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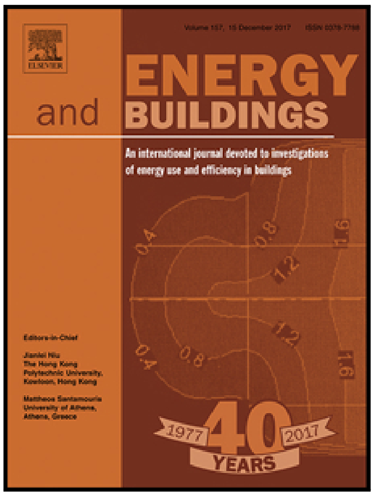

Building related energy poverty in developed countries — past, present, and future from a Canadian perspective

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Highlights

- In the past 15 years, household energy costs in Canada have risen at a much faster pace than real income, particularly in low-income households. Within-the-home energy poverty rates, as determined by various metrics, have followed suit.
- Low-income households across Canada consume the least amount of energy per year and per unit heated area. They also tend to live in smaller dwellings which require more energy per unit floor area.
- Low-income households tend to live in older, rented dwellings which are retrofitted less often than owner-occupied dwellings and are the least exposed to energy-saving technology.
- Other developed countries, particularly in Europe, have studied energy poverty and affordability across their populations and have used their results to analyse cases of freeloading and split-incentive and to optimize government subsidy programs.
- Energy efficiency rating systems for dwellings have been designed in some countries to help manage subsidies and determine patterns contributing to energy inefficiency.
- Energy rate increases across developed nations are part of a global trend which could be alleviated through sponsored retrofitting and income transfers.
- Several solutions can assist in reversing the increasing rates of energy poverty in Canada, including reinstating non-profit housing programs, providing on-site renewable energy generation and defining energy as a basic need.

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Keywords: Energy poverty, retrofits, energy efficiency, green construction, rental housing, built environment, heating energy, Canada.

1. Introduction

In his famous and ground-breaking paper on the hierarchy of human needs, Maslow argued that individuals cannot develop and actualize to their full potential unless all other needs located below in the hierarchy have been met [1]. Among other needs, the researcher placed shelter and environmental conditions at the core position of needs, as part of the physiological human need for homeostasis. These requirements are met in different ways across climates and cultures, according to the level of threat to physiology posed by exposure. Housing and energy affordability are therefore deeply related issues for large swaths of people around the world, who often need to balance thermal comfort with other necessities. Any sudden change to that balance could have the power to disrupt the living conditions of those households with the least capacity to absorb it.

Recent trends indicate that this balance is indeed being affected by persistent increases in both housing and energy costs resulting from various economic events. Also, in par with international climate change agreements, many countries are implementing taxes and policies aimed at reducing both greenhouse gas (GHG) emissions as well as overall energy consumption, which may be closely linked depending on fuel sources. Such is a worthwhile goal, but one which has the potential to further divide populations between the energy-poor and the energy-prosperous, with overall secondary effects on life outcomes.

The idea that unequal access to energy contributes to broader effects in the overall quality of life has been studied in some papers. In an overview of the energy sector, González-Eguino wrote that it will undergo three major “transformations”: through climate change, security of supply and energy poverty [2]. The author contends that that while the two former items have been thoroughly analyzed, energy poverty remains the topic that has been the least studied. In the paper, an overview of energy poverty is presented from the perspective of low- and high-income countries along with the challenges, investments and design philosophies that would be required to eradicate it.

While many studies regarding climate change and energy policy have originated from Canada, little research exists on their effects on Canadians, and particularly on lower-income segments of the population. This objective of this article is to approach the causes and effects of energy poverty in Canada and to propose remedies through analysis and lessons from other countries with similar issues.

2. Low-income housing and energy poverty in Canada

In Canada, one of the northernmost countries on Earth, warm shelters are significantly important to residents due to the country's unforgiving winter climate. Figure 1 indicates that heating energy represents over 60% of energy end-use in Canadian households, a proportion which has remained within the same range for decades [3]. Securing thermally insulated housing and the energy needed to keep the indoors at a livable temperature is an absolute necessity; beyond mere comfort, home heating in Canada is literally a matter of life and death.

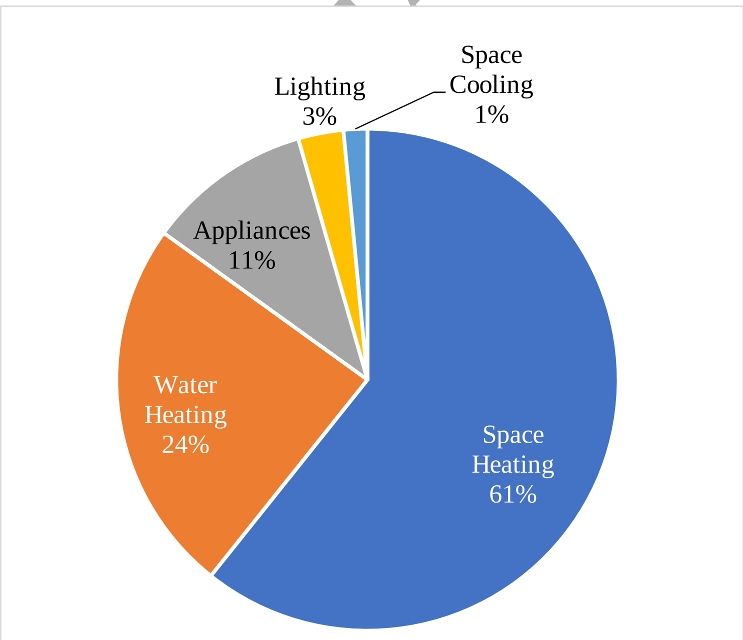


Figure 1 - Total Residential Energy Use by End-Use in Canada (2015) [3]

When adding the price of other necessities such as food (which in Canada must often be seasonally stored or imported) and transportation, the result is that a relatively high level of income is required for Canadian residents to meet their basic needs. While there is no official poverty line for the entire country, many studies have referred to Statistics Canada's *Low-Income Measure*, setting the poverty rate at 50% of the after-tax median Canadian household income with adjustments for household size [4]. In 2017, this measure was represented as an annual income of 22,133$ for a single person or 38,335$ for a family of three. By this metric, for 2015, a housing activism group declared that 13.9% of people in Canada (4.8 million people) lived in poverty and that 17.4% of children lived in low-income households [5]. The city of Windsor, Ontario, a traditional manufacturing hub which has seen steady economic decline in recent decades, had the highest rate of children living in low-income households among urban centres. Alberta, with high employment rates and median incomes, and Quebec, with high government benefits to families with children, had the lowest rates [6] among provinces.

According to the CMHC (Canada Mortgage and Housing Corporation), housing is considered "affordable" if it costs less than 30% of a household's before-tax income [7]. Housing which costs more than 30% can lead to a reduction in other household investments relating to food, education, health or transportation, lowering a person's relative position in society on every measure. Following changes in job markets, rapid increases in rental and home purchasing costs, Canadians have experienced rapid increases in levels of household debt as well as increases in demand for affordable housing [8]. Following a 225% increase in house prices between the years 2000 and 2017 [9] [10], a study led by a consortium of Canadian non-profit housing associations found that 40% of their tenants spent more than 30% of their household income on the cost of rent and utilities, with 20% spending more than half of their income, putting them at a risk of homelessness [11]. A 2016 survey found that in Ontario alone, 171 360 households (3.5% of the total) were on municipal waiting lists for subsidized housing [12]. Some studies showed that in many parts of the country, middle-class workers such as teachers, nurses, police officers, construction workers and other workers on reasonably good incomes have been shut out of the housing market entirely [13].

2.1. Residential Energy Costs and Poverty

Housing costs and energy costs are intrinsically linked because they combine to form the overall cost of maintaining a livable shelter. Yet, along with the growing share of Canadian household income directed towards obtaining housing, household energy costs have increased as well [14]. Figure 2 clearly shows a divergence between energy cost and personal disposable income increases in Canada which began in 2002, closed during the 2009 recession, and began again [15]. However, increases in energy costs are but one part of the energy affordability equation. Figure 3 shows that real-dollar (adjusted for inflation) income growth in Canada has not been distributed evenly across all quintiles of income over the period between 1999 and 2012 [16]. While the three middle quintiles have seen steady income gains in the vicinity of 15% and well over 20% for the top quintiles, Canadian families in the lower quintile have experienced income growth in the order of 5 to 8%.

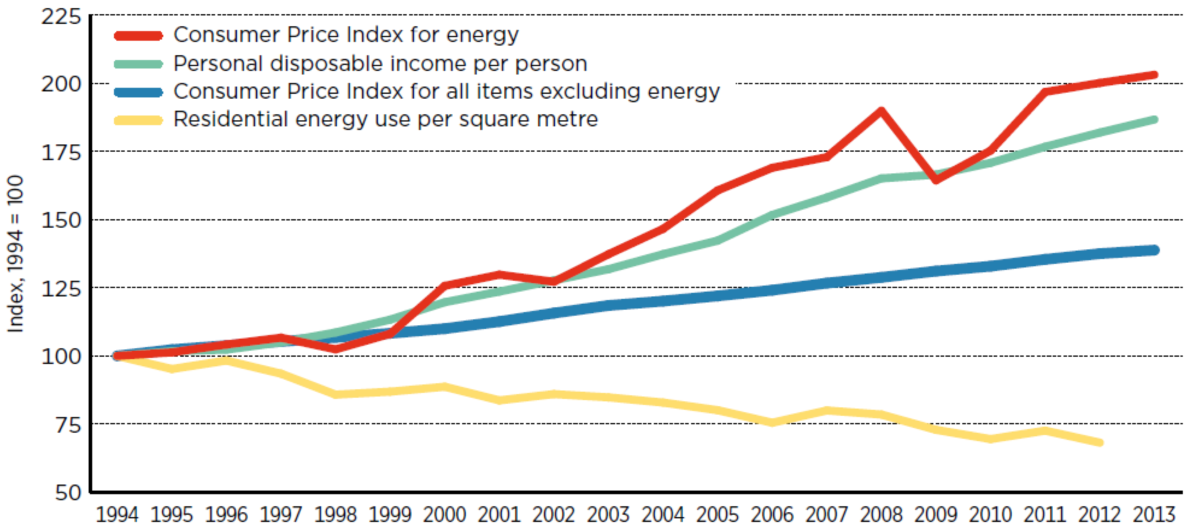


Figure 2 - Comparative growth in prices, income, and energy use, Canada, 1994–2013 [15]

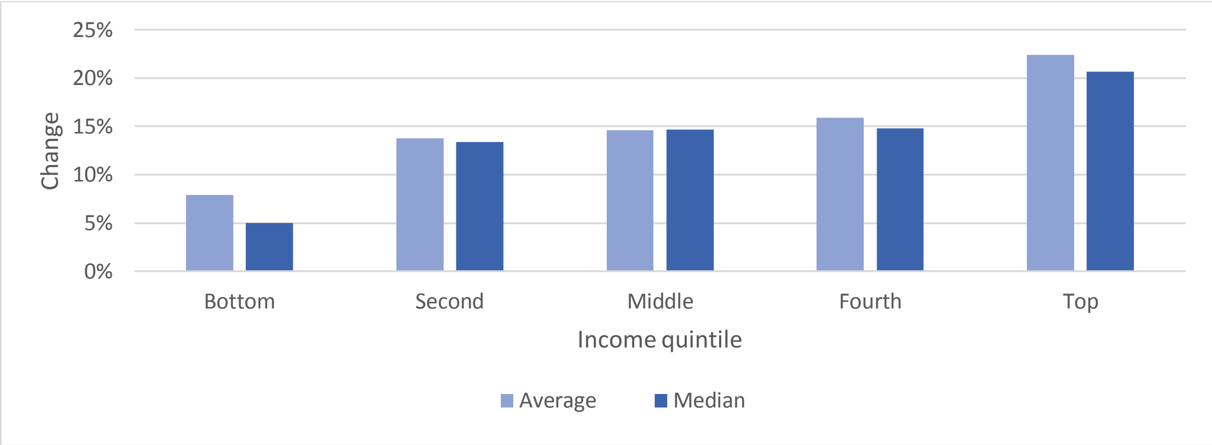


Figure 3 - Pre-tax family real income growth in Canada (1999 to 2012)

Increases in the affordability gap on this type of non-discretional spending has led to predictable results for the bottom quintiles of household income. In 2016, the Canada-based Fraser Institute published a study which claimed that roughly 8% of Canadians were spending 10% of their after-tax income on energy on their household, an increase from previous years shown on Figure 4 [15]. The study based itself on the fact that in 2013, 34% of Canadian households were earning poverty or near-poverty incomes and that the situation was deteriorating. In a similar study, some poverty elimination groups found that in 2011, 1 million households in Canada were affected by energy poverty, with direct effects on health and incidences of eviction and homelessness [17]. Interestingly, trends show increases in energy poverty rates in all income ranges, but most notably in the lower middle-income range of 27,000$ to 47 000$, with the rate of energy poverty reaching that of the lowest income echelon in 2013.

