Assessing the Prevalence of Energy Hardship in Canada: An Enhanced Methodology Integrating Energy Modeling

by

Sara Al Humidi

A thesis

presented to the University of Waterloo

in fulfillment of the

thesis requirement for the degree of

Master of Applied Science

in

Civil Engineering

Waterloo, Ontario, Canada 2025

© Sara Al Humidi 2025

Author’s Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

The building sector has focused on addressing climate mitigation through the electrification and decarbonization of households, mainly by upgrading building envelope and replacing combustion-based systems with electric heat pumps. However, the impact of climate change could result in more households falling into energy hardship, underscoring the need for an equitable transition. A household falls under energy hardship if its energy expenditure ratio exceeds the defined threshold, regardless of its total household income. Energy hardship encompasses both energy poverty and energy burden. Thus, a household experiences energy poverty if i) its energy expenditure ratio exceeds the defined threshold and ii) the total household income is below low-income cut-offs. A household experiences an energy burden if i) its energy expenditure ratio exceeds the defined threshold and ii) the total household income is above low-income cut-offs. Techno-economic factors such as energy costs, type of fuel, building age and envelope condition, and type of heating and cooling system in a household contribute to energy hardship. Socioeconomic factors such as income, education, and race are also catalysts to the problem, making energy poverty a multidimensional issue with great implications for public health, social equity, and environmental sustainability.

This study aims to quantify energy hardship in Canada in 2019 and 2021 and identify the building and household characteristics experiencing energy poverty. Further analysis was completed for Ontario, Canada to establish a correlation and quantify the impact climate change and household electrification (e.g., switching from a natural gas furnace to a heat pump) have on energy hardship. The study identified key indicators of energy poverty and burden, confirming that household income is the most critical factor. Nearly 40% of Canadian households with an income of CAD$29,000 fall under energy poverty. Older dwellings, which tend to be leaky with poor insulation and outdated HVAC systems, contribute to higher energy consumption. Single-detached homes, with major repair requirements, are likely to be energy burdened (17%). Additionally, socioeconomic factors play a role, one person households (31%) households being the most affected by energy hardship. Education and employment also indirectly impacted energy poverty (10%); households with a higher education and full-time employment were less likely to be energy poor. The Ontario-specific analysis mirrored national trends, revealing that energy burden is more pronounced in rural areas (36%).

In addition, an energy simulation study was performed for a median energy-poor household in Ontario. The study investigated two scenarios: a business-as-usual scenario where the households performed minimal energy efficiency upgrades, and an electrification and decarbonization scenario where energy-poor households implemented measures such as envelope renovations and switching to fully electric heating system (i.e., cold climate air source heat pump).

The energy modeling results revealed the importance of income levels in alleviating energy hardship. Regardless of the level of energy efficiency measures applied, the median energy-poor household remained in energy poverty after building enclosure and airtightness improvement when maintaining a natural gas furnace or fuel switching to a heat pump (11.2% and 14.3%, respectively), . Households earning CAD$50,000 after tax came out of energy hardship after insulation and airtightness upgrades. However, the adoption of an electric heat pump worsened energy hardship by doubling the costs of electricity despite the fact that reduced energy use intensity by nearly 50%. This concluded that energy efficiency measures alone are not enough to remove households out of energy poverty (or hardship, in general) in Ontario.

By analyzing the prevalence, causes, and impacts of energy poverty in Canada and Ontario, this study aims to develop a replicable methodology that provides evidence-based insights to inform policy decisions and support the development of effective interventions that are inclusive and equitable for all households.

Acknowledgments

I would like to thank my supervisor, Dr. Costa Kapsis, for his guidance and support on the development and completion of my thesis. As a mentor, I am grateful for your patience and empowerment throughout every step of this research journey. I would also like to thank Dr. Scott Walbridge for connecting me with you because I could not think of a better research group to bring me back to the University of Waterloo.

I would like to thank my thesis committee, Amy Li and Carl Haas for taking the time to review my thesis and for the valuable insight and feedback provided.

I thank the Statistics Canada, the Southwestern, and Toronto Research Data Centers. I thank Pat Newcombe for her support in vetting the data and your patience with all my questions, without you this work would not be possible.

