ease of improvement of the wall insulation.

Adding insulation to most homes, however, requires removing either the interior or exterior surface. If a home’s exterior cladding is being replaced, it can be cost-effective to also add insulation at that time. Increasing the insulation is also cost-effective during major renovations when the interior of outside walls may already be exposed. These homes would be rated “2” for ease of improvement of the wall insulation.

Homes with no empty wall cavities and no plans for major renovations involving exterior walls may find better value for money with other energy efficiency measures, they rate a “3”.

Foundations

Figure 11 shows the % of NRCan-evaluated homes in the Waterloo Region with each foundation rating. Nearly three quarters of homes have severely underperforming foundation insulation. Indeed, most of these may have no actual insulation on their foundation walls.

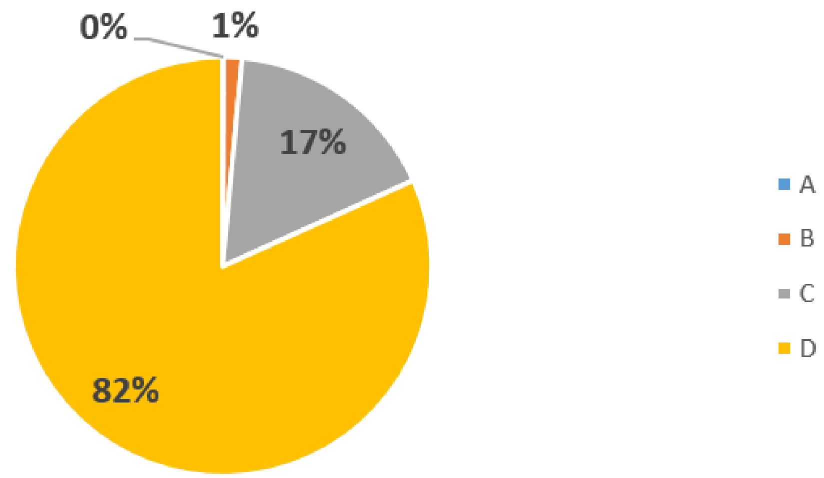

FIGURE 11 PERCENTAGE OF AUDITED WATERLOO REGION HOMES WITH EACH FOUNDATION INSULATION RATING.

The overall trend is toward greater foundation insulation values over time, but there are no obvious steps in the values that suggest changes in the building code (see Figure 12). It seems likely that values are more dependent on what renovations and upgrades homeowners have made to their basements rather than on how the home was originally constructed.