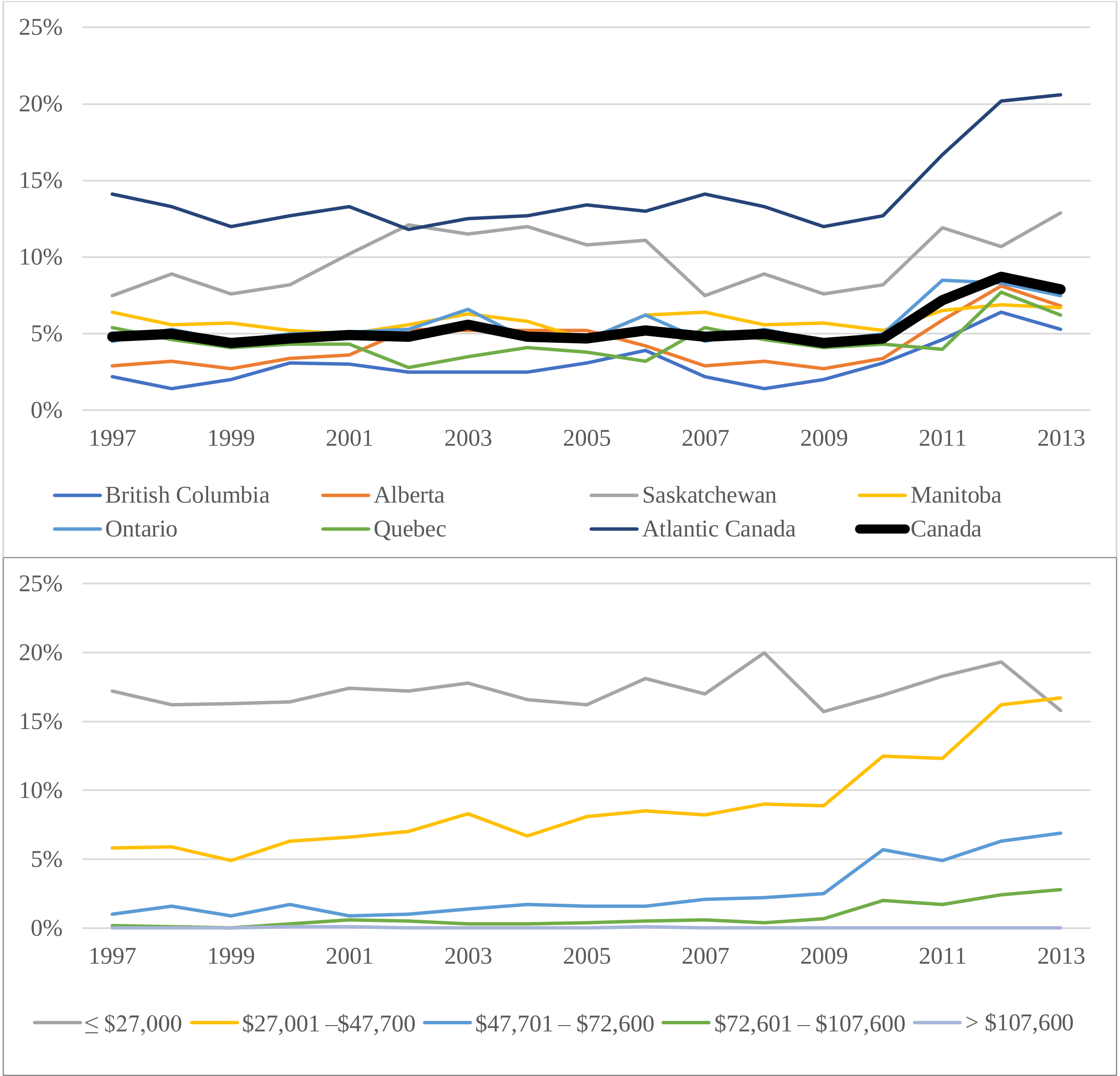


Figure 4 - Incidences of within-the-home energy poverty in Canada by region (a) and income (b) (1997 to 2013)

Economic theory dictates that all things being equal, when energy costs rise, housing prices should fall, but instead both have risen. Therefore, all other things being equal, if the cost of housing is inelastic, economic theory again predicts that household energy consumption will have to drop. True to form, data available from Statistics Canada and represented in Figure 5 shows a gradual reduction in overall household energy consumption across all income levels over the 2011 to 2015 period [18].

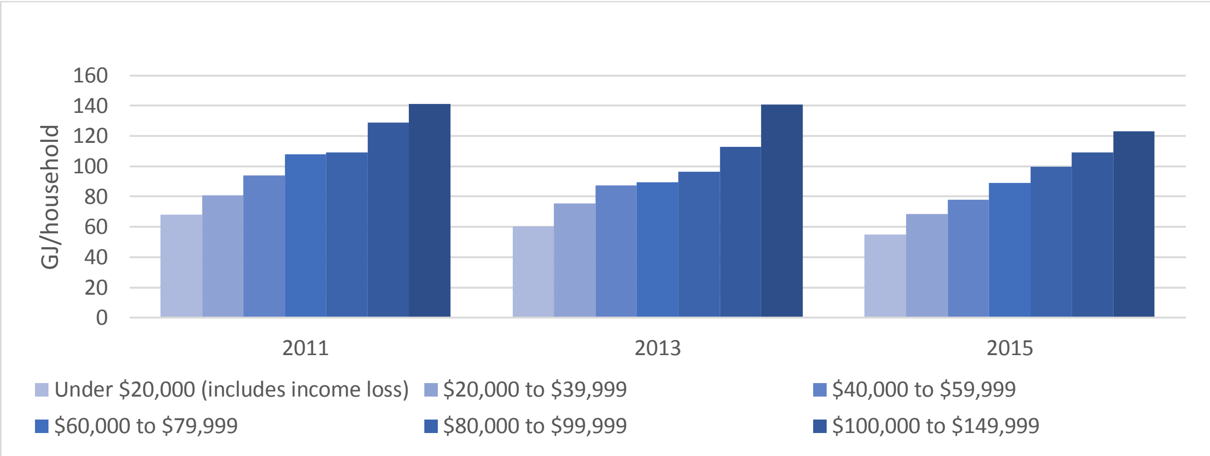


Figure 5 - Canadian household energy consumption, all types

In such an environment, energy cost increases may be understood as being socially regressive, as energy costs are based on flat rates which will disproportionally affect poorer households. Research has determined that expanding the definition of energy poverty into the Canadian housing context created new methods for measurement which set to define energy poverty as a relative problem instead of an absolute one [19]. Energy-poor households may resort to keeping their homes at lower temperatures in winter, leaving them to focus on various coping strategies to endure the cold [20]. In the summer, non-air-conditioned spaces can become deadly during heat waves for vulnerable segments of the population, as was in the case in Quebec in July 2018. Furthermore, high energy bills can lead to late or missed payments, leading to service disconnections (In 2015, 60,000 households were disconnected in the province of Ontario alone) and temporary losses of heating, lighting, hot water and refrigeration [21]. The ensuing reconnection fees and the loss of equalized bill payments have the effect of increasing precariousness.

Another problem relating to energy poverty in Canada is that those afflicted with it tend to live in older, lower-quality homes which may have been built with lower levels of insulation and higher rates of air infiltration, and which may not have been adequately maintained [19]. Although some owners are incentivized to renovate older homes in desirable neighbourhoods, data from Statistics Canada indicates a direct relationship, shown in Figure 6, between dwelling age and household energy use in every province

[18]. The situation is thus compounded by the fact that a larger amount of energy per floor area is required to attain livable home temperatures as compared to other homes.

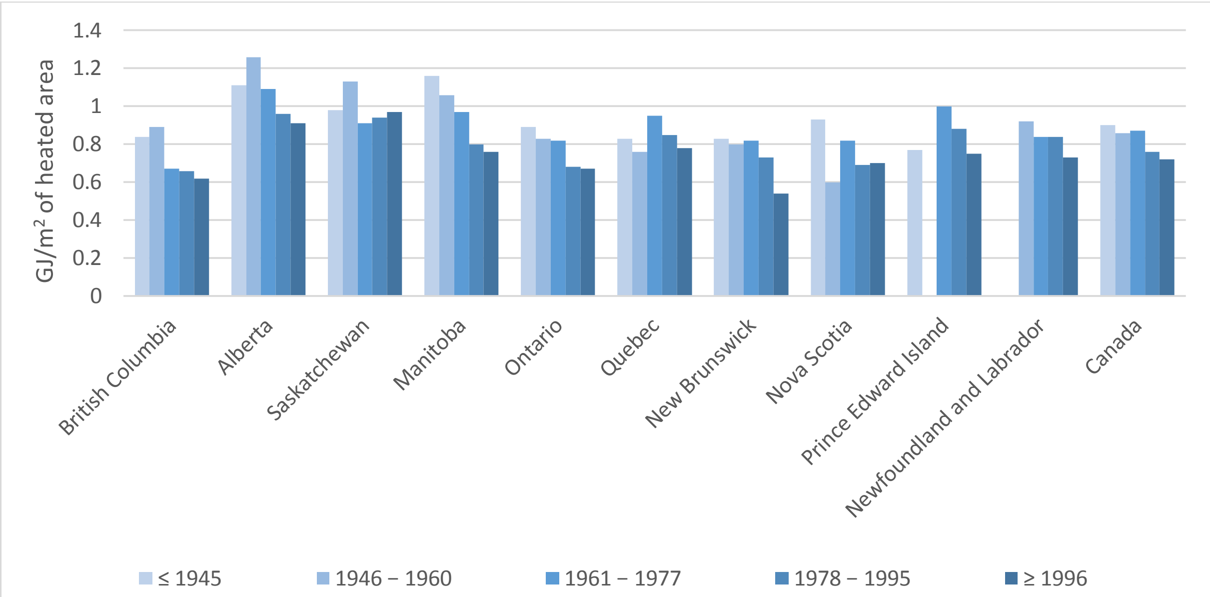
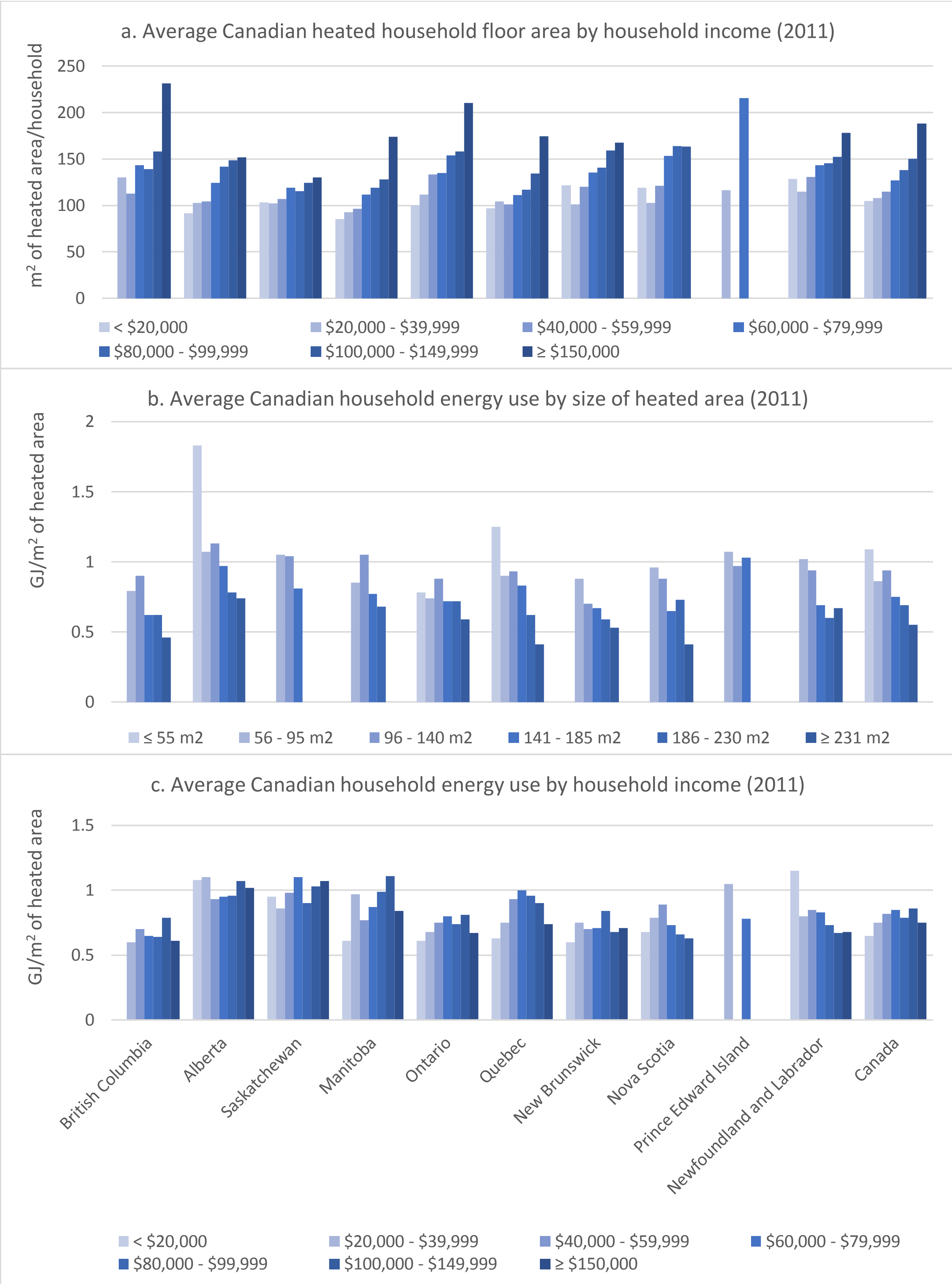