I am so grateful to the CRIB team for your support, kindness, and endless conversations, especially Harry Vallianos, Soukaina Jazouli, and Niloofar Elyasi.

To Andrea Atkins, thank you for consistently giving me opportunities to grow outside of my research, I have learned so much from you as an engineer, teacher, and friend.

I owe a great debt to my parents who sacrificed so much for me and my brothers, without your prayers and support this would not have been possible.

My dearest friends Daniela Roscetti and Hasan Basic, thank you for always opening your doors (and kitchen) for me whenever I needed a space to be.

Finally and most importantly, to the people of Gaza and Palestine. You may never read this, but your resiliency and steadfastness were the greatest lessons of all time. For the last 16 months, you have been at the forefront of my mind, you reminded me that our education is the greatest form of resistance.

Table of Contents

Author's Declaration ii

Abstract iii

Acknowledgments v

List of Figures viii

List of Tables x

List of Abbreviations xi

Chapter 1 : Introduction 1

1.1 Problem Statement 2

1.2 Research Needs 2

1.3 Research Objectives 2

1.4 Thesis Organization 3

Chapter 2 : Literature Review 4

2.1 On Terminology for Energy Poverty 4

2.2 On Terminology for Energy Burden 5

2.3 On Terminology for Energy Hardship 6

2.3.1 Energy Hardship in Canada 6

2.3.2 Energy Hardship & Socioeconomic Trends 8

2.3.3 Existing Policies 9

2.4 Energy Poverty in the US 10

2.5 Energy Poverty in the UK 12

2.6 Energy Poverty in Other Areas of the World 16

2.7 Building Energy Efficiency and Energy Poverty 17

2.8 Health Impact 20

Chapter 3 : Methodology 23

3.1 Statistical Input Data 23

3.2 Phase 1: Household Characteristics and Energy Burden and Poverty Assessment for Canada and Ontario 25

3.2.1 Data Clean-up and Aggregation 25

3.2.2 Calculating Energy Burden and Poverty Rates 25

3.2.3 Key Metrics for Assessing Energy Burden and Poverty 26

3.3 Phase 2: Energy Modeling for Efficiency and Climate Adaptation for Energy Poor Households in Toronto, Ontario 27
3.4 Methodological Limitations 28
Chapter 4 : Results & Discussion 29
4.1 National Statistical Results 29
4.1.1 Comparison with Past Energy Hardship Studies in Canada 32
4.1.2 National: Characteristics of Households Experiencing Energy Hardship 34
4.2 Ontario Statistical Results 40
4.2.1 Ontario: Characteristics of Households Experiencing Energy Hardship 42
4.3 Ontario Modelling Results 48
4.3.1 Modelling Baseline 48
4.3.2 Baseline Modelling Results 50
4.3.3 Energy Efficiency Measures 52
4.3.4 Impact of Household Income 56
Chapter 5 : Conclusions and Future Work 59
5.1 Summary and Conclusions 59
5.2 Recommendations for Future Work 60
References 61
Appendix A – National Statistical Results 70
Appendix B – Ontario Statistical Results 76
Appendix C – Modelling Results 81
Appendix D – Syntax used in the RDC for Statistical Analysis 85

