Deep Energy Retrofits in Housing for Low Income Household in BC and Manitoba: An Opportunity for Climate Mitigation and Social Equity

by

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Abstract

The low-income and vulnerable populations in Canada often live in social housing buildings with poor energy and environmental indoor performance. Many social housing buildings in Canada need major repairs and would also benefit from deep energy retrofits (DER) that could make them climate resilient, and safe for occupancy. The objective of this research was to investigate the GHG emissions reduction, as well as the energy and cost saving potential of different retrofit approaches in BC and Manitoba. I collected electricity and natural gas consumption data for 30 buildings in BC which were subsequently narrowed down to 6 building sites based on their location and type of retrofit. I also collected data for 2 buildings in Manitoba. One building received an interior insulating spray foam application, and the other, exterior spray foam. My study shows that different retrofit approaches executed in BC yielded 18% to 39% energy savings and 27% to 99% GHG emissions reduction as a result of the electrification of one or both end-use systems for space and water heating, as well as building envelope upgrade. Significant energy savings and GHG emissions reduction were also realized in the two Manitoba buildings where building envelope enhancements were executed including the installation of high efficiency heat recovery ventilation systems.
Acknowledgement

I would like to thank my supervisor Ed Nowicki for his moral support, expertise, and guidance in assisting me to complete this project. I would also like to express my gratitude and appreciation to my spouse for her support and encouragement in bringing this project to the finish line given the huge family and full-time work responsibilities I shouldered while I completed this project. I would also like to thank officials of BC Housing and Manitoba Housing for providing me with data on some of their social housing buildings.
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Chapter 1: Introduction

1.1 Overview

The low-income population often live in buildings with poor energy and environmental indoor performance and sadly in degraded sections of urban areas, which make them even more vulnerable to the impacts of climate change such as floods, heat waves etc. These also add to the burden of adverse health conditions, environmental hazards, financial hardships, and energy poverty borne by this segment of the general population. Energy poverty refers to the situation where households cannot meet their energy needs; they often must choose between meeting their energy needs and meeting other essential needs (Hernández, 2016). This situation is a social issue but given the energy elements of the situation, it can also be understood as a climate issue. The situation has been further exacerbated by the global pandemic which has undoubtedly disrupted so many aspects of life and further exposed the vulnerabilities of the most at risk, globally, and certainly in Canada. In general, a deep energy retrofit (DER), can be defined as an entire building construction upgrade with the objective to achieve an energy consumption reduction by 50% or more, compared to the reference pre-upgrade energy consumption, sometimes calculated with utility bills, using existing technologies, materials and construction practices (Less et al., 2012). A deep energy retrofit in the case of this study, could mean one of or a combination of the following: building envelope improvements to reduce air leakage; wall insulation; replacement of windows/doors and heating systems, heat recovery ventilator etc.

The opportunity that deep energy retrofits present in helping to bring about some level of social and climate equity for the low-income segment of the population is an area of interest for a growing number of stakeholders including governments around the world. This stems from the
argument that suggests that the “rich” or those in well-to-do households and communities are driving emissions due to their lifestyle. In contrast, those in poorer communities bear the burden of the impact of climate change (McKendry, 2016). Scientific research has also shown that the impact of environmental degradation, including climate change are felt the most by the vulnerable (Francis, 2019). Unfortunately, the vulnerable do not suffer only physical harm but also adverse health conditions including mental health. The vulnerable populations referred to in this project are people who face hardships and are prone to being affected by prejudice, discrimination, and stigma due to their socio-economic status, age, race/ethnicity, gender, cognitive and physical abilities. These difficulties are further exacerbated by the impacts of climate change and severe climate events (Benevolenza & DeRigne, 2019) For example, due to climate change, older populations face increased vulnerabilities, to environmental risks (Filiberto et al., 2009) which include extreme weather conditions such as heat waves such as experienced in the summer of 2021 in British Columbia which killed hundreds of people (Canada: Disastrous Impact of Extreme Heat, 2021). Housing that are not adapted to these types of severe climatic conditions make things worse. For example, according to researchers at the Human Rights Watch, over 88% of interviewees who said they experienced the impact of the heat wave are low-income people who could not afford cooling systems and lived in subsidized housing or small units without adequate ventilation. Heat waves are one of the most dangerous climatic hazards, and there are projections that they will get worse in frequency and intensity over the coming years (Jones et al., 2018). These issues raise the concern around social and climate justice and equity for low-income households and the vulnerable population.

It is also important to briefly consider the contributions of the building sector to global emissions because of the connection between global climate and local climate. Global climate
change increases the frequency of the severe climatic events that adversely impact vulnerable populations in their local communities (Synnefa et al., 2020). Globally, the building sector is responsible for 30-40% energy consumption and when the energy for construction and demolition is accounted for, the total energy consumption is around 50% (World Business Council for Sustainable Development [WBCSD], 2009). The building sector is also responsible for 38% of the global greenhouse gases (United Nations Environment Program [UNEP], 2012). It is obvious that the building sector has significant global and local carbon footprints which contribute to climate events that severely impact the most vulnerable in societies around the world and in Canada. This calls for action and deep energy retrofits present an opportunity.

One of the ways to go about conducting deep retrofits in social housing and housing for low-income and vulnerable populations in a way that makes economic sense is by adopting the Dutch energy model called “energiesprong”. A model used to implement deep energy retrofits en masse in affordable housing in a way that economies of scale was built as a result. Energiesprong in English means “energy leap” which is a solution implemented by market development teams in the Netherlands. These market development teams are intermediaries that focus on reshaping the retrofit market by organizing and consolidating the demand side. For example, aggregating the demand of building owners, landlords, user etc., and then working on the supply side with manufacturers, suppliers and contractors to meet the large, consolidated demand. This approach was used in the Netherlands to lower cost of retrofits and deliver them faster because of the economies of scale that was built. Other jurisdictions such as France, the UK and New York state have since adopted the model (Brendan, 2022). Canada certainly needs an approach like the energiesprong.
1.2 Research Question and Objectives

The objective of this research project is to investigate the GHG, and energy reduction potential of targeted DER program focussed on social housing in British Columbia and Manitoba. My research question is: What benefits are accrued by a given deep retrofit approach and how do cost savings and GHG reduction differ in relation to the type of retrofit done?