Figure 6 - Average household energy use by dwelling construction period (2011)

Results from a 2011 survey made by Statistics Canada and shown in Figure 7 indicate how energy is consumed across households and differentiated by floor area and income [18]. As the physical size of a home is an indicator of wealth, in every province in Canada there exists a direct relation between household income and the heated floor area of their dwelling, shown in (a). If the more affluent tend to live in larger, more expensive homes, a decreased wall-floor area ratio will translate to lower heating costs per unit floor area. The latter could also be benefitting from more sophisticated energy efficiency measures and control devices. This is confirmed in (b), where a clear inverse relationship is shown to exist between energy use per unit floor area and dwelling floor space across the country.

Logically, these trends should mean that households in the lowest income levels consume the most energy per unit floor area, however in most parts of Canada, this is not the case. While the exact distribution varies per province, an interesting parabolic relationship emerges in which the lowest and highest income levels both consume the least in-the-home energy per floor area while middle income levels consume the most. Reasons for this may vary, but it might easily demonstrate that lower income households could be voluntarily reducing their energy consumption as an attempt to reduce the amounts due on their energy bills by resorting to behaviours such as lowering room temperatures during the heating season.



a. Average Canadian heated household floor area by household income (2011)
m² of heated area/household
250
200
150
100
50
0
< $20,000
$20,000 - $39,999
$40,000 - $59,999
$60,000 - $79,999
$80,000 - $99,999
$100,000 - $149,999
≥ $150,000
b. Average Canadian household energy use by size of heated area (2011)
GJ/m² of heated area
2
1.5
1
0.5
0
≤ 55 m2
56 - 95 m2
96 - 140 m2
141 - 185 m2
186 - 230 m2
≥ 231 m2
c. Average Canadian household energy use by household income (2011)
GJ/m² of heated area
1.5
1
0.5
0
British Columbia
Alberta
Saskatchewan
Manitoba
Ontario
Quebec
New Brunswick
Nova Scotia
Prince Edward Island
Newfoundland and Labrador
Canada
< $20,000
$20,000 - $39,999
$40,000 - $59,999
$60,000 - $79,999
$80,000 - $99,999
$100,000 - $149,999
≥ $150,000

Figure 7

2.2. Heating Energy Costs

Energy policy and resource management are provincial responsibilities in Canada and may be run differently throughout the country. Most Canadians use either natural gas (50%) or electric baseboards (39%) as heating sources, with most of the remaining households relying on heating oil [18]. Variations in supply and prices across different energy sources over the past decade have meant that heating energy use has evolved differently across Canadian households. For homeowners using electricity as a heating fuel in some provinces, energy costs have increased considerably over the past decade. Over a 10-year span beginning in 2005, average Canadian electricity prices grew by 38%. In Ontario, Canada's leading province in terms of population and economic output, they grew by more than 50% over the same period [15]. After keeping in check with the rate of inflation for decades, the average residential price of electricity in Ontario doubled over the years 2009-2016 following public investments in renewable energy and the simultaneous closing of several coal and gas-fired plants as part of the Ontario Green Energy Act (GEA) of 2009.

As home and energy prices steadily rose throughout Ontario, median incomes barely budged [22]. With electricity bills rising to between $300 and $500 per month, many residents suffered a significant loss in quality of life, with the least affluent suddenly having to make choices between rent, heating, lighting and food. The situation forced the provincial government to implement a series of price-reduction measures in the province, which included time-of-day rate schemes to modify occupant behaviour and encourage strategic energy consumption. While in appearance these market instruments seem to promote efficiency and consumer choice, research has shown that dynamic grid tariffs are rather unfair as wealthier households often have more control over their schedules than others and can therefore benefit from reduced rates, further driving resource inequality [23].

While increases in electricity rates affect all ratepayers evenly, suburban and rural households in Canada tend to be more affected by electric rate increases due to their reliance on electric heating and cooking

[24]. The absence of district energy installations and steep exurban delivery charges could compound the effect.

High energy prices in a region contribute to energy poverty in other ways. Relatively high energy costs tend to make the area less attractive to business investment, and especially to energy-intensive industries such as resource extraction and manufacturing which often serve the broader economy in rural areas. Under this scenario, a hypothetical worker loses (or never obtains) a well-paying job in such an industry or a corollary one, and the financial situation which follows the loss of income is compounded by increases in household heating, cooking and lighting costs. These are deeply unsettling scenarios which have the potential to devastate entire communities through depression, substance abuse, and suicide [25] [26].

2.3. Retrofitting for energy efficiency

Low-income and socially-assisted households often do not own their homes, instead living in spaces that are rented out by landlords or non-profit organizations. Data from Statistics Canada shown on Figure 8 indicates that across Canada, significantly less energy per unit area is consumed in rented homes than in homes which are owner-occupied. It is likely that a larger proportions of rental units existing in apartment buildings with less outdoor envelope wall exposure, yet Figure 7(b) indicates that on average, the smallest households (likely apartments) consume more energy per unit area than larger ones.

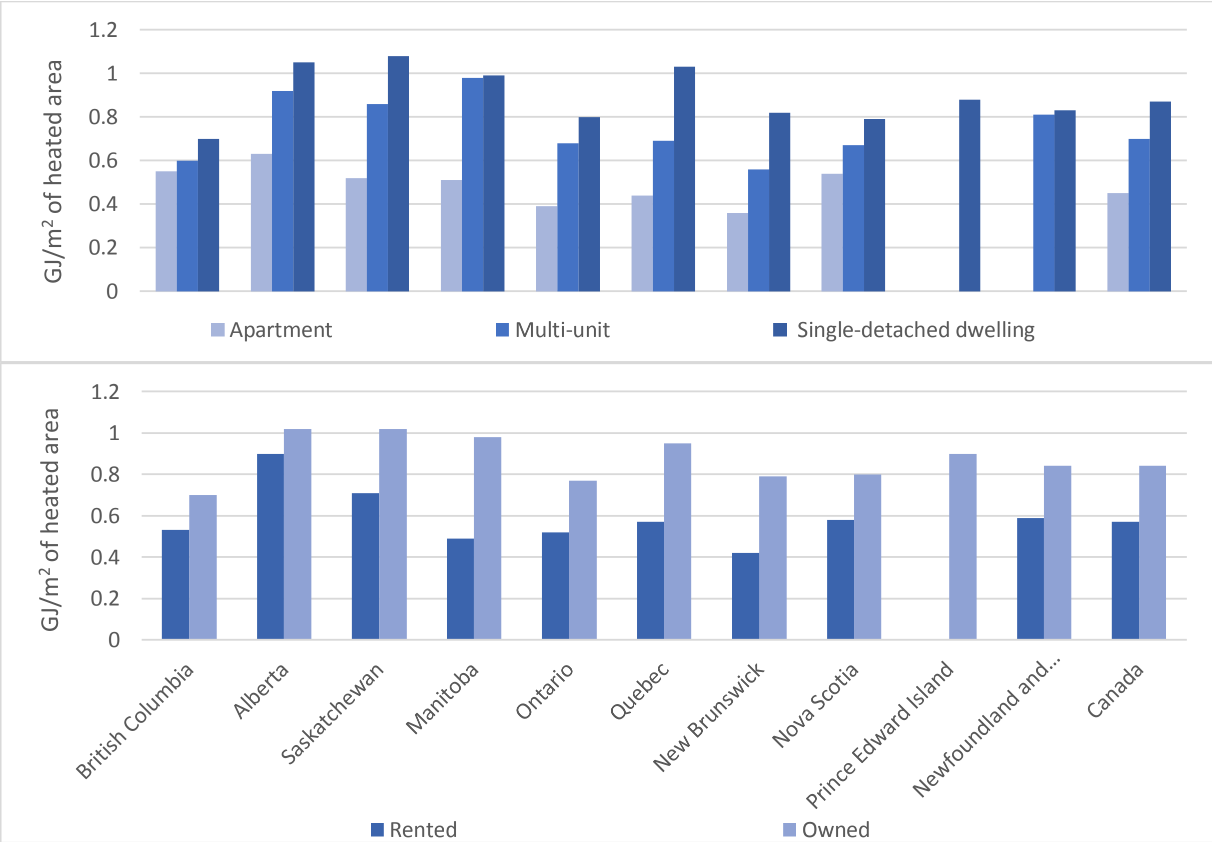


Figure 8 - Average household energy use by dwelling ownership type across different provinces (2011)

Technology improvements in households offer other pathways for improvements in energy efficiency and several studies have discussed their potential. One such study estimates that energy savings in the range of 21-26% can be obtained from replacing obsolete thermostats with programmable ones at the cost of a few hundred dollars [27]. Compact fluorescent or LED lighting also provide significant contributions to energy use reduction, especially following Canada's 2015 ban on incandescent light bulbs. However, such seemingly small investments could be enough to elude low-income households if finances are tight. Data compiled by Statistics Canada and represented in Figure 9 shows a clearly direct relationship between income, average heated floor area and the adoption of these two technologies in Canadian households [18]. It shows that wealthier people tend to live in larger households that are more likely to be equipped with energy-saving technology.