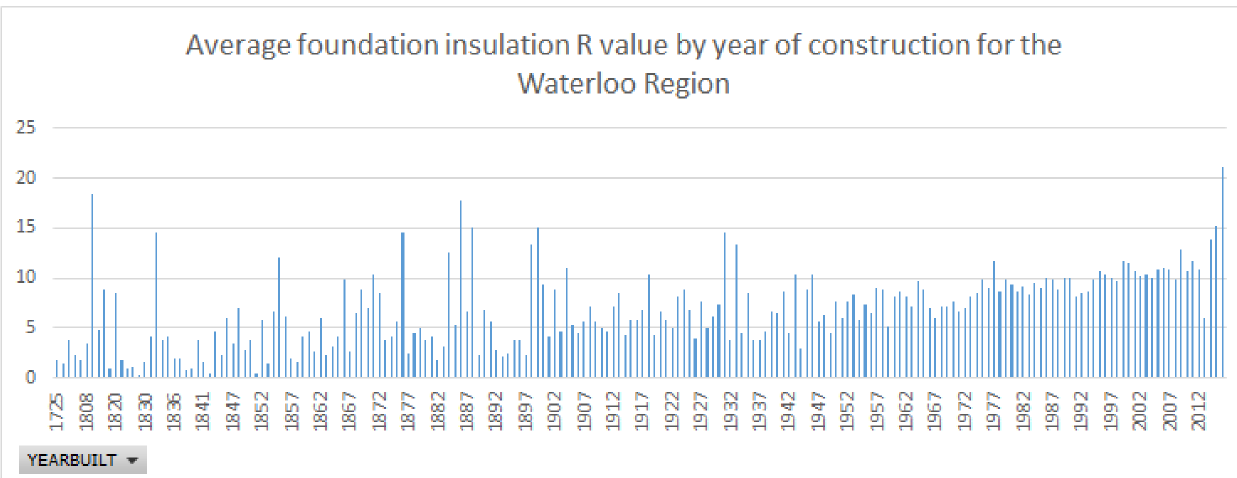

FIGURE 12 AVERAGE FOUNDATION INSULATION R VALUE BY YEAR OF CONSTRUCTION, WATERLOO REGION. SOURCE: NRCAN DATASET.

An unfinished basement would earn a "1" rating as adding insulation to bare concrete or stone walls is usually relatively cost-effective and easy. This can also increase the usable space in the home which has many benefits. Care should be taken when finishing a basement to ensure that water cannot enter through cracks in the foundation, through drains (using backflow valves) and that sump pumps are in working order. Climate change projections for the

Waterloo Region include increased probabilities of the extreme rainfall events that can cause basement flooding[14].

Just as with walls, a finished basement with an empty wall cavity is relatively easy to upgrade with blown in or sprayed in insulation. These foundations earn a "2" rating.

A finished basement with inadequate insulation and no empty wall cavity may be cost-prohibitive or inconvenient to upgrade: these homes earn a "3" rating.

Air tightness

Just over half of Waterloo Region homes with NRCan evaluations performed at a B rating for air tightness (see Figure 13). A substantial portion (12%) performed at an A level. Air tightness has generally improved with date of construction with a noteworthy reduction in air leakage since 2010 (see Figure 14).

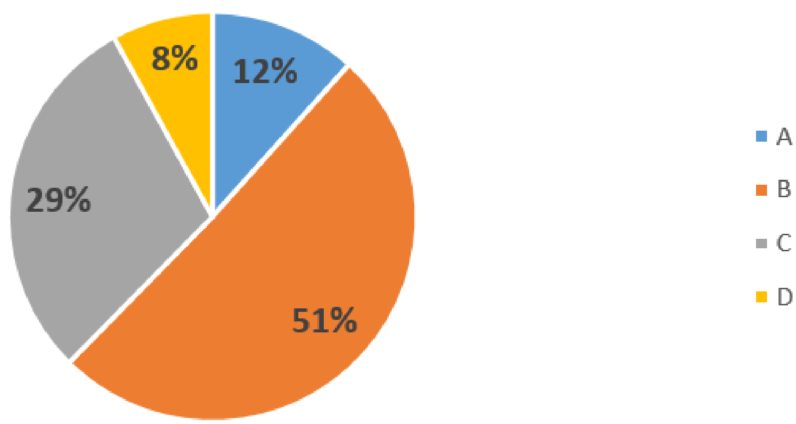

FIGURE 13 PERCENTAGE OF AUDITED WATERLOO REGION HOMES WITH EACH AIR TIGHTNESS RATING.