The literature demonstrates that the retrofit intervention type implemented in a social housing building could either benefit or disadvantage its occupants. The results of research performed by Underhill et al., 2018 indicate that residential energy retrofit intervention – building weatherization, HVAC filtration, local exhaust ventilation can influence indoor air quality (IAQ) and occupant health. They also found that the impacts of the retrofit intervention type vary based on the lifestyle of occupants (heavy cooking, smoking, window opening, etc.). Underhill’s results also demonstrate that a combination of energy and ventilation retrofits was resilient to a range of occupants’ lifestyle activities, while shallow interventions without ventilation improvements led to an increase in indoor PM$_{2.5}$ or NO$_2$ for some populations.

I suggest that the findings of Underhill’s research underscore the importance of executing retrofits from a systems perspective and having occupants and their different lifestyles in mind. This also means that an integrated approach which involves different trades working collaboratively and communicating effectively with each other on retrofit projects is important. This would ensure that the outcome of such projects will be beneficial and not detrimental to occupants.

In conducting the research underlying this report, my overarching purpose of this study was to investigate the impact of different retrofit intervention in social housing executed in Manitoba.
and British Columbia which have social and climate justice implications and impact on low-income and vulnerable populations in Canada.

1.3 The Interdisciplinary Approach

Implementing deep energy retrofits in housing for the low-income and vulnerable populations attends to the three pillars of sustainability and sustainable development which include the environment, the economy, and the society in other words environmental, social and economic sustainability. Sustainability could be defined as a system of living that does not harm the environment and society, and also does not jeopardize the economy for the present and future generations (McGill, n.d.).

There is an obvious connection between deep energy retrofits and sustainability given that deep energy retrofits in housing for the low-income and the vulnerable population are aimed at reducing emissions associated with energy used for the operation of these housing buildings (Singh et al., 2019) and if properly implemented has the potential of reducing energy poverty and making the buildings safer and more habitable with resultant health benefits for occupants.

1.3.1 Energy

Globally, the building sector is responsible for 30-40% of energy consumption and when the energy for construction and demolition is accounted for then the total energy consumption is around 50% (World Business Council for Sustainable Development [WBCSD], 2009).

In Canada, most of the social housing stock was built between the 1930’s and the early 2000’s. This housing stock has not been retrofitted and is highly energy inefficient. This means that they consume a lot of energy and emit high amounts of greenhouse gas (Tsenkova, 2013).
For example, a study commissioned by the BC Ministry of Energy, Mines and Petroleum Resources (MEMPR) in collaboration with the BC non-profit Housing Association found that the average energy intensity of most non-profit apartment buildings was higher than the BC average. While the average energy intensity for an apartment building in BC was found to be 0.86 GJ/m² or 239 kWh/m², per year, the average energy intensity of a building in the non-profit sector, which provides housing for mostly low-income households and the vulnerable, was found to be as high as 1.36 GJ/m² or 377 kWh/m², per year (City Green Solutions, 2010). The report by City Green Solutions (2010) found that in addition to high energy intensity, most of the social housing stock need repairs, roof replacement, improvement in ventilation and insulation which makes the need for deep energy retrofit more pertinent. It was also estimated that $500,000 in energy savings could be accrued from each percentage drop in energy consumption in social housing in BC (City Green Solutions, 2010).

1.3.2 Environment

The building sector is responsible for about one-third of global raw material use and waste generation when construction and generation are accounted for (Minunno et al., 2020). According to the United Nations Environment Program (UNEP, 2012), this sector is also responsible for approximately 38% of the global greenhouse gases (United Nations Environment Program [UNEP], 2012). The building sector contributes to the negative impact on the environment and the climate both globally and locally.

The impacts of both global and local climate change are felt the most by the low-income and vulnerable populations in Canada and many countries around the world. However, these
impacts can be mitigated by implementing mass energy retrofit programs in residential buildings especially in housing for the low-income and vulnerable populations.

1.3.3 Social

A situation of energy poverty where households cannot meet their energy needs and often must choose between meeting their energy needs and meeting other needs such as buying groceries is clearly a social issue (Hernández, 2016). According to Kantamneni and Haley (2021), Canada needs a national energy poverty reduction strategy which would have as its core a focus on targeting the least efficient homes and lowest income households. Canada needs to take a cue from the United Kingdom (UK) where energy poverty reduction is a legislated duty for the UK government. In the UK, energy poverty is seen as a situation where a low-income household spends over 10% of its gross income on energy for the year 2016, while the national median expenditure at the time in the UK was 5% of household income. In Canada, the median expenditure is 3% of household income on energy cost. Going by the UK characterization, these figures indicate that those who spend over 6% of their household income in Canada are energy poor (Kantamneni & Haley, 2021). In tackling energy poverty in the UK, the UK government went further to include their energy poverty reduction strategy in statutory targets. This measure binds future governments to the commitment that focuses on making sure that energy efficiency in the homes of the energy-poor is equivalent or perhaps better than 20% most efficient homes in the UK. The UK government also adopted indicators such as LIHC – Low Income High Cost and most recently in 2021, Low Income Low Energy Efficiency which are official indicators the UK government uses to measure energy poverty (Kantamneni & Haley, 2021).
In the European Union (EU), the creation of a Social Climate Fund is one of the instruments being contemplated for mitigating and addressing energy poverty and fostering a socially just transition to a climate-neutral continent by 2050. The fund as contemplated will address the social and distributional impacts on the most vulnerable of energy price increases emanating from emissions trading in the building and transportation sectors. The Social Climate Fund will be invested in the increased energy efficiency of buildings, decarbonization of heating and cooling of buildings, including the integration of renewable energy sources (European Commission [EU], 2021).

I suggest that the Government of Canada can use a mix of policy instruments including deep energy retrofits to target the homes of low-income households and vulnerable populations.

1.3.4 Sustainable Development Goals

Deep energy retrofits in housing for the low-income align with Sustainable Development Goal (SDG) 11 aimed at reducing inequalities and making cities and human settlements inclusive, safe, resilient and sustainable (SDG).