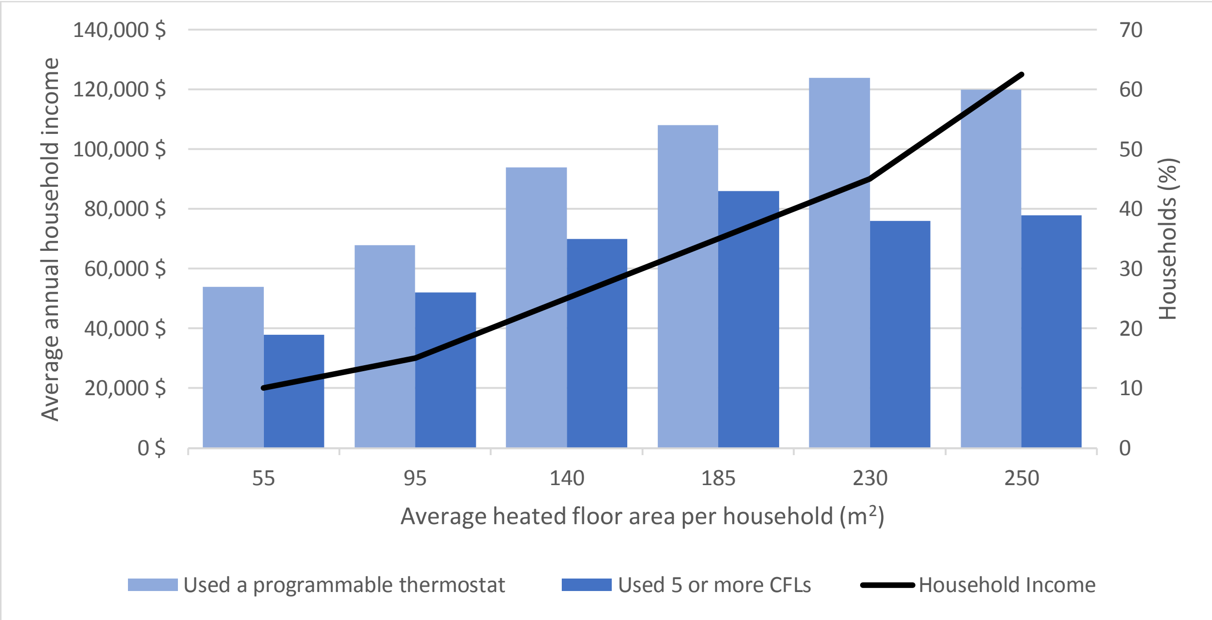


Figure 9 – Income and energy-saving device use in Canada by size of heated area (2011) [18]

Since low-income households in Canada tend to be positively associated with energy-inefficient dwellings, retrofitting programs which provide financial or professional assistance could benefit such households. The two programs later cited in section 3.3 are examples. However, few studies on retrofitting practices and outcomes for low-income housing in Canada have been carried out. Statistics Canada periodically provides overall data on retrofitting practices in provinces, which indicates a slightly greater focus on insulation and envelope elements in older buildings, as shown in Figure 10 [18]. However, this data is limited, as it only includes owner-occupied dwellings outside of apartment buildings.

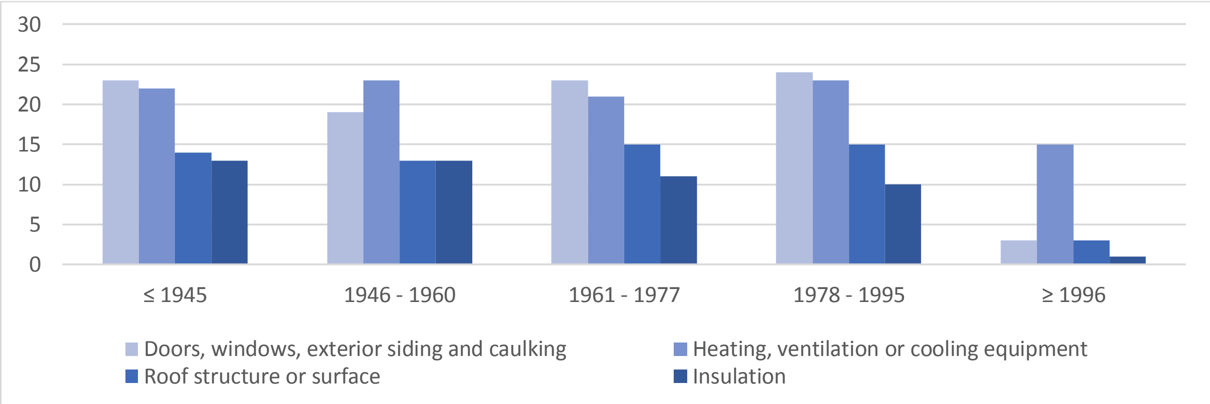


Figure 10 - Retrofitting practices in Canada, by dwelling construction period, 2008 to 2011 (%) [18]

Rezaei found that residential retrofitting was not often identified as a priority in energy poverty or climate change mitigation policies because research studies that were made in the United States and Canada were doubtful on the effectiveness and relatively high costs of such programs [19] [28]. One such economic study dating from 1993 found that, when relevant costs and behavior were accounted for, the effects of a $14.7 billion investment on mitigating residential demand were hardly worth the effort [29]. Such studies could now be obsolete. Since most of the research used for these analyses was carried out in the 1990's, evaluating programs that had been implemented a decade earlier, it is possible that current priorities, energy costs and technologies could make such programs feasible again.

3. Lessons from different countries

3.1. Retrofitting for energy efficiency in rental housing

While many cases of energy poverty can be linked to low-income housing, unique challenges exist as an obstacle to the implementation of energy efficient measures in this sector. In the Netherlands, Hope and Booth demonstrated that landlords are often not financially motivated to improve the energy efficiency of rented homes, especially low-income ones [30]. In their survey, only 2% of responding landlords qualified the energy efficiency of their dwellings with the highest rating of "excellent". Several deterrents were identified, such as high upfront costs, the lack of personal benefit, satisfied tenants and uncertainties relating to actual cost savings. Only 7% of those surveyed responded that improvements were deterred due to the lack of government subsidies. Many rental property owners either abstain from or delay making energy efficiency improvements in their dwellings because they do not live in the rented space and because their tenants are often responsible for paying their own energy bills.

Hough and White suggested that the private rental sector is disengaged from the issue of energy efficiency and that government initiatives, such as the United Kingdom's *Green Deal Initiative*, must be adapted to further engage landlords if energy efficiency or carbon reduction policy objectives are to be met since current policies offer little incentive for improvement [31]. The issue should continue to be of importance due to renewed interest in rental housing in Europe following the global housing crunch [32]. The sector has recently demonstrated its competitiveness, with positive effects on the overall economy. De Boer and Bitetti indicated that there exists a revival of the Private Rental Sector (PRS) in Germany and in other European countries [33]. If the trend continues, new construction could thus present itself as an opportunity for energy savings in the housing sector.

In line with their Dutch counterparts, Charlier et al. explored determinants of excessive energy consumption in French households and the effect current policies had on its reduction [34]. The researchers considered that households suffered from energy burden when their energy-income ratio was greater than 10% and when they tended to live in poorly insulated housing which they could not afford to improve. They studied programs in France which existed to subsidize renovation costs and increase energy efficiency and other programs which assisted low-income households in paying their energy bills. The researchers developed an elaborate and calibrated physical and economic simulation model to combine energy consumption, renovations costs, income and decisional scenarios based on incentives and costs. Through this model, predictions shown in Figure 11 were made for future energy consumption, GHG emissions and energy to income ratios per income quintile and type of building in the country until 2050. The results led to suggestions towards optimising policy tools, such as carbon taxes and subsidies.

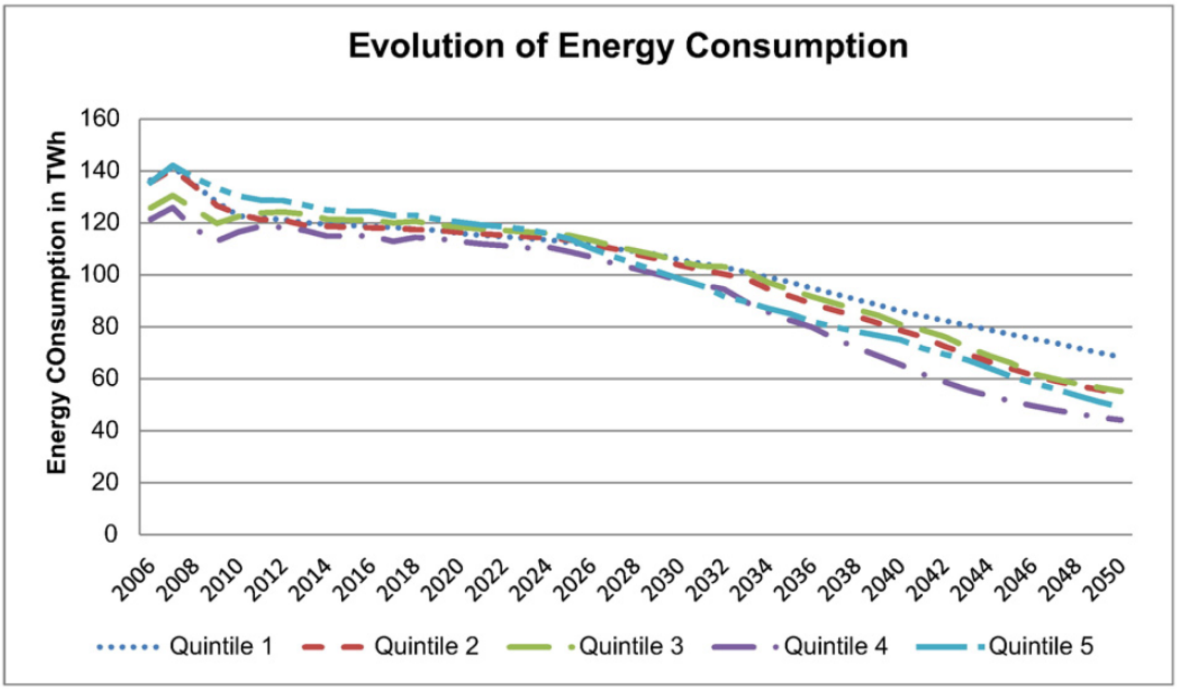


Figure 11 – Historical and predicted household energy consumption by quintile, France [34].

The researchers found that for past and future renovations, 75% of households would have made the energy-efficiency investments even in the absence of these programs and that a much greater proportion of these households were in the highest quintile than the lower quintile of income. The study revealed that many of the existing programs (such as tax credits and zero-interest loans for renovations) ended up increasing social disparities and that vouchers alone were not enough to reach the ambitious energy consumption and GHG reduction goals that France had set out to achieve. The study explored the idea that at a high public cost of approximately 800 € per eliminated ton of CO_2, the state should ultimately subsidize home retrofitting costs while making sure that the amounts are not absorbed by building renovation professionals. Similarly, in Estonia, Gros and Roth found that while retrofitting subsidy programs existed in the country as an incentive to save energy and achieve Europe 2020 goals, the distribution of funds ended up being very unequal (with economically low-performing regions obtaining less subsidies overall than high-performing ones) to the point where real estate values became the strongest predictor for grant distribution [35]. Again, they warned against misguided climate change policies that had the final effect of widening existing socio-economic differences instead of narrowing them [36].

In Australia, Wrigley and Crawford found that improvements in energy efficiency and achievements in climate change mitigation could be found through wide-scale improvements to the rental housing market, which had been slow to materialize compared to other housing sectors [37]. The paper identified which barriers prevented the adoption of policies, the overall effect of these barriers on low-income households, and policy levers that could be used to improve outcomes in this sector. In Sweden, with its more northern climate and elaborate social safety net, improving energy efficiency in housing remains a high priority in the country [38]. Like elsewhere, it was found that cost-based rents reduced the incentive to implement energy efficiency measures. However, researchers in the country have taken the subject a step further by stating that a virtuous energy-saving cycle would appear following rate rises from energy utilities that would result from a widespread push towards energy efficiency in housing. In contrast, a study done in the Irish context demonstrated that such measures could lead to opposite effects [39]. It was found that existing programs aimed at upgrades in energy efficiency in social or rental housing units in that country only reduced heating loads by a third of the expected margin. Tenants in improved homes were taking advantage of the upgrades to increase the internal temperature of their dwellings during the heating season. However, as discussed in section 2.2, it is reasonable to speculate that tenants could have been be prioritizing improving their own comfort over pursuing climate change objectives.

Some landlords are not motivated to improve their properties simply for reasons related to risk. In the U.K., many energy-poor adult tenants were found to have behaviours which had damaging effects on the buildings they inhabited [40]. A study in nearly 4000 social housing properties obtained through questionnaires revealed that energy-poor households were correlated with reduced ventilation usage, increased air contamination and poor hygrothermal conditions. These factors in turn increased the risk of mould contamination, posing a risk to the health of the occupants, including asthma in vulnerable populations. The researchers concluded that improvements in household energy efficiency in low-income housing should accompany effective control and communication strategies if they are to be successful.

3.2. Retrofitting for energy efficiency in non-profit housing

Energy poverty is one of the major issues faced by several member states within the European Union (EU). It has been found that 50 million European households had difficulties paying their utility bills on time, and that solving the issue throughout the union represented a major challenge [41]. To address the situation, some countries have taken different approaches to the issue of improving the low to average income level housing stock. Existing buildings in the EU represent 38% of the region's final energy consumption and 36% of its CO_2 emissions [42]. Another reason is that, due to its large population and strain on energy resources, the whole of Europe is highly invested in reducing its energetic and carbon footprint. Each country, however, is responsible for implementing its own measures with respect to international climate change agreements and may approach the issue differently.