List of Figures

Figure 1. Canadian Residential Distribution of Energy Use by End-Use 9
Figure 2.2. Measuring Energy Poverty in the UK [51] 13
Figure 2.3. The Cost Difference Between Modeled and Actual Energy Consumption as FPPER Band Decreases [53] 15
Figure 4.1. Percentage of Canadian Households in Energy Hardship based on four EERs 30
Figure 4.2. Per Province Analysis of Energy Burden and Poverty using the 2M, before and after Housing Costs 31
Figure 4.3. Per Province Analysis of Energy Burden and Poverty Using the 2M, after Food, Medicine, Additional Heating and Cooling Costs 32
Figure 4.4. Heating Degree-Days in Canada, 2000 – 2020 [111]. 34
Figure 4.5. Percentage of Canadian Households in Energy Burden and Poverty based on Income, for 2019 and 2021 35
Figure 4.6. National Energy Burden and Poverty as a Function of Employment and Education Status, Before Housing Cost, using 2M Thresholds, for 2019 and 2021. 36
Figure 4.7. Percentage of Canadian Households in Energy Burden and Poverty as a Function of Dwelling Age and Type, for 2019 and 2021 37
Figure 4.8. Percentage of Households in Energy Burden or Poverty as a Function of Household Size (Number of People) and Number of Bedrooms, for 2019 and 2021. 38
Figure 4.9. Percentage of Canadian Households in Energy Burden and Poverty as a Function of Tenure Type and Maintenance, for 2019 and 2021. 39
Figure 4.10. Percentage of Canadian Households in Energy Burden and Poverty as a Function of Family and Marital Status, for 2019 and 2021. 40
Figure 4.11. Percentage of Households in Ontario under Energy Burden and Poverty, for 2019 and 2021 41
Figure 4.12. Percentage of Households in Ontario in Energy Burden or Poverty based on Income, for 2019 and 2021 42
Figure 4.13. Percentage of Households in Ontario in Energy Burden or Poverty based Employment Status and Education Level, for 2019 and 2021. 43
Figure 4.14. Percentage of households in Energy Burden and Poverty as a Function of Population Size and City, for 2019 and 2021 44
Figure 4.15. Percentage of Households in Ontario in Energy Burden or Poverty based on Dwelling Age or Type, for 2019 and 2021 45
Figure 4.16. Percentage of Households in Ontario in Energy Burden or Poverty based on Household Size and Number of Bedrooms, for 2019 and 2021. 45
Figure 4.17. Households in Ontario in Energy Burden as Poverty as a function of Tenure Type and Maintenance Requirements, for 2019 and 2021. 46
Figure 4.18. Percentage of households in Energy Burden and Poverty based on Household Type and Marital Status, for 2019 and 2021. 47
Figure 4.19. EUI and End Use Breakdown for the Baseline and GWP 2.5°C and 3.5°C 51

Figure 4.20. Energy Efficiency Measures Analysis Pedagogy 52
Figure 4.21. EUI and End-Use breakdown for Natural Gas Furnace and Domestic Hot Water Scenarios 54
Figure 4.22. EUI and End-Use breakdown for Electric Heat Pump and Domestic Hot Water Scenarios 55
Figure 4.23. Basic Energy Expenditure Ratio and Energy Retrofit Scenarios 56
Figure 4.24. The Relationship of Income to EER for a Household using a Gas Furnace, under various retrofit scenarios. 57
Figure 4.25. The relationship of income to EER and Heat Pump Retrofits 58

List of Tables

Table 3.1. Low-income cut-offs (LICOs) after tax by family size, in current dollars [106] 26
Table 4.1. Calculated Twice the Median (2M) Thresholds for Energy Expenditure Ratios 29
Table 4.2. Prevalence of National Energy Hardship Based on the 6% and 10% Thresholds from 2017 to 2021. 33
Table 4.3. Calculated Twice the Median (2M) Thresholds for Energy Expenditure Ratios for Ontario 41
Table 4.4. Median Energy Consumption and Income Breakdown for Ontario, in Canadian Dollars. 48
Table 4.5. Baseline Model Assumptions 49
Table 4.6. Final Baseline Model Energy Expenditure, EER and Energy Poverty Status 50
Table 4.7. Energy Performance of the Baseline Model under Current Climate Conditions (2021), GWP2.5 and GWP3.5. 51

List of Abbreviations

EER	Energy Expenditure Ratio
2M	Twice the Median
CHS	Canadian Housing Survey
CUSP	Canadian Urban Sustainability Practitioners
DHW	Domestic Hot Water
EB	Energy Burden
EER_{hcfh}	EER Excluding Housing, Food & ,Medicine Costs
EER_{hctax}	EER Excluding Tax and Housing Costs
EER_{hchac}	EER Excluding Income, Housing, Food, Medicine, Additional Heating& Cooling Costs
EER_{it}	EER Excluding Tax
EH	Energy Hardship
EIA	Energy Information Administration
EL	Electric
EP	Energy Poverty
EPC	Energy Efficiency Certificate
EPEE	European Fuel Poverty and Energy Efficiency program
EUI	Energy Use Intensity
HVAC	Heating, Ventilation and Air Conditioning
IEA	International Energy Agency
IEQ	Indoor Environmental Quality
INF	Infiltration
LEAP	Low-income Energy Assistance Program
LICO	Low-Income Cut Off
LIHC	Low Income High Cost
LIHEAP	the Low Income Home Energy Assistance Program
LILEE	Low Income Low Energy Efficiency
LPD	Lighting Power Density
MIS	Minimum Income Standard
NG	Natural Gas
NRCAN	Natural Resources Canada
OEB	Ontario Energy Board
OESP	Electricity Support Program
RDC	Research Data Centre
SHS	Survey of Household Spending
THI	Total Household Income
WAP	Weatherization Assistance Program