One of the ways of achieving this SDG goal is by retrofitting buildings and cutting GHG emissions. The housing sector is one area to look to for quick gains in cutting Canada’s emissions given that Canadians are among the highest GHG emitters and energy users in the world (Organization for Economic Development and Cooperation [OECD], 2019). The building sector (residential and commercial) contributes approximately 85 megatons per year or 12% of the national emissions (Environment and Climate Change Canada [ECCC], 2019). These GHG emissions are projected to continue to rise in a business-as-usual scenario with the consequent
negative impact on the climate which severely impacts the low-income and vulnerable populations in Canada.
Chapter 2: Literature Review

2.1 Social Housing in Canada

Social housing in Canada is often defined as subsidized housing developed by governments in collaboration with private and not-for-profit sectors and delivered to those who on their own are unable to afford to live in housing that passes the suitability and adequacy test. The client group for social housing includes low-income households (singles and families), recent immigrants, lone-parents, seniors, persons with disabilities, Indigenous peoples, victims of domestic violence, and other vulnerable groups.

Social housing in Canada has its foundation as a government policy instrument in times of severe housing shortages with the primary goal of providing homes to those who were unable to afford the cost of housing in the private market environment (Canada Mortgage and Housing Corporation [CMHC], 2011).

In 2011, there were about 630,000 units of social housing in Canada which represented less than 6% of the housing stock nationwide. Approximately 30% of social housing in Canada is publicly owned, about 12% is owned by cooperatives while the remaining is owned and managed by non-profit housing organizations. Canada Mortgage and Housing Corporation administered 15% of the social housing stock while the remaining 85% were administered by the provinces and territories. Table 1 below shows a distribution of social housing in Canada by province and territories slightly over ten years ago (Tsenkova, 2013) which might not be too different from what is obtainable in 2022 given that buildings have long lifespans.
As discussed earlier, most of the social housing stock were built between the 1930’s and 2000’s. This social housing stock needs significant repairs including deep energy retrofits. Sadly, those who live in most of the social housing stock are also experiencing energy poverty among many of the social issues they continually face.

2.2 Energy Poverty in Canada

Energy poverty is defined as a situation in which households or communities are unable to heat or cool their homes, keep their lights on and their appliances functioning. Those experiencing this situation often struggle to meet their energy needs. They also face multiple challenges and impacts, including (CUSP, 2019):

- Choosing between meeting energy needs and sacrificing other essentials such as food and medications.
● Unaffordability of utility costs with consequent shut offs which disrupts their lives such as inability to cook and having to deal with spoiled foods.

● Discomfort from living in cold and drafty homes during cold seasons, and hot and improperly ventilated homes in the hot summer months.

● Respiratory illness in children and infants due to poor ventilation.

● Poor mental health outcomes due to increased stress levels in adults.

● Inability to fully participate in community life due to the unsuitability and inadequacy of the homes of the energy poor.

2.2.1 Measuring Energy Poverty

Energy poverty is being measured by researchers using one or more metrics such as energy costs relative to household income, subjective measurement of thermal comfort levels, access to the electricity grid or clean energy sources, and occurrence of utility disconnections and burden of arrears (CUSH, 2019). Figure 1 shows the percentage and number of people experiencing energy poverty in each Canadian province as of 2019. Given the increasing cost of energy, these figures may have also increased in 2022.

In Canada, unlike in Europe, there is no formal nor official metric used to characterize energy poverty however it is commonly referred to in terms of high energy cost burdens through the concept of affordability. In Canada, the median household energy expenditure is 3% of household
income. Going by the UK characterization, it means that those who spend over 6% of their household income in Canada are experiencing energy poverty (Kantamneni & Haley, 2021).

Figure 1: Percentage and number of households experiencing energy poverty per province in Canada

According to CUSP, 2019, energy poverty may be experienced by households because of the interaction of numerous variables including housing characteristics which contribute significantly to the level of energy cost burden a household could face. The age of a home, energy performance (types of windows used, insulation, air tightness, energy efficient appliances, HVAC system), and type of home affect the likelihood of a household to experience energy poverty or high energy cost burden. It is no surprise that those who live in less efficient homes will have higher energy costs than people in more efficient homes. Figure 2 below shows the number of people experiencing high energy costs relative to the age of their housing. Given that most social housing stock were built between the 1930’s and 2000’s, it suffices to deduct that the
client group for social housing are experiencing energy poverty due to the age of their housing which need repairs including deep energy retrofit.

Figure 2: Percentage and number of households experiencing high home energy cost burdens by period of construction of the home

2.3 Jurisdictional Scan – The US, and the Netherlands

2.3.1 The US Department of Energy’s Weatherization Assistance Program (WAP)

The US Department of Energy’s (DOE’s) Weatherization Assistance Program (WAP) which has been running for over 45 years since inception helps to reduce the cost of energy for low-income households by making their homes energy efficient, safe, and healthy to live in. WAP provides weatherization services to about 35,000 homes every year using DOE funds. This number is much higher when partner funds are accounted for. As a result, more than 2 million metric tons CO₂ equivalent are cut every year (US Department of Energy [DOE], 2021).
2.3.1.1 Program Funding Mechanism

The DOE appropriates WAP funding to all 50 states, the District of Columbia, federal territories, and indigenous communities based on a formula that considers factors such as the number of low-income households, severity of local climate change, and energy cost burden experienced by the low-income families. These entities deliver the funding independently by contracting with over 800 agencies nationwide. Some of them use in-house employees while others use private contractors to provide the weatherization services to low-income households in their communities.

The program also attracts and unlocks partner funding. According to (National Association for State Community Services Program [NASCSP], 2018), $US 860 million additional funding was provided by states and utilities. This amounts to $US 3.48 of funding for every dollar invested by the DOE.

2.3.1.2 Impact on Low-Income Households

According to the US Department of Energy [DOE], 2021, low-income households spend about 13.9% of their total annual income compared to 3% spent by other American households. This means less amount of disposable income available for other key living essentials such as health care, groceries, childcare, and even entertainment due to the heavy energy cost burden borne by these households.