One popular tool for relieving poverty has been for European governments to fund a variety of social housing programs which began during the postwar reconstruction period [43]. In Europe, non-profit housing is known to reunite three common elements: a mission of great interest, affordable housing for the low-income population and the realization of specific targets defined in terms of socio-economic status or vulnerability [42]. Research based on a multi-criteria sample found that structures resulting from social housing programs in Europe were indeed numerous and inhabited by below-average income households [44]. Even with these programs in place, assisted households were found to be economically vulnerable to high energy expenditures caused by several factors, including structural, economic, and behavioral factors.

Focusing on the important non-profit housing sector in the Netherlands and using a statistical model using data from a revolving fund to subsidize energy savings in buildings and from the Dutch national EPC (Energy Performance Coefficient) program discussed in section 3.3, Filippidou et al. noted that while some improvements in window and ventilation systems were routinely made with assistance from the program, most improvements could be described as “low-hanging fruit”, such as the replacement of heating systems and domestic hot water tanks that were either being phased out or were nearing their retirement date [42]. Most of the energy improvements done with the program resulted in small changes in energy efficiency and deep and major energy renovations in the non-profit housing sector were very rarely done. The latter was interpreted as an improvement of three *Energy Index* label steps or more and only represented between 0.6% to 0.9% of all renovations. Improvements to building envelopes were especially found to be lacking, making overall progress on the sectors’ energy efficiency rather modest, and rendering it impossible to reach ambitious national and international policy targets on schedule. In fact, in the last two years of the study period, it was found that nearly 94% of renovations in the non-profit rental housing sector did not lead to any label step increase.

Other similar programs have been successful. Several non-profit housing buildings in the United Kingdom, initially built on inadequate energy designs, were retrofitted with assistance from such programs, and post-construction research has shown that these improvements have led to both energy savings and positive impacts on thermal comfort for occupants. As shown in Figure 12, in one case, Calderón and Beltrán found that a retrofit which involved installing high-density mineral wool and new double-glazed windows reduced overall energy consumption by 27% [45].

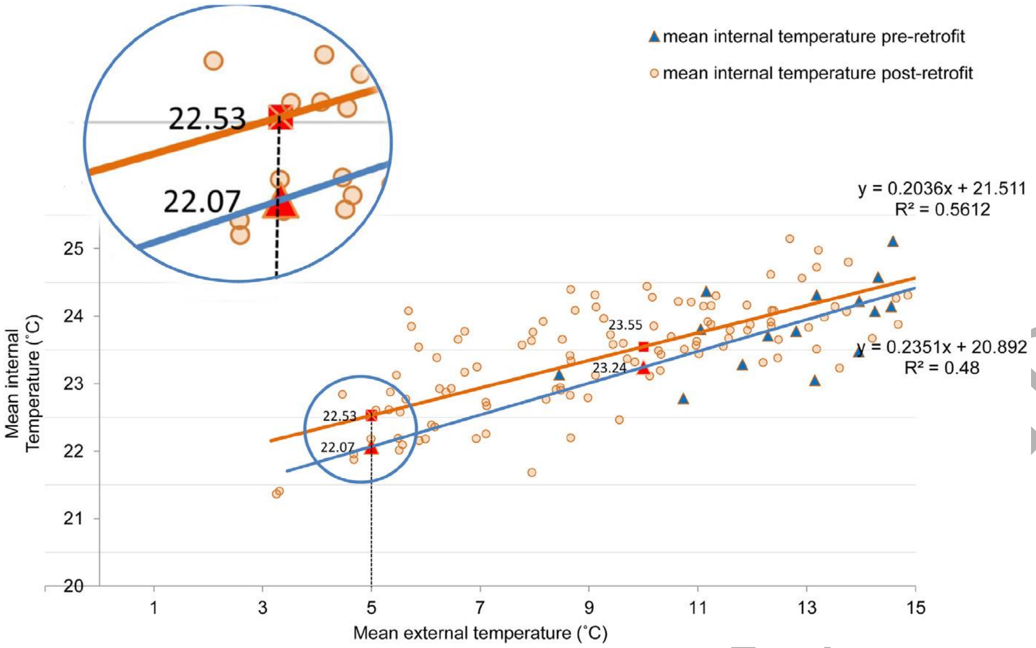


*Figure 12 – Standardised mean internal air temperature of the target building, at 5.0 °C external temperature. Pre- and post-retrofit (*n = 9*) in Newcastle upon Tyne, U.K [45].*

The researchers found that improving physical factors such as energy-efficiency improvements had a much greater effect on energy consumption than the positive change in behavioural factors which followed the retrofit, part of which had previously been affected by excess heat originating from corridor piping.

In Spain, households of lower socio-economic status living in assisted multi-family dwellings built between 1940 and 1980 were also found to be associated with inadequate heating systems and poor insulation [46]. Poorer households were more often associated with heating-restricting behaviours, window opening patterns and heating activation patterns [47]. To model dwelling occupant behaviour, a paper by Nicol and Humphreys was used to define an approach in which the natural tendency of occupants was to adapt to changing conditions in their environment [48]. As a result, ambient air temperatures in these households were much more often found to be at or below 18°C than in other households. It was found that behavioural and retrofitting measures as well as financial solutions could be applied in Spain's social housing stock which would mitigate these problems, arriving at savings of 55% of initial energy costs at a payback period of 1.5 years [49]. Cooling energy conditions in Spain were not analysed due to comfortable (under 28°C) summer temperatures in the region. Other energy issues in this region were related to the use of single room heaters and lack of central heating in some buildings [49].

Retrofitting programs and practices have also been deployed outside of Europe. In Mexico, an economic study was made to assess the costs and benefits resulting from a nationwide social housing program [50]. For all home types, very few dwellings were built for energy efficiency, and that absolutely no consideration for energy efficiency were made for social housing. It was found that retrofitting would be economically viable for 40% of all housing in Mexico and would reduce cases of abandonment. Similarly, in a study meant to find improvements to the Brazilian "My house, my life" program, a series of low-cost strategies could be used to improve energy efficiency in these homes during design [51]. These included the addition of insulation materials and other envelope components which were derived from the Passivhaus standard, materials with varying thermal mass and airtight window materials. Selective ventilation and infiltration, strategic shading and efficient lighting measures could also be implemented. It was found that the best performing envelopes could improve thermal comfort by as much as 97% but would cost 50% more than the original design. The most cost-effective improvements increased thermal comfort by 42%, yet only increased costs by 10%.

Some have proposed that, beyond providing energy-efficient housing for low-income residents, the Brazilian program could be entirely remade and put to even better use if it was geared towards reaching the country's climate change and energy efficiency objectives [52]. Others have determined that government-imposed restrictions affected energy efficiency in the Brazilian national housing program [53] and that this program could be made more flexible and expanded into collective spaces, enhancing energy-efficiency across cities. In another study, Kós et al. describe how this flexibility could be used to reconnect housed occupants to natural cycles through home automation, increasing overall comfort and well-being [54].

Dwelling overheating can also be an energy concern in northern countries. McLeod and Swainson found that overheating often occurred in high-density urban dwellings in London during heat waves due to from poorly integrated architectural and MEP designs, leading to thermal discomfort and ultimately increased air conditioning use [55]. Many households in social housing blocks in Spain have been found to be overly vulnerable to overheating due to the nature of their construction, significantly increasing cooling energy costs in a country where energy is relatively expensive [56]. Since building new homes is also expensive, many have explored the idea that the current social housing stock could be retrofitted to improve their performance and to remove the energy and thermal burdens from their inhabitants.

One advantage stemming from non-profit housing projects is that energy resources can be planned at the community level. As an example of how district energy projects can succeed, Sosa et al. found that beyond individual houses, bioclimatic design strategies for low-density social neighbourhood planning in Argentina had the effect of lowering temperatures in low-density social housing, which in turned reduced cooling energy consumption in the entire neighbourhood [57]. The group conducted multiple simulations to test layouts with differing street widths, layout grids, tree selections, street orientations and building material albedo, and found that savings of at least 21% of the summer cooling energy could be made. The study concluded that properly designed district strategies could thus have a large impact on household energy consumption.

3.3. Developing an energy-efficiency rating system for housing

While some Canadian government programs such as Quebec's *Programme Rénoclimat* or the now-defunct *Ontario Green Investment Fund* hired appraisers or used other tools to determine overall energy efficiency in homes, no standard metric or guideline seems to exist to rate dwellings in Canada [58] [59]. For this reason, owners or tenants might not even be aware of the level of efficiency or potential for improvement in their dwellings.

By comparison, in the Netherlands, many researchers have conducted studies into matters of energy efficiency for housing, and some have focused on non-profit social housing occupied by lower-income households. At 1.5 million dwellings mostly built before the 1970's, or 31% of the total housing stock, non-profit housing has a clear impact on the overall housing market [60]. They point out to a measure known as the *Energy Index* (*EI*) on which homes are rated based on their mean actual primary energy consumption with corrections applied on floor area so not to penalize larger dwellings.

Table 1 – Energy labels based on EI ratings for dwellings, Netherlands.

Energy Label	Energy Index (EI)	Mean actual primary energy consumption (kWh/m^2/year)
A (A+, A++)	<1.05	138.48
B	1.06–1.3	162.08
C	1.31–1.6	174.27
D	1.61–2.0	195.60
E	2.01–2.4	211.55
F	2.41–2.9	223.83
G	>2.9	232.10

Where, until the equation was changed to a point-based system in 2015,

$$EI = \frac{Q_{total}}{(155\ A_{floor} + 106\ A_{loss} + 9560)} \quad \left(\frac{MJ}{m^2 \cdot yr}\right) \tag{1}$$

$$Q_{total} = (Q_{spaceheating} + Q_{waterheating} + Q_{aux.energy} + Q_{lighting}) - (Q_{pv} - Q_{cogeneration}) \tag{2}$$

The use of equation (2) to quantify household energy means that the *EI* for dwellings for which renewable on-site energy production exists may approach zero or even be negative. A_{floor} refers to the total heated area in the home, and A_{loss} refers to non-heated areas. The labels have the dual function of informing households and owners of the thermal quality of their dwellings and as an incentive for retrofitting by linking amounts from national subsidy programs with changes in *EI* levels.

Many non-profit housing associations participated in such programs. While energy indices in the non-profit housing stock improved by one label step, or a mean value 4% over the years 2010 to 2013, the researchers found that the rate of improvement would not attain 2020 energy efficiency targets in the Netherlands. Energy efficiency in the non-profit housing sector remained low in comparison to the rest of the housing stock. Therefore, in 2016, the Dutch federal government changed its guidelines so that funding would only be provided to housing associations if energy labels were increased by at least three levels following a retrofit. To monitor the effect of this program, AEDES, a group representing housing associations, created a database from voluntary inputs for 60% of the non-profit housing stock, which included values for overall thermal transmittance (U) and wall element thermal resistance (R_C) to calculate the *EI* for every home. The database also contained information about water heaters, gas and electric boilers, heat pumps, ventilation systems, windows and district heating systems to make calculations, establish statistics and eventually direct policymakers towards priorities.

3.4. Identifying energy consumption patterns

In their paper on housing governance in Europe, Visscher et al. argued that beyond broad directives, strict and supportive policies were required if energy- and carbon-neutrality was to be achieved in the overall housing stock, as current governance instruments were deemed ineffective in their impact on actual energy consumption and GHG reductions [61]. They proposed a radical rethink of the entire regulatory system and deep engagement with occupant practices and behaviours if Europe's ambitious energy policy objectives were to be achieved. In fact, in the Netherlands, Boerenfijn et al. found that beyond architectural measures, energy efficiency in social housing for older adults could be highly affected by behaviour through several case studies from interventions in housing which included the use of "smart" technology and feedback systems [62]. Others proposed confronting the situation by intervening with an optimization tool based on a methodological assessment method and models relying on variables which are known to affect energy consumption [44] [63]. Energy poverty rates in low-income households can also be reduced by modifying certain behaviors through communication, incentives or control measures. Even some energy-saving practices from the past can again be implemented through automation. For example, a century ago in Sweden, households closed entire rooms in the winter to conserve energy.