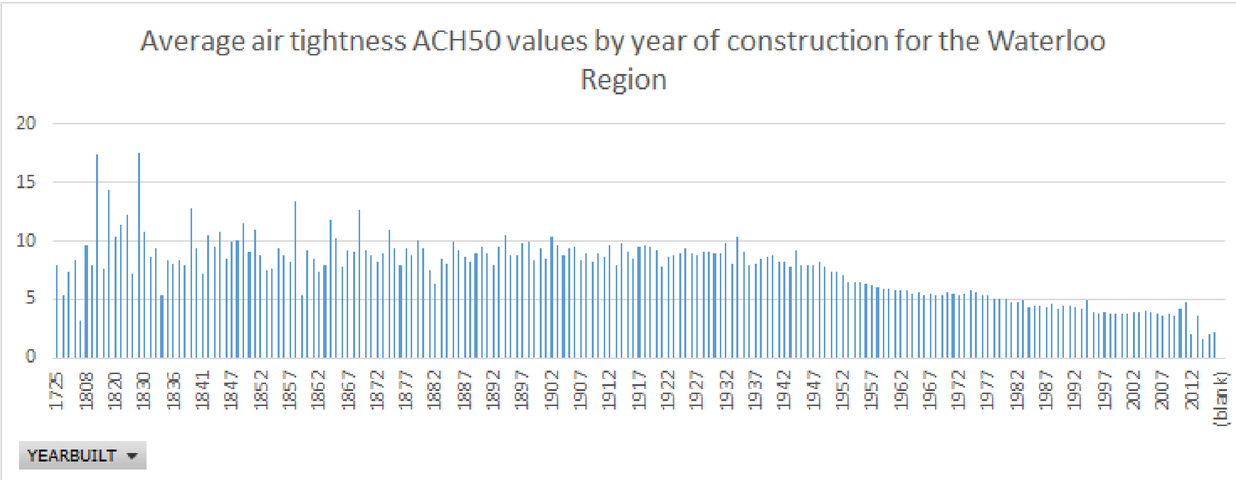

FIGURE 14 AVERAGE AIR TIGHTNESS ACH50 VALUE BY YEAR OF CONSTRUCTION, WATERLOO REGION. SOURCE: NRCAN DATASET.

Air tightness can improve from a variety of direct and indirect measures. A professional who knows where to look for leaks and who has a variety of sealing materials at their disposal can make a significant impact on air leakage. Homes that have undergone professional air sealing earn a "3" rating. Homes that have obvious leaks or very poor performance on air tightness tests earn a "1" rating. All other homes rate a "2" rating.

As homes become more air tight, they may also trap increasing concentrations of air pollutants and moisture. HRVs and ERVs (heat and energy recovery ventilators respectively) that minimize energy losses when bringing in fresh air may be required. These ventilators can improve the indoor air quality, but may slightly reduce the home's overall energy efficiency performance.

Windows and doors

The NRCan dataset did not include characterization of the windows and doors beyond counting those that earned an ENERGYSTAR rating. The data would generally suggest that most homes have either few or no ENERGYSTAR rated windows and doors. However, a window or door will generally only be noted as ENERGYSTAR by the auditor if there is documentation to that effect, and therefore these results may underestimate the number of high performance windows and doors.

ENERGYSTAR windows are typically double-glazed with a low E (emissivity) coating, with argon gas between the panes, and quality framing[15]. ENERGYSTAR doors have an insulated core, a tight seal with the frame and any glass is double-glazed. Very high performing homes, such as Passive House require higher standards similar to those used for an A rating here. There are no simple criteria that make windows and doors more or less easy or cost-effective to replace and therefore these elements are not rated for ease of upgrading.

Space heating

Most homes in the dataset upgraded their furnace to be higher efficiency (75% of homes that performed a post-upgrade audit), presumably to take advantage of available incentives. It is therefore unsurprising that the majority of homes in our dataset have B-rated heating systems (see Figure 15).