WAP assists low-income households mitigate high energy cost burden through improvements to building shell and envelope, heating, ventilation, and cooling (HVAC) systems, lighting, and appliances. As a result, households can save on average about $US283 (18% annual heating consumption savings and 7% annual electric consumption savings). These savings could be
directed towards other key living expenses and help to improve the standard of living of the low-income households. The DOE also estimates that $US1.72 is generated in energy benefits and $US2.78 in non-energy benefits for every $US1 invested in the program.

2.3.1.3 Impact on Communities

Based on the national evaluation of WAP, the DOE concluded that weatherization helps not only low-income households but also helps to revitalize communities by driving economic activities and growth and reducing environmental impact. The DOE estimates that WAP’s return on investment is $US 2.78 in non-energy benefits for every $US1 invested in the program. The DOE also estimates that after weatherization, an average of $514 is saved due to decrease in out-of-pocket expenses. The total savings and benefits accrued to a household after weatherization for each unit averages $US14,148. The program also supports about 8,500 jobs (US Department of Energy [DOE], 2021).

2.3.1.4 Typical Weatherization Measures

Table 2
Typical weatherization measures (US Department of Energy [DOE], 2021)

<table>
<thead>
<tr>
<th>Measure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Building Shell</strong></td>
<td>• Installation of insulation where needed</td>
</tr>
<tr>
<td></td>
<td>• Air sealing where needed</td>
</tr>
<tr>
<td></td>
<td>• Repair and replacement of windows and doors</td>
</tr>
<tr>
<td></td>
<td>• Installation of window film, awnings, and solar screens</td>
</tr>
<tr>
<td>Measure</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>● Repair of minor roof and wall leaks prior to attic or wall insulation.</td>
<td></td>
</tr>
</tbody>
</table>

**Mechanical**  
● Cleaning, tuning, repair, or replacement of heating and/or cooling systems  
● Installation of duct and heating pipe insulation  
● Repair of leaks in heating/cooling ducts  
● Installation of programmable thermostats  
● Repair/replacement of water heaters  
● Installation of water heater tank insulation  
● Insulation of water heating pipes  
● Installation of solar hot water heating systems

**Health and Safety**  
● Heating system safety testing  
● Testing combustion appliance safety  
● Repair or replacement of vent systems to ensure combustion gas drafts safely outside  
● Installation of mechanical ventilation to ensure adequate indoor air quality  
● Installation of smoke and carbon monoxide alarms when and where needed  
● Evaluation of mold/moisture hazards  
● Implementation of incidental safety repairs when needed
<table>
<thead>
<tr>
<th>Measure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical and</td>
<td>• Installation of efficient light sources</td>
</tr>
<tr>
<td>Water</td>
<td>• Installation of low-flow showerheads</td>
</tr>
<tr>
<td></td>
<td>• Replacement of inefficient refrigerators with energy-efficient</td>
</tr>
<tr>
<td>Client Education</td>
<td>• Education on the potential household hazards such as carbon monoxide, mold</td>
</tr>
<tr>
<td></td>
<td>and moisture, fire, indoor air pollutants, lead paint, and radon.</td>
</tr>
<tr>
<td></td>
<td>• Educating clients on the key functions of any new mechanical equipment or</td>
</tr>
<tr>
<td></td>
<td>appliances.</td>
</tr>
<tr>
<td></td>
<td>• Discussions on the benefits of using energy-efficient products.</td>
</tr>
</tbody>
</table>

2.3.2 The Dutch Energiesprong (Energy Leap) Model

Energiesprong is a market-led initiative to achieve net-zero energy homes facilitated by the Dutch government in 2013 when they funded the initiative with about 45 million Euros. The aim was to achieve a self-sustaining market for net-zero homes through a new policy mechanism of delivery using an intermediary. Energiesprong is an effective model used to implement deep energy retrofits en masse in affordable housing in a way that economies of scale were built as a result. Energiesprong in English means “energy leap” which is a solution implemented by market development teams in the Netherlands. These market development teams are intermediaries that were assembled because of the Dutch government’s search for a new way to deliver energy-
efficient buildings at a large scale without dependence on government subsidies and to overcome the problems of the piecemeal approach.

The intermediaries focus on reshaping the retrofit market by organizing and consolidating the demand side. For example, aggregating the demand of building owners, landlords, users etc., and then working on the supply side with manufacturers, suppliers, and contractors to meet the large, consolidated demand. This approach was used in the Netherlands to lower cost of retrofits and deliver them faster because of the economies of scale that was built. Other jurisdictions such as France, the UK, and New York state have since adopted the model (Brendan, 2022).

The whole-house-retrofit is the main value proposition of the energiesprong model. In this model, offsite manufactured and assembled integrated energy modules, which include heat pumps, ventilation units, solar inverters, and insulated facades, are offered as a single solution to clients with a performance guarantee for a net-zero annual energy consumption amortized over the 30-year period. The performance guarantee includes an internal temperature of 21°C and fixed hot water and electricity consumption, similar to a mobile telephone contract with usage conditions and limits.

The economies of scale spurred by this model have the potential to drive industrialization and offsite manufacture of integrated energy modules, reduce cost and installation times and help jurisdictions improve the living conditions of their most vulnerable and low-income populations. In the Netherlands, one-day retrofits are now being achieved (Brown et al., 2019).
2.4 Analysis of Current Government Programs in Canadian Jurisdictions Supporting Energy Retrofits in Housing.

There are various national, provincial, and territorial programs that support energy retrofits in housing intended to achieve a range of goals. For example, the Government of Canada through its Greener Homes Initiative intends to help homeowners save money, create new jobs across Canada for energy advisors, and fight climate change. This section as presented in Table 3, is intended to analyze energy efficiency programs in Canadian jurisdictions (both national and sub-national) to highlight the gaps within them as it relates to supporting low-income households and vulnerable populations.