Today's "smart" occupancy detection and prediction devices could allow households to reproduce similar behaviours.

Proper decision-making on the issue may require large samples of data for analysis. Each specific climate, energy source, culture, population density and other factors lead to differences in energy consumption. Data on energy consumption and behavioral parameters in individual homes and buildings are therefore crucial to understanding which patterns drive energy issues in households. Such an analysis was completed by Kuo et al [64]. The researchers developed an extensive model which relied on machine learning and big data mining to correlate and analyze overall consumption patterns in 1052 chain convenience stores in Taiwan. The study found that the stores had an average *Energy Usage Intensity* (EUI) factor, or yearly energy consumption per floor area, of 1501 kWh/(m^2·yr.), a much higher number than the average EUI factor for other types of businesses in the country. Each EUI factor from every convenience store could be plotted against equipment and weather variables, as shown on Figure 13. Lighting and refrigeration were found to be the main drivers of energy consumption, which could be reduced by using more intelligent configurations on a store- or sector-wide scale. The researchers proposed that their results could be used to assist planners and decision-makers in devising policies aimed at reducing overall energy consumption and carbon emissions in the country.

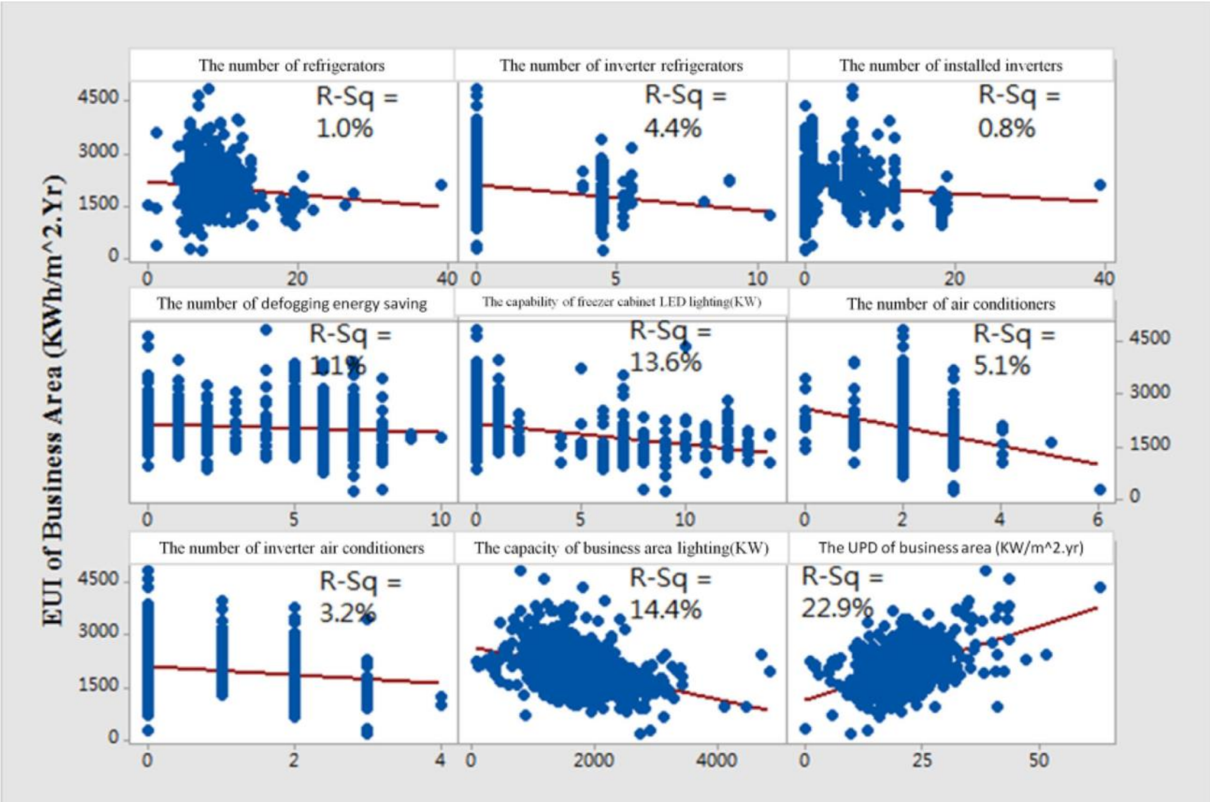


Figure 13 - Scatterplots of EUI and convenience store business equipment in Taiwan [64].

It is noteworthy to mention that while such data could be collected and analyzed anywhere, it may be difficult to achieve if privacy laws or corporate or government ownership prevent researchers from accessing base consumption data, as legislation on the issue varies in each jurisdiction.

3.5. Income transfers

While many countries are tempted to define energy poverty as an issue regarding the state of infrastructure or in terms of supply and demand, others view energy poverty as a subset of general poverty. In France, the *Observatoire National de la Précarité Energétique* (OPNE), which by virtue of its title monitors energy poverty in the country, has long defined household energy costs as part of the modern cost of living. With the rise of energy prices following market liberalization following the 2008 financial crisis, it began to view energy poverty as a problem in its own right [65]. In addition to measures seeking to improve energy efficiency, the French government has implemented policies aimed at increasing affordability such as social tariffs for low-income households, debt reduction and other government-funded benefits.

In France, Devalière and Tessier determined that 40% of eligible households (those in the first decile of income) are certain to obtain government subsidies as they are considered having “very low incomes” [66]. Other criteria also allow the bottom 30% of households on the income scale that are spending over 10% of their income to be eligible. The authors contend that the country’s complex formulation prevents half of all eligible households from receiving subsidies, and that formulating effective policies can be quite challenging.

Other authors have also argued that today’s notions of energy poverty are but symptoms of the emergence of a liberalized energy sector in both developed and developing nations. For example, post-communist central European nations have endured a dramatic increase in the prevalence of energy poverty following the rapid liberalization of the energy sector and the elimination of massive government energy subsidies [67]. A culture of viewing energy as a “freely available good rather than a service associated with a unit price” had taken hold, a welcome trait in an infrastructure environment that was generally characterized by poor building energy efficiency.

Chester and Morris have argued that the restructuring of the electricity sector in parts of Europe has led to electricity rates rising by 100% between 2000 and 2010, which has led to deprivation and social exclusion of an estimated 150 million people [68]. In their country, Australia, deregulation has led to energy rates increasing by an average of 80% within the 5 years leading up to 2012. These findings are in line with the results of a wave of deregulation which took place throughout the developed world in the last decades. These changes which were meant to deliver lower consumer prices through market efficiencies; instead, electricity rates far exceeded wage movements, as shown in Figure 14. In fact, rates have been rising so rapidly that in many cases governments have been forced to legislate artificial price caps on electricity.

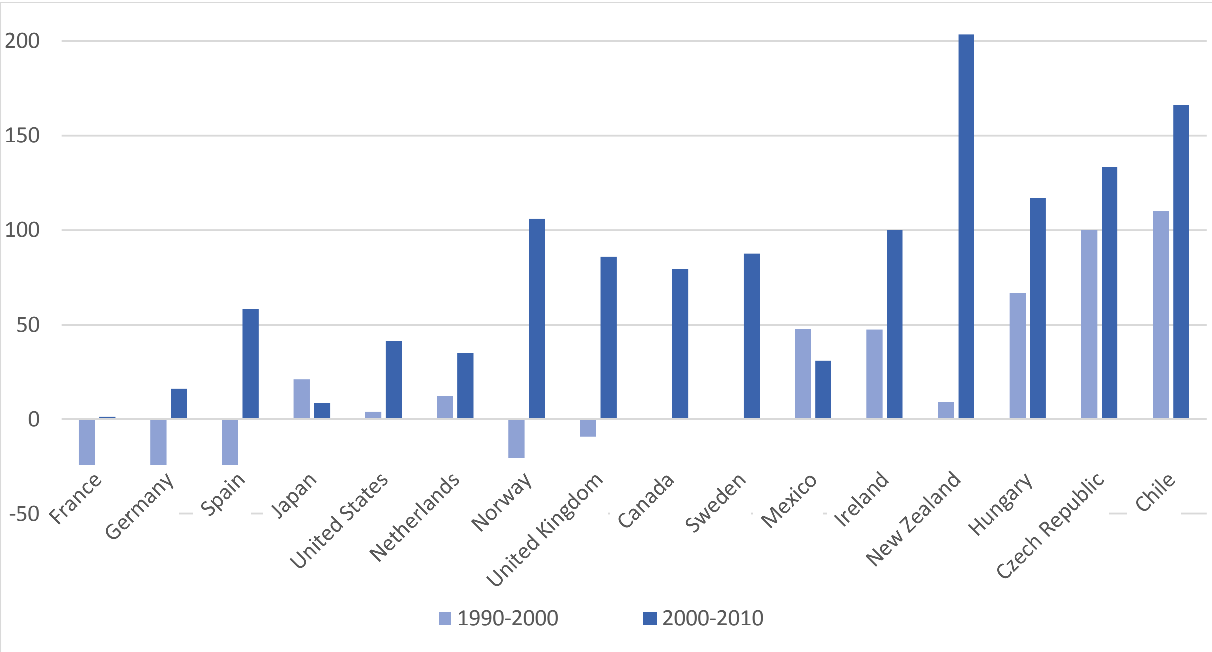


Figure 14 - Nominal changes in household electricity prices for selected countries, 1990-2010 (%) [68]

The consequences stemming from the rate increase on the 3.5 million Australian households in the two lowest income quintiles have not been well documented, but the authors point to other studies which have demonstrated misery and discomfort, reduced health, poorer diets, longer absences from school and work, and worsened life and educational outcomes [69]. As with other countries, the Australian government requires utilities to provide "hardship programs" to low-income households, such as payment arrangements and reduced tariffs. The government also provides direct subsidies to such households. However, the researchers contend that these measures are so tightly targeted that they fail to encompass all households experiencing energy poverty.

While economic theory boasts that rising rates should motivate all households to modify their behavior or to renovate their housing (or at least demand it from landlords), it is possible that rates have risen so rapidly in comparison to base wages that lower-income households have been left with little chance to adapt. One of the main ideological drivers on the debate is whether energy can be qualified as a basic human need, the ones located at the bottom of Maslow's pyramid, in the modern world. Some argue that income transfers do nothing to eradicate poverty and that real progress will only be made by increasing the human capital of the economically disadvantaged, while others contend that economic growth itself increases income inequality and therefore drives energy resource inequality [70].

4. Recommendations for Canada

4.1. Non-profit housing programs

Governments at the municipal, provincial and federal levels in Canada must be encouraged to find solutions to alleviate housing and energy poverty, as recent experience has shown that the issue is of enough importance to decide elections and fuel the type of electoral anger that can cancel renewable energy projects and efficiency programs. One method of doing so is through the reintegration of non-profit housing structures built with modern amenities. Within these programs, government-regulated housing associations becomes involved in providing housing to low-income households by charging rents which are situated below market prices.

Such programs were popular in Canada in the 20th century. Canadian postwar migration towards urban centres created a situation in which rapid housing development was required and nearby farmland or forests were converted for middle-class residential use. To counter the lack of affordable housing, many public housing projects were approved by provinces, territories and municipalities between 1950 and 1985 in which low-income households paid a rental price that was determined as a function of their yearly income [7]. Other non-profit or co-operative housing programs were launched in the years up to the early 1990s alongside programs which assisted First Nations households and several government-run rent supplement programs were launched to aid low-income renters. After running for many years, most of these programs were ended in a series of federal cutbacks between 1985 and 1995 and few of them remain today [71] [72]. This approach has recently been revisited in various parts of the world, and while numerous challenges and difficulties have presented themselves, their experience remains a possible roadmap towards solving deteriorating energy poverty issues in some regions in Canada. Non-profit community housing programs are attractive because the financial burdens preventing lower-income households from accessing property and implementing energy efficiency measures are distributed over several households who then collectively reap the benefits.

While generalized energy efficiency retrofitting programs for the housing stock are available in Canada, little is known about the existence of the type of research activities discussed in Section 3. Due to the existence of similar issues regarding energy poverty and supply and as a signatory to the United Nations Framework Convention on Climate Change, such research could shed light on the situation and assist the Canadian or provincial governments in reaching their goals towards improving energy efficiency, mitigating climate change, and eliminating energy poverty.