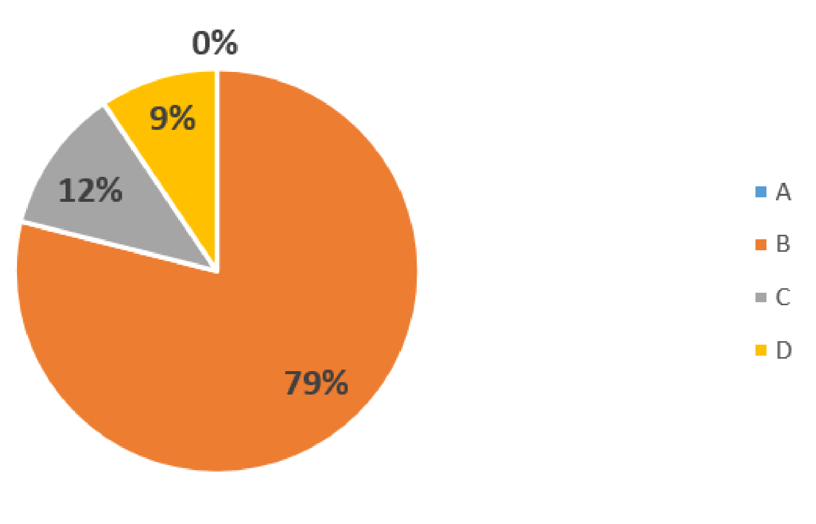

FIGURE 15 PERCENTAGE OF AUDITED WATERLOO REGION HOMES WITH EACH FURNACE RATING.

To achieve an A rating on our scale, a home must install a heat pump system. Because heat pumps move heat rather than generating heat, they can achieve average efficiencies of 300-400%. Heat pumps are also fueled by electricity, which in Ontario is largely decarbonized. Heat pump systems capable of meeting all of a home's heating and cooling needs in our climate are available, and in many cases, they are comparable in cost or better to operate as compared to fossil fuel-based systems (yet remain more expensive upfront)[16].

Analysis of data from the Waterloo Region suggests that air source heat pumps are cheaper to own and operate over their lifetimes than heating systems fueled by propane, heating oil and electricity (electric baseboard heating or electric furnace)[17]. When compared to natural gas, these heat pumps are operationally cost effective (not including upfront cost to install) in approximately 22% of local homes if the homes save the connection and delivery fees by disconnecting the gas supply (July 2020 utility prices). These homes have lower heating loads, often due to such things as smaller size (generally under 300 m2 or 3200 sq ft) and shared walls (row housing and semi-detached housing).

Most high efficiency residential space heaters have a lifespan of 12-18 years: it is therefore likely that many of these homes will be looking to replace their heating system in the coming years. Indeed, between now and 2050, when we aim to reduce emissions by 80%, most homes will replace their heating systems once or twice. If we are to meet our climate targets, the transition to electrified heating must start now.

Water heating

Figure 16 suggests that the vast majority of homes in the Waterloo Region have low efficiency hot water heaters. Heat pump water heaters are lower cost to own and operate over their lifetimes than water heaters that are fueled with propane, heating oil and conventional electrical systems[18]. When compared to natural gas, they are lower cost to operate but more expensive upfront. Incentives of ~$1000 would be required to make these systems economically attractive to most homeowners.

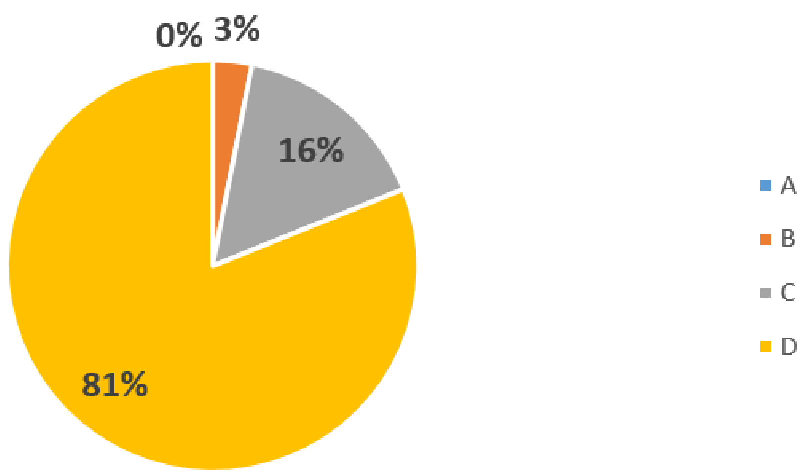

FIGURE 16 PERCENTAGE OF AUDITED WATERLOO REGION HOMES WITH EACH WATER HEATER RATING.