Table 3

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Program</th>
<th>Funding Depth</th>
<th>Requirements</th>
<th>Benefit or Gap in relation to low-income and the Vulnerable</th>
</tr>
</thead>
</table>
| Canada        | Canada Greener Homes Grant Initiative | ● up to $5,000 total for eligible retrofits undertaken after December 1, 2020.  
● up to $600 for the combined cost of pre- and post-retrofit EnerGuide evaluations. | ● Homeownership  
● Execute eligible retrofit and submit application with supporting documents to receive grant. | ● The Canada Greener Homes Grant Initiative process takes time as it consists of several steps, including application review and confirmation of eligibility, pre- and post-retrofit EnerGuide home evaluations, and payment processing.  
● It requires the homeowner to provide upfront costs which might be challenging for moderate income to low-income households. |
| Canada        | Canada Greener Homes Loan         | Loan details  
Maximum: $40,000  
Minimum: $5,000  
Repayment term: 10 years, interest-free  
Loan type: Unsecured personal loan on approved credit | ● Eligible applicants who are applying to Canada Greener Homes Grant.  
● Active applicants at the pre-retrofit EnerGuide evaluation stage | ● To access this loan the low-income household will need to provide upfront capital and be eligible for or be an active applicant in the Grant initiative process.  
● To achieve a DER, the low-income homeowner will have to take on a debt which will |
<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Program</th>
<th>Funding Depth</th>
<th>Requirements</th>
<th>Benefit or Gap in relation to low-income and the Vulnerable</th>
</tr>
</thead>
</table>
| Federation of Canadian Municipalities (FCM) – Green Municipal Fund (GMF) | Sustainable Affordable Housing (SAH) | Supports Retrofit (to a minimum of 25% energy reduction) or NZER New Builds of Affordable Housing. | • Good credit history.  
• The applicant will be required to share financial information to demonstrate that you have the financial capacity to repay the loan.  
• The home must be a primary residence. | • To be eligible for the loan to do a DER the low-income household will have to show that they can pay back. With the rising cost of living in Canada, this is a challenge for mid-income families let alone low-income households who face more severe needs.  
• Landlords can’t access this loan to make their houses more energy efficient even when they house low-income families. |
| Federation of Canadian Municipalities (FCM) – Green Municipal Fund (GMF) | Community Efficiency Financing (CEF) | The CEF helps municipalities deliver energy financing programs for low-rise residential properties. | • Eligible recipients are municipalities, municipal housing authorities, and non-profit affordable housing providers | • The SAH funding focuses on municipal and non-profit housing providers, ensuring that smaller affordable housing providers can access funds.  
• There is complementarity between SAH and the Co-Investment Fund of the Canada Mortgage Housing Corporation (CMHC) which allows the dollars to be stretched to build more sustainable affordable housing. |
<p>| Manitoba | Efficiency Manitoba | Up to 100% of the insulation material | | |</p>
<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Program</th>
<th>Funding Depth</th>
<th>Requirements</th>
<th>Benefit or Gap in relation to low-income and the Vulnerable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manitoba</td>
<td>Energy Efficiency Assistance Program</td>
<td>Free or subsidized energy efficiency upgrades for income qualifying households</td>
<td>Income verification documentation</td>
<td>This program applies to the following:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>● Homeowners with limited income and are interested in energy efficiency upgrades.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>● Home renters with a limited income.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>● Landlords who are interested in increasing their property value and reducing their tenant’s energy consumption.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>● Renter of apartment suites that are interested in energy efficiency upgrades that will help them save money and energy.</td>
</tr>
<tr>
<td>Manitoba</td>
<td>Energy Efficient Upgrades for First Nation Communities</td>
<td>• Free insulation upgrades&lt;br&gt;• Free led lighting&lt;br&gt;• Free low-flow showerheads and faucet aerators&lt;br&gt;• Free insulated pipe wrap&lt;br&gt;• Free draft proofing</td>
<td>First Nations Communities</td>
<td>The program targets First Nation Communities.</td>
</tr>
<tr>
<td>British Columbia</td>
<td>Home Renovation Rebate Program</td>
<td>• Depending on the type of retrofit done, rebates can vary between $300 up to $6000&lt;br&gt;• Single family home (detached dwelling).&lt;br&gt;• Separately metered</td>
<td>The program being a rebate initiative contemplates that retrofit work must be completed by eligible households before rebates could be received. This</td>
<td></td>
</tr>
<tr>
<td>Jurisdiction</td>
<td>Program</td>
<td>Funding Depth</td>
<td>Requirements</td>
<td>Benefit or Gap in relation to low-income and the Vulnerable</td>
</tr>
<tr>
<td>-------------------</td>
<td>--------------------------------------------------------------------------</td>
<td>----------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>and CleanBC Home Efficiency Rebates</td>
<td>● Additional bonus of $300 for implementing 2 upgrade retrofit, or ● Additional $750 - $2000 for 3 upgrade retrofit and for completing pre- and post-upgrade EnerGuide home evaluation within 18 months of upgrade completion.</td>
<td>secondary suite in a single-family home (detached dwelling) individually metered. ● A mobile home that is permanently fixed, sits on a foundation and is structurally complete with installed and connected plumbing, heating, electrical, water and sewer services; towing apparatus and axle must be removed. ● Duplex, triplex, row home or townhome, where each unit has its own natural gas and/or electricity meter.</td>
<td>may also not be favourable to low-income households as this will involve upfront cost.</td>
</tr>
<tr>
<td>British Columbia</td>
<td>CleanBC Better Homes New Construction Program</td>
<td>Up to $15,000 for the construction of new, high-performance, electric homes.</td>
<td>Open to licensed residential builders, owner builders who are authorized by BC Housing, and buildings authorized by Indigenous communities who are building a new home in B.C.</td>
<td>Through the CleanBC plan, the province is supporting the adoption of the BC Energy Step Code and making energy efficient, climate-friendly homes more affordable and accessible for British Columbians</td>
</tr>
</tbody>
</table>
2.5 Barriers Faced by Social Housing Providers in Relation to Deep Energy Retrofits

2.5.1 Expiry of Operating Agreements

One of the greatest challenges facing social housing providers in Canada is the issue of expiration of operating agreements. Through these agreements, subsidies are provided to housing operators by provincial and (or) federal governments. The operating agreements also stipulate the amount, duration and conditions of subsidies and were structured to provide theses subsidies for as long as mortgage on the properties was being repaid.

As organizations pay off mortgages and operating agreements between governments expire, some housing providers may be left in the precarious situation of operating budget deficits with deferred maintenance including DER’s. In addition, a housing operator whose funding agreement has expired may not have the ability to obtain loans to fund DER’s especially when their forecasted net operating income is the negative (Frappé-Sénéclauze, 2017).