4.2. Renewable generation and energy efficiency

Improving the energy efficiency of Canada's low-income housing stock could have a direct, positive effect towards reducing the growing incidence of energy poverty in these households, which would lead to improved health and life outcomes. In her research, Rezaei proposed broad suggestions to reduce energy poverty in Canada and its impact on its residents' lives, such as the creation of programs that would make subsidized energy retrofits available to people in situations of energy poverty [19]. The researcher also suggested that winter disconnection moratoriums should be enacted across the country and that governments could focus on energy poverty when designing policies that raised energy prices, including carbon taxes, which could then be used to subsidize retrofits. Finally, she argued that energy policy and planning should be more open and deliberative to the population.

For new construction, in areas in Canada where electrical rates are high and are where trends show that they will remain so, affordable housing could be provided in well-insulated, purposely-built multi-unit buildings heated and cooled with a combination of renewables and centralized hydronic systems under modern energy-saving designs. Several researchers studied the possibility of using community-built housing to improve the thermal comfort of low-income households or other vulnerable populations such as seniors. Through interviews with designers and architects for extra-care housing, it was found that communal and under-floor heating and heated corridors, could lower energy consumption per user, but certain problems were found to prevail because thermal comfort needs in this population were highly diverse [73].

Well-designed renewable energy generation systems can contribute both to alleviating energy poverty and reaching climate change mitigation goals. Brownfield lands could be prime locations for renewable energy production, directed towards nearby social housing with the use of ground source heat pumps [74]. To complement this production, excess heating energy could be supplied by natural gas furnaces at the building or district level.

In recent years, natural gas (a low carbon-emitting fossil fuel) originating from shale gas fields in the United States have led to a 5-year low in production costs (less than 2$ per gigajoule in January 2018) and is forecasted to remain low for a long period [75]. Residential natural gas rates across Canada have also dropped, and in many areas, provincial law prevents distributors from making a profit off sales. In Ontario, natural gas rates in 2018 (which vary from 9¢/m^3 to 15¢/m^3 depending on location) were a quarter of what they were in 2006 [76]. While such thinking is controversial, natural gas can arguably become a stepping stone on the path towards vastly eliminating GHG emissions in the future.

Government-led investments in renewable energy and energy efficiency in residential areas are appealing, but they are also not guaranteed to come without controversy. The Fraser Institute published a report stating that the Ontario government had planned to spend billions of dollars for programs supporting renewable development, cycling and walking, carbon footprint reduction and improvements in energy efficiency in multi-tenant residential buildings [77]. They stated that while these policies would have improved the overall quality of life for some residents, they came at such an incredible cost that they would have delivered a definite blow to Ontario’s economic competitiveness. Immediate costs to ratepayers were such that a newly-elected government campaigned on cancelling the program, which was done immediately in July 2018.

4.3. The Quebec Model: Socially Mandated Energy

While it is tempting to look outside Canada for avenues and solutions to alleviating energy poverty, some ideas can be found within Canada itself. Ontario's eastern neighbour, Quebec, is second in Canada in terms of population and overall economic output. It's GDP per capita is lower by 18%, but at an overall rate of around 7¢/kWh, Quebec's residential, commercial and industrial electric rates are among the most affordable in North America, if not the most affordable. The favorable rate environment is a boon to energy-intensive industries such as aluminium, aerospace, manufacturing and mining, which attracts investment and employs hundreds of thousands of workers, thus allowing the province to collect taxes and subsidize its social programs. Low rates also allow residents to use electricity for space and water heating at an affordable (and predictable) cost. In 2017, it was estimated that electricity accounted for 67% of all residential energy consumption in Quebec, including space heating [78].

Quebec also deals with issues relating to energy poverty. A relatively large percentage of households are rented, and since energy for heating has been relatively inexpensive for decades, landlords have not felt the need to upgrade the legacy housing stock [79] [80] [81]. To make matters worse, Quebec, including the greater region of Montreal, has one of the lowest incomes per capita in Canada [82]. In 2014, 14.6% of households in Quebec were classified as low-income relative to the cost of living [83]. An important segment of households in the province of Quebec therefore rely on both inexpensive rents and electricity to secure housing and energy.

To understand why two bordering provinces with similar climates, hydroelectric resources, populations and economies within the same country differ so much in terms of energy affordability, it is important to examine the unique relationship which exists between Quebecers, Hydro-Québec, and the provincial government.

Hydro-Québec, the product of a series of hydroelectric plant nationalizations between 1944 and 1979, is completely owned by the provincial government, to which it pays annual dividends, and is the only entity which can legally sell electricity in Québec. It became an integral part of Québec's *Quiet Revolution* as part of a series of government-led changes meant to improve the standard of living of francophones in the province. Ever since, Quebecers have generally maintained a positive relationship with the utility, accepting that it is entirely run by government if it keeps rates affordable and consistent in accordance with the 1944 social pact on electricity, namely that "Hydro-Québec's rates must be uniform within Québec's territory as a whole; its rates must be set at the lowest levels compatible with sound financial management." [84]. While the utility will eventually disconnect unpaying customers, it is forbidden to do so during the winter heating season. Even with these restrictions, the utility is very profitable, posting a net income after taxes of 2,8 B$ in 2017 [85].

The province's monopoly on electricity affects costs in other parts of the energy spectrum. In Québec, where the provincial government investment arm also owns natural gas distributor Énergir, natural gas rates have been maintained to avoid direct competition with Hydro-Québec and to stabilize prices over time [86]. Hydro-Québec also has a counterintuitive interest in improving the energy efficiency of its client households, since it will allow the utility to control production and distribution costs and to export a greater amount of electricity to neighbouring jurisdictions at higher prices. Since governments are mandated with improving infrastructure and the lives of their constituents, and since the low cost of energy from Hydro-Québec does not motivate homeowners and landlords in the province to make energy improvements on their own, both entities have resorted to providing numerous incentives and subsidies to encourage the implementation of energy-saving measures. Therefore, in Quebec, it could be assumed that all stakeholders would have much to gain from the type of thorough energy analyses that have been discussed in this paper.

5. Conclusions

Energy poverty in 21st century Canada has been identified as a real issue by several academic sources and other organizations, and it is becoming increasingly clear that “the needs of low-income households in particular should always be a concern when energy policies are devised [87].” Case studies show that energy policies which exacerbate wealth differences between income segments are counterproductive and that free-riding diminishes the validity of a subsidy program. Recent examples throughout the world have clearly shown that a reasonable balance between comfort, construction costs and energy efficiency must be maintained for any social housing or retrofitting program to succeed. To find this balance, policymakers could use models which rely on broad and detailed information on the built environment and its specific yearly energy consumption.

Given the current energy challenges with regards to heating energy, resource use and GHG emission reduction policies, we believe that many Canadian provinces are ready for large-scale study and modelling of the energy-efficiency of their legacy residential housing stock, with special consideration to lower-income households. Unlike several countries in northern Europe with similar issues, no rating system, database or evaluation model seems to exist in the country, or at least have not been made public. We believe that such tools would be widely beneficial to both utility managers, researchers and policymakers, as they would help identify energy consumption patterns and provide them with models which would improve energy and infrastructure planning, financial resource analysis, energy poverty mitigation and the optimization of government programs designed to assist social and rental housing retrofitting measures.

References

[1] A. H. Maslow, "A Theory of Human Motivation," *Psychological Review,* vol. 50, pp. 370-396, 1943.

[2] M. González-Eguino, "Energy poverty: An overview," *Renewable and Sustainable Energy Reviews,* vol. 47, pp. 377-385, July 2015.

[3] Natural Resources Canada, "Energy Efficiency Trends Analysis Tables," Government of Canada, [Online]. Available: http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/analysis/tables.cfm. [Accessed 23 January 2019].

[4] Statistics Canada, "Annual Income Estimates for Census Families and Individuals (T1 Family File)," Minister of Industry, Ottawa, 2016.

[5] Citizens for Public Justice, "Poverty Trends 2017," Citizens for Public Justice, Ottawa, 2017.

[6] K. Hulse, "Housing Allowances and Private Renting in Liberal Welfare Regimes," *Housing, Theory and Society,* vol. 20, no. 1, pp. 28-42, 2003.

[7] Canada Mortgage and Housing Corporation, "About Affordable Housing in Canada," 31 March 2018. [Online]. Available: https://www.cmhc-schl.gc.ca/en/Developing-and-Renovating/Develop-New-Affordable-Housing/Programs-and-information/About-Affordable-Housing-in-Canada.

[8] D. Simone and A. Walks, "Immigration, Race, Mortgage Lending, and the Geography of Debt in Canada's Global Cities.," *Geoforum,* April 2017.

[9] A. J. Pollock, "Has Canada's housing bubble finally reached bursting point?," *Housing Finance International,* pp. 13-14, Autumn 2017.

[10] A. Iqbal and M. Vitner, "Did Monetary Policy Fuel the Housing Bubble?," *The Journal of Private Enterprise,* vol. 29, no. 1, pp. 1-24, 2013.

[11] BC Non-Profit Housing Association, "Canadian Rental Housing Index," 2016. [Online]. Available: http://www.rentalhousingindex.ca/en/.

[12] ONPHA, "2016 Waiting Lists Survey Report," Ontario Non-profit Housing Association, Toronto, 2016.

[13] M. Shapcott, "Federal affordable housing investments: Critical to national social and economic investment plans," Wellesley Institute, Toronto, 2012.

[14] A. Head and H. Lloyd-Ellis, "Has Canadian House Price Growth been Excessive?," *Canadian Journal of Economics,* vol. 49, no. 4, pp. 1367-1400, 23 December 2016.

[15] K. P. Green, T. Jackson, I. Herzog and M. Palacios, "Energy Costs and Canadian Households," Fraser Institute, Vancouver, 2016.

[16] S. Uppal and S. LaRochelle-Côté , "Changes in wealth across the income distribution, 1999 to 2012".*Insights on Canadian Society*.

[17] Guelph and Wellington Task Force for Poverty Elimination, "Energy Poverty," Poverty Task Force, Guelph, 2011.

[18] Statistics Canada, "Households and the Environment: Energy Use 2011," Minister of Industry, Ottawa, 2013.

[19] M. Rezaei, "Power to the People: Thinking (and rethinking) energy poverty in British Columbia, Canada," University of British Columbia, Vancouver, 2009.

[20] K.-M. Brunner, M. Spitzer and A. Christanell, "Fuel poverty. A case study of vulnerable households in Vienna/Austria," *Energy Policy,* vol. 49, pp. 53-59, October 2012.

[21] Ontario Energy Board, "2015 Yearbook of Electricity Distributors," Ontario Energy Board, Toronto, 2016.

[22] Statistics Canada, "Household income in Canada: Key results from the 2016 Census," Statistics Canada catalogue no. 11-001-X, Ottawa, 2017.

[23] S. Neuteleers, M. Mulder and F. Hindriks, "Assessing fairness of dynamic grid tariffs," *Energy Policy,* vol. 108, pp. 111-120, 2017.

[24] H. Karunathilake, K. Hewage and R. Sadiq, "Opportunities and challenges in energy demand reduction for Canadian residential sector: A review.," *Renewable and Sustainable Energy Reviews,* vol. 82, no. 3, pp. 2005-2016, 2017.

[25] J. Goldman-Hasbun, E. Nosova, K. DeBeck and L. Dahlby, "Food insufficiency is associated with depression among street-involved youth in a Canadian setting," *Public Health Nutrition,* vol. 22, no. 1, pp. 115-121, January 2019.

[26] V. A. Pear, W. R. Ponicki, A. Gaidus, K. M. Keyes, S. S. Martins, D. S. Fink, A. Rivera-Aguirre, P. J. Guenewald and M. Cerdá, "Urban-rural variation in the socioeconomic determinants of opioid overdose," *Drug and Alcohol Dependence,* vol. 195, no. 1, pp. 66-73, 2019.

[27] F. Nägele, T. Kasper and B. Girod, "Turning up the heat on obsolete thermostats: A simulation-based comparison of intelligent control approaches for residential heating systems.," *Renewable & Sustainable Energy Reviews,* vol. 75, pp. 1254-1268, August 2017.

[28] J. Kulick and D. S. Loughran, "Demand-side management and energy efficiency in the United

States," *The Energy Journal,* vol. 25, no. 1, pp. 19-44, January 2004.

[29] P. L. Joskow and D. P. Marron, "What does a negawatt really cost? Further thoughts and evidence.," *The Electricity Journal,* vol. 6, no. 6, p. 140, 1993.