The average lifespan of a hot water heater is 8-13 years[19], and as with space heating systems, heat pump water heaters are the most energy efficient and least carbon-intensive choice.

Whole home archetype analysis

Many communities have developed housing archetypes that can be used as models for testing the effects of different energy efficiency upgrades on emissions and energy use. These archetypes should ideally be close matches for large numbers of existing homes. In Toronto, for example, low rise housing has been classified into the categories of Victorian/Edwardian, Post War, Split Level, Town House[20] for the purposes of modeling retrofit cost-effectiveness. These categories may reflect large building booms within the city when the approach to designing the building envelope was relatively uniform. We could find no satisfactory housing archetypes for modeling purposes in the available data.

Therefore, we looked at the modeled GHG emissions and energy efficiency potential for homes with the same A-D rating for all building envelope elements. Most homes will have a combination of ratings for different elements so this classification will only reflect a fraction of existing homes. However, this analysis illuminates the relative importance of energy efficiency upgrades and electrification in homes with different overall performances.

A rated homes

Only one home in the dataset showed an overall A rating for all building envelope elements (see Table 7). The home was built in 2009 and it is noteworthy in its large size: 942 m2 (10,100 sq ft). This home already performed better than the targets for deep energy efficiency upgrades, except in air tightness, and the home also had efficient mechanical systems. The only meaningful approach to improving the energy efficiency and GHG emissions in these A homes is through electrification. This step would produce a modeled 60% reduction in GHG emissions and a 55% reduction in energy use. However, the large size of the home means that it also has a high baseline value for energy consumption and GHG emissions. This highlights the fact that energy efficient gains can be wiped out by greater consumption: ultimately we may need to consider developing acceptable limits on conditioned space available per person[21].

TABLE 7 AVERAGE HOME CHARACTERISTICS AND MODELED VALUES FOR WATERLOO REGION HOMES RATED A FOR ALL ELEMENTS.

	Units	Pre-upgrade	Deep energy efficiency upgrades	Electrification	Deep upgrades + electrification
Number of homes		1	1	1	1
Building Characteristics					
Average year built		2009	2009	2009	2009
Average floor area	m2	942	942	942	942
Building envelope					
Attic	R	>/=55	60	>55	60
Wall	R	>/=30	40	>30	40
Foundation	R	>/=25	25	>25	25
Air sealing	ACH50	<3	1.0	<3	1.0
Mechanicals					
Furnace efficiency		100%	100%	300%	300%
Water heater efficiency		82%	82%	350%	350%
Energy use					
Calculated total energy use/home	MJ	189,498	183,817	86,010	84,116
Energy efficiency gain			3%	55%	56%
GHG emissions reduction					
GHG emissions/home/yr	tCO2/ home/yr	8.6	8.4	3.4	3.3
GHG emissions reduction			2%	60%	61%

B rated homes

Homes that rated a B for all building envelope elements were also rare (4 out of 44,463 homes; see Table 8). The average year of construction for these homes is 1986, and the size is a more moderate 263 m2 (2830 sq ft). Deep energy efficiency upgrades only reduce energy and emissions by approximately a quarter in these homes, but a reduction of approximately 60% is possible with electrification. When both approaches are combined, the energy efficiency improves by 66%, and the GHG emissions drop by 69%. Electrification should be the priority in these homes.

TABLE 8 AVERAGE HOME CHARACTERISTICS AND MODELED VALUES FOR WATERLOO REGION HOMES RATED B FOR ALL ELEMENTS.