2.5.2 Lack of Incentive to Undertake DERs due to the Type of Operating Agreements

Some operating agreements between some governments and housing providers may be the barrier faced by these providers in implementing DERs in their buildings. Under some operating agreements, energy costs are regarded as uncontrolled or variable expense. This means that funding from the province is regularly changed to account for the variation in energy costs. In this case, where additional retrofit is implemented by the provider, the provider will not be able to recoup energy costs saving due to the reduction in funding to reflect lower operating cost accrued from implemented DER. This means that any DER implemented under this type of operating agreement will benefit the funding government rather than the housing provider. This
leaves the housing provider without an incentive to undertake energy saving initiatives (Frappé-Sénéclauze, 2017).

2.5.3 Lack of Dedicated Funding for DERs in Low-Income Housing and Retrofit Funding Programs Design Issues

Canada and most Canadian provinces have some type of energy retrofit and (or) efficiency programs but not with issues. Some of the issues include low funding levels (Kantamneni & Haley, 2021); low-income households not being considered in program designs that require low-income homeowners to come up with upfront capital to unlock grants. Some require uptake of loan burdens to implement meaningful DERs to their homes. Other loan programs such as the CMHC co-investment fund have onerous requirements and lengthy application processes which can be challenging for some housing providers to obtain funding for the desperately needed repairs to their buildings.

2.5.4 Building Workforce Labour Shortage

According to Kacary, 2021, the building workforce is experiencing labour shortage. Many of the professions in the building sector are facing the challenge of attracting new talent. In addition, current workforce is aging taking skills and experienced with them into retirement with fewer and fewer people available to them to transfer their knowledge. Digital skills and literacy will continue to be in high demand as new technologies are increasingly being deployed to the building process and sector. Technologies such as smart building that leverage information technology, Data collection, artificial intelligence solutions and applications, energy management
and sustainability technologies, tenant focused solutions would have significant impact on the building sector and energy efficiency goals.
Chapter 3: Methodology

3.1 Research Approach

To understand the world of deep energy retrofits in social housing, I conducted a comprehensive literature review. The review included academic literature and some non-academic sources such as reports, supporting articles from websites, blogs by reputable individuals, and news sources. The literature review also included jurisdictional scans. This was necessary to understand how other jurisdictions similar to Canada were tackling the issue of deep energy retrofits in social housing.

Although there are numerous academic articles relating to deep energy retrofits, there is an extremely limited number of publications that touch on deep energy retrofits in social housing for low-income and vulnerable populations. There are also little, or no linkages or connections made between deep energy retrofits as an instrument or tool that could be used for social and climate equity.

3.2 Data Collection

At the onset of this project, my intention was to gather as much data as possible from agencies, government departments, and not-for-profit organizations who are stakeholders in the housing sector and are involved in either providing funds for affordable housing or executing deep energy retrofit projects in social housing. The organizations were not randomly picked but were selected because of an effective level of interaction I had with them during the research phase of this project, or in the past in the course of my professional work in the housing sector. Such organizations include:
• British Columbia Housing – has a large portfolio of social housing and executes retrofit projects on them.

• Government of Manitoba – a colleague who was an executive director in housing informed me that there could be a repository of data on deep retrofits done on Manitoba’s portfolio.

• Federation of Canadian Municipalities – has a Sustainable Affordable Housing (SAH) program.

• Environment Climate Change Canada (ECCC) – Low Carbon Economy Fund: supported some provincial programs to improve energy efficiency for low-income Canadians or affordable housing providers.

I collected data for 30 buildings where deep energy retrofits were executed in BC. I analyzed and narrowed down the data to six (6) sites based on the variety of retrofits done and the location of the buildings, as shown in Table 4. Of these six sites, a total of four (4) sites are located in lower mainland BC (Vancouver, Burnaby, and Port Coquitlam). These sites are in climatic zone 7/8 with moderate temperatures. The remaining two (2) sites are in Clinton and Vernon, which are located in climatic zone 5/6.

All six (6) sites used natural gas for both building space heating and water heating needs except for building C where electric baseboards and make-up air gas is used for space heating.

I also collected data from Manitoba for a 6-story building in Minnedosa and an 11-story building in Winnipeg. An overview is presented in Table 5.
### Table 4

Overview of BC social housing building characteristics pre-retrofit

<table>
<thead>
<tr>
<th>Building</th>
<th>Building location</th>
<th>Number of buildings</th>
<th>Number of units in building</th>
<th>Total square footage of building</th>
<th>Age of building (in years)</th>
<th>Building’s space heating system</th>
<th>Building’s water heating system</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Vancouver</td>
<td>2</td>
<td>82</td>
<td>64,000</td>
<td>48</td>
<td>Natural Gas</td>
<td>Natural Gas</td>
</tr>
<tr>
<td>B</td>
<td>Burnaby</td>
<td>1</td>
<td>56</td>
<td>47,248</td>
<td>47</td>
<td>Natural Gas</td>
<td>Natural Gas</td>
</tr>
<tr>
<td>C</td>
<td>Port Coquitlam</td>
<td>1</td>
<td>20</td>
<td>12,000</td>
<td>33</td>
<td>Electric baseboards &amp; MUA</td>
<td>Natural Gas</td>
</tr>
<tr>
<td>D</td>
<td>Clinton</td>
<td>1</td>
<td>14</td>
<td>9,041</td>
<td>44</td>
<td>Individual gas heaters</td>
<td>Natural gas</td>
</tr>
<tr>
<td>E</td>
<td>Vancouver</td>
<td>1</td>
<td>29</td>
<td>30,000</td>
<td>28</td>
<td>Natural Gas</td>
<td>Natural Gas</td>
</tr>
<tr>
<td>F</td>
<td>Vernon</td>
<td>1</td>
<td>75</td>
<td>43,200</td>
<td>47</td>
<td>Natural Gas</td>
<td>Natural Gas</td>
</tr>
</tbody>
</table>

### Table 5

Overview of the analyzed social housing building in Manitoba.