[30] A. J. Hope and A. Booth, "Attitudes and behaviours of private sector landlords towards the energy efficiency of tenanted homes," *Energy Policy,* vol. 75, pp. 369-378, December 2014.

[31] D. Hough and E. White, "The Green Deal," UK House of Commons Library, London, 2014.

[32] P. Teresio and C. Whitehead, "Social housing in Europe: legacies, new trends and the crisis," *Critical Housing Analysis,* vol. 4, no. 1, pp. 1-10, 2017.

[33] R. de Boer and R. Bitetti, "A Revival of the Private Rental Sector of the Housing Market?: Lessons from Germany, Finland, the Czech Republic and the Netherlands," *OECD Economics Department Working Papers,* vol. 1170, 2014.

[34] D. Charlier, A. Risch and C. Salmon, "Analysis: Energy Burden Alleviation and Greenhouse Gas Emissions Reduction: Can We Reach Two Objectives With One Policy?," *Ecological Economics,* vol. 143, pp. 294-313, January 2018.

[35] D. Gros and F. Roth, "The Europe 2020 Strategy: Can it Maintain the EU's Competitiveness in the World?," Centre for European Policy Studies, Brussels, 2012.

[36] L. Lihtmaa, D. B. Hess and K. Leetmaa, "Intersection of the global climate agenda with regional development: Unequal distribution of energy efficiency-based renovation subsidies for apartment buildings.," *In Energy Policy,* vol. 119, pp. 327-338, August 2018.

[37] K. Wrigley and R. Crawford, "Identifying policy solutions for improving the energy efficiency of rental properties," *Energy Policy,* vol. 108, pp. 369-378, 2017.

[38] H. Lind, "Pricing principles and incentives for energy efficiency investments in multi-family rental housing: The case of Sweden," *Energy Policy,* vol. 49, pp. 528-530, 2012.

[39] B. Coyne, S. Lyons and D. McCoy, "The effects of home energy efficiency upgrades on social housing tenants: evidence from Ireland.," *Energy Efficiency,* pp. 1-24, 16 June 2018.

[40] R. Sharpe, C. Thornton, V. Nikolaou and N. Osborne, "Fuel poverty increases risk of mould contamination, regardless of adult risk perception & ventilation in social housing properties.," *Environment International,* vol. 79, pp. 115-129, 28 March 2015.

[41] R. Filčák and L. Živčič, "Energy poverty and multi-dimensional perspectives of social inequalities and policy challenges.," *International Issues & Slovak Foreign Policy Affairs,* vol. 26, no. 1/2, pp. 40-61, 2017.

[42] F. Filippidou, N. Nieboer and H. Visscher, "Are we moving fast enough? The energy renovation rate of the Dutch non-profit housing using the national energy labelling database.," *In Energy Policy,* vol. 109, pp. 488-498, October 2017.

[43] T. Poggio and C. Whitehead, "Social housing in Europe: legacies, new trends and the crisis," *Critical Housing Analysis,* vol. 4, no. 1, pp. 1-10, 2017.

[44] E. Llera-Sastresa, S. Scarpellini, P. Rivera-Torres, J. Aranda, I. Zabalza-Bribián and A. Aranda-Usón., "Energy Vulnerability Composite Index in Social Housing, from a Household Energy Poverty Perspective.," *Sustainability,* vol. 9, no. 5, p. 691, 2017.

[45] C. Calderón and M. R. Beltrán, "Effects of fabric retrofit insulation in a UK high-rise social housing building on temperature take-back.," *Energy & Buildings,* vol. 173, pp. 470-488, 2018.

[46] J. San Miguel-Bellod, P. González-Martínez and A. Sánchez-Ostiz, "The relationship between poverty and indoor temperatures in winter: Determinants of cold homes in social housing contexts

from the 40s–80s in Northern Spain.," *Energy & Buildings,* vol. 173, pp. 428-442., 15 August 2018.

[47] J. Terés-Zubiaga, K. Martín, A. Erkoreka and J. M. Sala, "Field assessment of thermal behaviour of social housing apartments in Bilbao, Northern Spain.," *Energy & Buildings,* vol. 67, pp. 118-135, December 2013.

[48] J. Nicol and M. Humphreys, "Adaptive thermal comfort and sustainable thermal standards for buildings.," *Energy and Buildings,* vol. 34, pp. 563-572, 2002.

[49] J. Aranda, I. Zabalza, A. Conserva and G. Millán., "Analysis of Energy Efficiency Measures and Retrofitting Solutions for Social Housing Buildings in Spain as a Way to Mitigate Energy Poverty.," *Sustainability,* vol. 9, no. 10, p. 1869, 2017.

[50] L. E. Merano-Gomez and A. E. Izquierdo, "Social housing retrofit: Improving energy efficiency and thermal comfort for the housing stock recovery in Mexico," *Energy Procedia,* vol. 121, pp. 41-48, 2017.

[51] R. Tubelo, L. Rodrigues, M. Gillott and J. C. G. Soares, "Cost-effective envelope optimisation for social housing in Brazil's moderate climate zones.," *Building and Environment,* vol. 133, pp. 213-227, 2018.

[52] M. A. Triana, R. Lamberts and P. Sassi, "Should we consider climate change for Brazilian social housing?Assessment of energy efficiency adaptation measures," *Energy and Buildings,* vol. 158, pp. 1379-1392, 2018.

[53] L. Mesquita and J. R. Kós, "Towards more resilient and energy efficient social housing in Brazil," *Energy Procedia,* vol. 121, pp. 65-70, 2017.

[54] J. R. Kós, M. Contatto and J. Miyamoto, "Nature as an extended interface to home automation systems," in *International Conference on Improving Residential Energy Efficiency,* Wollongong,

2017.

[55] R. McLeod and M. Swainson, "Chronic overheating in low carbon urban developments in a temperate climate.," *Renewable & Sustainable Energy Reviews,* vol. 74, pp. 201-220, July 2017.

[56] C. Sánchez-Guevara Sánchez, N. González and A. Hernández Aja, "Energy poverty methodology based on minimal thermal habitability conditions for low income housing in Spain.," *Energy & Buildings,* vol. 169, pp. 127-140, 15 June 2018.

[57] M. B. Sosa, E. N. Correa and M. A. Cantón, "Neighborhood designs for low-density social housing energy efficiency: Case study of an arid city in Argentina," *Energy & Buildings,* vol. 168, pp. 137-146, 2018.

[58] Transition Énergétique Québec, "Rénoclimat," Gouvernement du Québec, 2017. [Online]. Available: http://www.transitionenergetique.gouv.qc.ca/en/my-home/renoclimat/.

[59] Government of Ontario, "Green Investment Fund," Queen's Printer for Ontario, 4 February 2016. [Online]. Available: https://www.ontario.ca/page/green-investment-fund.

[60] F. Filippidou, N. Nieboer and H. Visscher, "Energy efficiency measures implemented in the Dutch non-profit housing sector.," *Energy & Buildings,* vol. 132, pp. 107-116, 15 November 2016.

[61] H. Visscher, F. Meijer, D. Majcen and L. Itard, "Improved governance for energy efficiency in housing.," *Building Research & Information,* vol. 44, no. 5/6, pp. 552-561, July-August 2016.

[62] P. Boerenfijn, J. K. Kazak, L. Schellen and J. van Hoof, "Review: A multi-case study of innovations in energy performance of social housing for older adults in the Netherlands.," *Energy & Buildings,* vol. 158, pp. 1762-1769, January 2018.

[63] J. Aranda, I. Zabalza, E. Llera-Sastresa, S. Scarpellini and A. Alcalde., "Building Energy Assessment

and Computer Simulation Applied to Social Housing in Spain.," *Buildings,* vol. 8, no. 1, p. 11, 2018.

[64] C.-F. J. Kuo, C.-H. Lin and M.-H. Lee, "Analyze the energy consumption characteristics and affecting factors of Taiwan's convenience stores-using the big data mining approach," *Energy & Buildings,* vol. 168, pp. 120-136, 1 June 2018.

[65] N. Kerr, R. Gillard and L. Middlemiss, "Politics, problematisation, and policy: a comparative analysis of energy poverty in England, Ireland and France," *Energy and Buildings,* 2018.

[66] I. Devalière and O. Tessier, "Les indicateurs de la précarité énergétique et l'impact de deux dispositifs nationaux sur le phénomène.," *Informations sociales,* vol. 184, no. 4, pp. 115-124, 2014.

[67] S. Bouzarovski and S. T. Herrero, "Geographies of injustice: the socio-spatial determinants of energy poverty in Poland, the Czech Republic and Hungary," *Post-Communist Economies,* vol. 29, no. 1, pp. 27-50, 2017.

[68] L. Chester and A. Morris, "A new form of energy poverty is the hallmark of liberalised electricity sectors.," *Australian Journal of Social Issues,* vol. 46, no. 4, pp. 435-459, 2011.

[69] N. Sharma, "It doesn't happen here; the reality of child poverty in the UK," Barnardo's, Essex, 2007.

[70] D. J. Besharov and D. M. Call, "Income Transfers Alone Won't Eradicate Poverty.," *Policy Studies Journal,* vol. 37, no. 4, pp. 599-631, 2009.

[71] M. G. Cohen, J. Morrison and D. Smith, "Dismantling Social Welfare: Chronology of federal govt. cutbacks, 1985-1995," *CCPA Monitor,* pp. 9-12, November 1995.

[72] Karsh, Fern;, "A Comparison of Canadian and American Welfare Reforms and Their Effects on Poverty After 1990," *Western Undergraduate Economics Review,* pp. 45-53, March 2009.

[73] A. Lewis, "Designing for an imagined user: Provision for thermal comfort in energy-efficient extra-care housing.," *In Energy Policy,* vol. 84, pp. 204-212, September 2015.

[74] R. Donaldson and R. Lord, "Can brownfield land be reused for ground source heating to alleviate fuel poverty?.," *Renewable Energy,* vol. 116, pp. 344-355, February 2018.

[75] BMI Research, "Canada Oil & Gas Report Q2 2018," Business Monitor International, London, 2018.

[76] Ontario Energy Board, "Historical natural gas rates," 2018. [Online]. Available: https://www.oeb.ca/rates-and-your-bill/natural-gas-rates/historical-natural-gas-rates.

[77] K. P. Green and T. Jackson, "Climate change plan another blow to Ontario's competitiveness and consumers," 25 June 2016. [Online]. Available: https://www.fraserinstitute.org/article/climate-change-plan-another-blow-to-ontarios-competitiveness-and-consumers.

[78] J. Whitmore and P.-O. Pineau, "État de l'Énergie au Québec," Chaire de gestion du secteur de l'énergie, HEC Montréal, Montreal, 2018.

[79] R. Fischler, L. Wiginton and S. Kraemer, "A Place to Stand on Your Own Two Feet: Th e Role of Community Housing in Immigrant Integration in Montréal, Quebec," *Canadian Journal of Urban Research,* vol. 26, no. 2, pp. 15-32, 2017.

[80] M. H. Choko, "Le «boom» des immeubles d'appartements à Montréal de 1921 à 1951," *Urban History Review,* vol. 23, no. 1, pp. 3-18, November 1994.

[81] A. Germain, "A closer look at Montréal: is the housing situation for immigrants becoming more precarious?," *The Canadian Geographer,* vol. 53, no. 3, pp. 340-344, 2009.

[82] The Conference Board of Canada, "Metropolitan Outlook 1: Economic Insights Into 13 Canadian Metropolitan Economies," The Conference Board of Canada, Ottawa, 2017.

[83] Transition Énergétique Québec, "Bâtiment Résidentiel," Gouvernement du Québec, Québec, 2018.

[84] G. Lafond, "Hydro-Québec : louve ou vache à lait," in *Hydro-Québec : autres temps, autres défis*, Sainte-Foy, Presses de l'Université du Québec, 1995, p. 293.

[85] Hydro-Québec, "Annual Report 2017," Hydro-Québec, Montreal, 2018.

[86] Énergir, s.e.c, "Calculs mensuels du prix des services de fourniture et du SPEDE," Régie de l'énergie du Québec, Montreal, 2018.

[87] K. P. Green, T. Jackson and I. Herzog, "Higher energy prices fuel energy poverty in Canada—especially in Ontario," *National Newswatch*, 18 March 2016.