	Units	Pre-upgrade	Deep energy efficiency upgrades	Electrification	Deep upgrades + electrification
Number of homes		4	4	4	4
Building Characteristics					
Average year built		1986	1986	1986	1986
Average floor area	m2	263	263	263	263
Building envelope					
Attic	R	40-54	60	40-54	60
Wall	R	16-29	40	16-29	40
Foundation	R	16-24	25	16-24	25
Air sealing	ACH50	3.1-6.0	1.0	3.1-6.0	1.0
Mechanicals					
Furnace efficiency		97%	97%	300%	300%
Water heater efficiency		76%	76%	350%	350%
Energy use					
Calculated total energy use/home	MJ	133,500	102,031	55,652	45,687
Energy efficiency gain			24%	58%	66%
GHG emissions reduction					
GHG emissions/home/yr	tCO2/ home/yr	6.2	4.6	2.3	1.8
GHG emissions reduction			26%	63%	69%

C rated homes

More homes rated a C for all building envelope elements (301 homes; see Table 8). The average year of construction for these homes is 1981 and the size is 191 m2 (2055 sq ft). Electrification has nearly twice the impact as deep energy efficiency upgrades on energy efficiency and GHG emissions in these homes. Together, these measures achieve our community's climate target of an 80% reduction in emissions. Some of the energy efficiency upgrades required to achieve an A rating will not be practical in these homes. Therefore, it will be essential to be selective in which upgrades to recommend and to combine these with recommendations for electrification.

TABLE 9 AVERAGE HOME CHARACTERISTICS AND MODELED VALUES FOR WATERLOO REGION HOMES RATED C FOR ALL ELEMENTS.

	Units	Pre-upgrade	Deep energy efficiency upgrades	Electrification	Deep upgrades + electrification
Number of homes		301	301	301	301
Building Characteristics					
Average year built		1981	1981	1981	1981
Average floor area	m2	191	191	191	191
Building envelope					
Attic	R	20-39	60	20-39	60
Wall	R	11-15	40	11-15	40
Foundation	R	11-15	25	11-15	25
Air sealing	ACH50	6.1-10.0	1.0	6.1-10.0	1.0
Mechanicals					
Furnace efficiency		84%	84%	300%	300%
Water heater efficiency		58%	58%	350%	350%
Energy use					
Calculated total energy use/home	MJ	155,148	98,459	48,764	32,971
Energy efficiency gain			37%	69%	79%
GHG emissions reduction					
GHG emissions/home/yr	tCO2/ home/yr	7.5	4.7	2.2	1.4
GHG emissions reduction			37%	71%	81%

D rated homes

Homes with an overall D rating were the most common (2,876 homes; see Table 10). These are overwhelmingly older homes, with an average date of construction of 1919 and an average size of 189 m2 (2034 sq ft). The poor performance of the building envelope means that the total modeled energy use of these homes was nearly 5 times greater than the overall A home. Energy efficiency upgrades are the most effective tool for reducing energy use and GHG emissions in these homes (75 and 77% reductions respectively), although it is unlikely that it will be practical to upgrade all of the way to an A rating for all elements. Consequently, electrification of space and water heating will also be necessary for these homes to reach our targets.

TABLE 10 AVERAGE HOME CHARACTERISTICS AND MODELED VALUES FOR WATERLOO REGION HOMES RATED D FOR ALL ELEMENTS.

	Units	Pre-upgrade	Deep energy efficiency upgrades	Electrification	Deep upgrades + electrification
Number of homes		2,876	2,876	2,876	2,876
Building Characteristics					
Average year built		1919	1919	1919	1919
Average floor area	m2	189	189	189	189
Building envelope					
Attic	R	</=19	60	</=19	60
Wall	R	</=10	40	</=10	40
Foundation	R	</=10	25	</=10	25
Air sealing	ACH50	>10.1	1.0	>10.1	1.0
Mechanicals					
Furnace efficiency		83%	83%	300%	300%
Water heater efficiency		62%	62%	350%	350%
Energy use					
Calculated total energy use/home	MJ	284,302	70,382	85,735	26,650
Energy efficiency gain					
GHG emissions reduction			75%	70%	91%
GHG emissions/home/yr	tCO_2/ home/yr	13.9	3.2	4.0	1.0
GHG emissions reduction			77%	71%	93%

Conclusions

Achieving the Region of Waterloo's climate target of an 80% reduction in GHG emissions below 2010 levels by 2050 will require nearly every home in our region to undergo some form of home energy upgrade: air sealing and adding insulation, electrifying space, and water heating, or both.