<table>
<thead>
<tr>
<th>Location of Building</th>
<th>Building Type</th>
<th>Retrofit Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winnipeg</td>
<td>11-story</td>
<td>Interior Spray foam and dual-core reverse flow HRVs with 90+% efficiency</td>
</tr>
<tr>
<td>Minnedosa</td>
<td>6-Story</td>
<td>Exterior Spray foam and dual-core reverse flow HRVs with 90+% efficiency</td>
</tr>
</tbody>
</table>
In the Manitoba DER, insulating spray foam was applied over the exterior of the 6-story Minnedosa building, whereas the 11-story Winnipeg building received an interior application of insulating spray foam. In both cases, fully upgraded ventilation systems with the addition of dual-core reverse flow Heat Recovery Ventilators (HRVs) with 90+\% efficiency, were also installed in the buildings.

It is important to note that the collection of data from different jurisdictions and organizations in Canada on deep retrofit in social housing is quite challenging and time consuming. This calls for some form of a national database for energy retrofit in the housing sector.
Chapter 4: Discussions and Interpretations of Findings

4.1 BC Analysis, Discussions, and Interpretation

According to officials in BC Housing, the variety of DERs options executed in the buildings were informed by several factors which include the Government of British Columbia’s GHG reduction mandate, recommendations of consultants who conducted energy audits on the buildings, cost of retrofit and the availability of funds, building location and the feasibility of a retrofit type based on cost and local building codes etc. In cases where a retrofit type could trigger a more expensive deep retrofit, an alternative DER was chosen instead. For the six (6) sites as shown in Table 6 and Figure 3, I analyzed the pre- and post electricity data to determine the impact of the DERs on electricity consumption in the buildings.

Table 6

Electricity consumption pre- and post retrofit in BC social housing building

<table>
<thead>
<tr>
<th>Building - Retrofit type</th>
<th>Electricity Use Pre-Retrofit (kWh/yr)</th>
<th>Electricity Use Post-Retrofit (kWh/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bldg A – Domestic Hot Water Heat (DHW) Pumps</td>
<td>274,885</td>
<td>349,585</td>
</tr>
<tr>
<td>Bldg B – Building Envelope Wall Installation, Windows &amp; Doors</td>
<td>638,850</td>
<td>638,850</td>
</tr>
<tr>
<td>Bldg C – Make Up Air Heat Pumps</td>
<td>168,606</td>
<td>187,006</td>
</tr>
<tr>
<td>Bldg D – Ductless Mini Split (DMS) Heat Pumps &amp; Electric DHW Heater</td>
<td>11,944</td>
<td>23,888</td>
</tr>
<tr>
<td>Bldg E – Make Up Air Hybrid NG/Heat Pump</td>
<td>67,920</td>
<td>81,390</td>
</tr>
<tr>
<td>Bldg F – Mini Split (MS) Wall mounted heat/cool Unit</td>
<td>52,980</td>
<td>134,280</td>
</tr>
</tbody>
</table>
In all buildings except building B, the electricity consumption post retrofit increased. This increase could be attributed to electrification of one or both end-use systems (space or water heating). In Building B where only building envelope, windows and doors were installed, electricity consumption remained approximately the same post retrofit.

Given the electrification of one or both end-use systems, I analyzed the natural gas data to determine how natural gas consumption was impacted as shown in Table 7 and Figure 4.

Table 7

Natural gas consumption pre- and post retrofit in BC

<table>
<thead>
<tr>
<th>Building - Retrofit type</th>
<th>Pre-Retrofit Annual NG Use (GJ/yr)</th>
<th>Post Retrofit Annual NG Use (GJ/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bldg A – Domestic Hot Water Heat (DHW) Pumps</td>
<td>4,490</td>
<td>3220</td>
</tr>
<tr>
<td>Bldg B – Building Envelope Wall Installation, Windows &amp; Doors</td>
<td>5,580</td>
<td>3404</td>
</tr>
<tr>
<td>Bldg C – Make Up Air Heat Pumps</td>
<td>665</td>
<td>255</td>
</tr>
<tr>
<td>Bldg D – Ductless Mini Split (DMS) Heat Pumps &amp; Electric DHW Heater</td>
<td>480</td>
<td>0</td>
</tr>
<tr>
<td>Bldg E – Make Up Air Hybrid NG/Heat Pump</td>
<td>1,364</td>
<td>834</td>
</tr>
<tr>
<td>Bldg F – Mini Split (MS) Wall mounted heat/Cool Unit</td>
<td>1,488</td>
<td>540</td>
</tr>
</tbody>
</table>
Figure 4: Natural gas consumption in BC social housing buildings pre- and post retrofit

As expected, the natural gas consumption in all the buildings dropped significantly. In building D, natural gas use was eliminated given the complete electrification of the two end-use systems. Given the energy use data, I was able to determine the percentage energy savings and GHG reduction percentages in each of the buildings analysed, as shown in Table 8 and Figure 5.

Table 8
Total energy savings and GHG emission reduction (%)

<table>
<thead>
<tr>
<th>Total energy savings and GHG emission reduction (%)</th>
<th>% Total Energy Savings</th>
<th>% GHG reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bldg A – Domestic Hot Water Heat (DHW) Pumps</td>
<td>18</td>
<td>27</td>
</tr>
<tr>
<td>Bldg B – Building Envelope Wall Installation, Windows &amp; Doors</td>
<td>28</td>
<td>38</td>
</tr>
<tr>
<td>Bldg C – Make Up Air Heat Pumps</td>
<td>27</td>
<td>58</td>
</tr>
<tr>
<td>Bldg D – Ductless Mini Split (DMS) Heat Pumps &amp; Electric DHW Heater</td>
<td>3</td>
<td>99</td>
</tr>
<tr>
<td>Bldg E – Make Up Air Hybrid NG/Heat Pump</td>
<td>30</td>
<td>58</td>
</tr>
<tr>
<td>Bldg F – Mini Split (MS) Wall mounted heat/Cool Unit</td>
<td>39</td>
<td>62</td>
</tr>
</tbody>
</table>
In all the buildings as shown in the Table 8 and Figure 5, energy savings are within the range of 3 to 39% depending on the DER type. It is important to note that I conducted my energy savings calculation using aggregated electricity and natural gas data. The use of disaggregated data may produce a slightly different set of results. In the case of GHG emissions reduction, percentages ranging from 27 to 99% were achieved. In the case of Building D, a 99% reduction in GHG could be explained by complete elimination of the natural gas use for space and water heating through electrification and the fact that BC’s electricity generation is predominantly hydro. It is important to note that the GHG reduction percentages achieved in the buildings are only related to the energy consumption in the building for space and water heating. GHG emissions from other aspects of the building lifecycle and (or) embodied carbon of the buildings were not considered.
It is worth mentioning that aside energy and GHG reduction benefits, BC Housing also reported significant non-energy benefits such as post-retrofit reduction in the NYMBISM (not-in-my back yard) phenomenon associated with social housing in many communities not only in BC but Canada wide. BC housing reported reduction in tenant turn over in retrofitted building, and greater acceptance of occupants of social housing within their communities. Given this greater acceptance benefit, one can anecdotally infer that, the mental health of those living in the BC social housing is positively impacted. I suggest a more detailed study on the non-energy benefits in the BC social housing.