Previous rates of energy efficiency upgrades suggest that this activity is highest when attractive incentives are present. The most common energy efficiency measures have been furnace upgrades, air sealing, and window upgrades. To date, 19% of Waterloo Region homes have performed post-upgrade audits and, in these homes, the average energy efficiency gains and GHG emission reduction was 20%. Even if these homes were to upgrade their building envelope to the very high standards needed to be net zero energy ready, they would only cut their total emissions by roughly a half. Our models suggest that electrification of space and water heating with heat pumps would achieve a GHG emission reduction of ~70%. Combining electrification with comprehensive upgrades to the building envelope would achieve a greater than 80% emissions reduction and energy efficiency gain.

Streamlining residential building upgrades and electrification will require a system to efficiently assess which measures will most effectively reduce emissions and improve the home while keeping costs and disruptions to a minimum. A system of rating homes for each element of a home (attic, walls, foundations, windows, doors, space heaters, water heaters) was developed in this report. A letter grade (A-D) indicates the home's energy performance while the numbers (1-3) are used to show how easy and cost-effective it would be to perform an upgrade. Most homes in our dataset performed at a C or D level for all elements except air tightness and furnace performance where B and C were the most common ratings.

An analysis of homes with the same rating for all building envelope elements was used to assess the relative potential of energy efficiency upgrades and electrification in homes with different baseline performance levels. This analysis highlights the greater potential for energy efficiency upgrades in poorly performing homes and the greater potential for electrification in better performing homes. Ultimately, both will be required to some degree in all homes if we are to meet our climate targets.

This report shows that cutting emissions from Waterloo Region's housing sector by 80% below 2010 levels by 2050 is achievable, but it will require a streamlined approach in which building envelope upgrades are prioritized in poorly performing homes, particularly to elements that are easy and cost-effective to perform. However, this measure will not be enough: all homes will need to move away from the use of fossil fuels for space and water heating and move toward the adoption of highly efficient heat pump systems. There is much work to be done.

Appendix A: Assumptions and calculations

Data cleaning:

For exposed floor and foundation insulation values, there were a subset of values that indicated RSI values substantially > 10 (R values >55). These were likely entered incorrectly, and these values were excluded from the analysis.

Assumptions and constants used

- When calculating GHG emissions, it was assumed that all homes use natural gas for space and water heating.
- Windows and doors were assumed to have an initial R value of 2 and an R value of 3 when upgraded to ENERGYSTAR
- Emissions factors of 1.888 kgCO2/m3[22] natural gas and 0.100 kg CO2/kWh electricity were used.
- Conversion factors of 38 MJ/m3 natural gas and 3.6 MJ/kWh were used.
- A conversion factor of 5.678 R/RSI was used.
- Water heaters were assumed to use an average 13.6 GJ/yr [23]
- Energy efficiency gains were assumed to have no impact on total electricity usage
- When counting the number of energy efficiency upgrades, it was assumed that any improvement of 10% or greater was the result of an upgrade
- For Table 2, only homes that performed post-upgrade audits were included in the analysis. In all other cases, all homes were used in the analysis.

Calculations

To calculate the energy efficiency gains and GHG emissions reduction for proposed upgrades, the modeled heat loss value (in MJ) for each home was multiplied by the ratio of the upgraded to existing value for insulation, air sealing, or furnace/water heater efficiency to reach a new heat loss value. The total home energy use value was the sum of all heat loss values, the average electrical energy use and hot water energy use.

For Figures 2 and 7-16, the most recent audit data was used. For Tables 7-10, the initial audit data was used for calculations.

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