4.2 Manitoba Analysis, Discussions and Interpretation

I collected electricity and natural gas data from Manitoba for a 6-story building in Minnedosa and an 11-story building in Winnipeg. Electricity and natural gas consumption data for the month of January for each year between 2010 and 2020 were extracted and analyzed. GHG emissions data were calculated using the electricity grid factor and natural gas combustion emission factor for Manitoba. It is important to note that I couldn’t find the electricity grid factor for Manitoba pre-2016 so I assumed that the grid factor pre-2016 is the same as the grid factor in 2016. Figure 6 shows the changes in electricity consumption pre- and post DER. According to Manitoba Housing the retrofit project in the Minnedosa building took place between 2014 and 2016. My analysis as shown in figure 6 indicates that over 20,000 kWh reduction in electricity consumption and over 40 Kg CO₂e was achieved post-retrofit. Figure 7 also shows a drop in the consumption of natural gas following the retrofit (Exterior Spray foam and dual-core reverse flow HRVs with 90+% efficiency). The drop in the consumption of natural gas consequently led to GHG emissions and cost reduction.
Figure 6: Electricity use and GHG emissions reduction in Manitoba's Minnedosa 6-story building in the month of January of each year.

Figure 7: Natural gas use, GHG emissions reduction and cost data in Manitoba's Minnedosa 6-story building in the month of January of each year.
As shown in Figure 8, analysis of the energy consumption data in the 11-story Winnipeg building pre- and post retrofit show similar pattern as the 6-story Minnedosa building even though the retrofit approaches for both building were slightly different. Exterior foam spray in Minnedosa versus interior spray in Winnipeg. In both cases a dual-core reverse flow heat recovery ventilation systems (HRV) with 90+% efficiency was installed. In Winnipeg, over 50,000kWh in electricity consumption reduction and over 150KgCO$_2$e of GHG emissions reduction was achieved.

![Energy Use Pre- and Post Retrofit](image)

**Figure 8**: Electricity consumption and GHG emissions reduction in the Winnipeg 11-story building in the month of January of each year.

The reduction in the consumption of electricity in both buildings because of the enhancements in the building envelope was unexpected given that similar enhancements in building B in BC did not impact the electricity consumption. However, it may be erroneous to compare buildings in Manitoba and BC as there are different factors that could be at play in the different locations. The reduction in electricity consumption in the buildings in Manitoba may be attributed to the installation of high efficiency dual-core reverse flow heat recovery ventilation systems. Further
investigation may still be required to fully understand why the building envelope retrofit approach impacted electricity consumption. It is possible that building occupants used electric heating systems in their units in January to provide extra heat and no longer required extra heating post-retrofit. If this is the case, then the impact of the building envelope retrofit on electricity consumption in the buildings in Manitoba could further be explained.

Figure 9: Cost of electricity in Minnedosa and Winnipeg buildings in the month of January of each year

The cost data for electricity consumption for both buildings in Manitoba was analyzed as shown in Figure 9. The cost of electricity dipped in 2017 in the Minnedosa building and in 2019 in the Winnipeg building because of low building occupancy and subsequently increased as the building gradually became occupied post-retrofit. Overall, the building retrofit had an impact on the cost of electricity consumption. This is reasonable. I expected the cost of electricity consumption to reduce as electricity consumption reduced.
Chapter 5: Conclusions, Limitations and Recommendations for Future

5.1 Conclusion

It is critical to strike a balance between the requirements for energy savings, GHG reduction and cost savings so that the gains made in one aspect will not erode the other. For example, you may electrify the whole building end-use system and achieve a very high GHG emission reduction from the energy use but end up increasing the cost of building operation because of the significant increase due to high consumption of electricity hence, high cost of electricity consumption.

5.2 Recommendation

For a deep energy retrofit to be meaningful in achieving the desired level of energy savings and reduction in the emission of CO2, and to provide the desired level of comfort and safety for occupants, I recommend executing the deep energy retrofit from a building-as-a-system perspective as shown in Figure 10. The building retrofit should take into account the balance between the requirements for GHG emission reduction, energy savings and cost reduction. It should also consider the appropriate technology mix, status and lifestyle of occupants, communication between trades on the retrofit project, the most appropriate sequence for doing the retrofit and most importantly, the non-energy benefits of DERs.
I also believe that the piecemeal approach to DERs is no longer sustainable, and the government alone does not have the resources to execute the urgently needed mass whole house deep energy retrofits in the social housing sector. However, it is believed by many that climate mitigation and adaptation is a collective responsibility, and it is more equitable to finance deep energy retrofits in social housing for low-income and vulnerable populations through taxes. Given that Canada and Canadian jurisdictions have carbon tax regimes, I recommend using a portion of carbon taxes to finance deep energy retrofits in social housing.

5.3 Limitations

Given the limited time to complete this project and report, it was not possible to obtain data from Manitoba that would allow an analysis of the different energy retrofit approaches completed in a range of buildings, in different locations, in Manitoba as was conducted for buildings in BC. An analysis of the non-energy benefits including a survey of occupant mental and physical health was not performed; however, this would be an excellent follow-up study for my capstone project.
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Tsenkova, S. (2013). *Retrofits for the future: Affordable housing and energy efficiency programs in Canada*. University of Calgary, Faculty of Environmental Design.