Chapter 1 : Introduction

Climate change is one of the most pressing challenges of our time, with existing energy systems identified by the International Energy Agency (IEA) as significant contributors to global warming, responsible for approximately 75% of all greenhouse gas emissions. Amongst these energy systems, building operations account for 30% of the final global energy consumption and 26% of global energy-related emissions [1]. Addressing these emissions is critical to achieving the Paris Agreement's goals, which aim to enhance the global response to climate change. The Agreement reaffirms the objective of limiting the global temperature increase to below 2°C above pre-industrial levels while striving to limit the increase to 1.5°C. To keep the global temperature rising to 1.5°C and minimize climate-related risks, achieving net-zero greenhouse gas emissions by 2050 is crucial, as outlined by the Intergovernmental Panel on Climate Change (IPCC) [1], [2].

Canada is a key participant in the global fight against climate change. In 2024, Canada announced a target to cut emissions by 45-50% by 2035, reinforcing its goal of achieving net-zero emissions by 2050 [3]. To support these ambitions, the government has implemented a range of long-term policies, including carbon pricing mechanisms and significant investments in energy efficiency measures and clean technology. Plans such as the Pan-Canadian Framework on Clean Growth and Climate Change (2016) and "*A Healthy Environment and a Healthy Economy*" (2020) outline the strategies needed to meet these targets [4], [5].

Despite these efforts, substantial challenges remain. Canada's greenhouse gas emissions have increased over the past three decades, highlighting the need for transformative action across all sectors, including buildings. Furthermore, recent natural disasters and extreme weather events have underscored the urgency of building resilience against climate impacts. Achieving Canada’s ambitious climate goals will require continued innovation, significant investment, and a commitment to ensuring that no community is left behind in transitioning to a sustainable net-zero carbon future.

A critical aspect of this transition is addressing energy hardship, which remains a significant barrier to achieving equitable climate resilience. Energy poverty is broadly described as the inability of households to afford adequate energy services and maintain a comfortable indoor temperature. It disproportionately affects low-income households, rural and Indigenous communities, and other vulnerable populations such as the elderly. Despite Canada’s wealth and abundant energy resources, many households struggle to meet basic energy needs due to high energy costs, poor housing infrastructure, and geographic location[6].

This issue is further compounded by the growing urgency to address climate change through building electrification and decarbonization initiatives. While these measures are critical for

reducing greenhouse gas emissions and future-proofing buildings against extreme climate events, they often require substantial financial investments in retrofits, energy-efficient equipment, and renewable energy systems. These costs risk exacerbating existing social inequities by disproportionately burdening energy poor households, who may already struggle with affordability and lack access to funding, technical expertise, and representation in decision-making processes [7].

1.1 Problem Statement

As Canada works toward its net-zero emissions target by 2050, there is a pressing need to ensure that climate policies, particularly those aimed at transforming the built environment, are equitable and inclusive. This requires deliberate efforts to i) monitor, ii) understand the nature of, and iii) integrate energy hardship considerations into climate action strategies. Without such efforts, vulnerable populations risk further marginalization, jeopardizing social equity and weakening the effectiveness of climate resilience initiatives.

1.2 Research Needs

There is limited research on how the 2050 decarbonization goals affect vulnerable populations in Canada, particularly those experiencing or at risk of energy poverty. While there have been limited efforts to monitor and address energy poverty in Canada, the concept of energy poverty lacks a clear and consistent definition, which hampers efforts to identify affected populations accurately. Developing a standardized methodology to measure and analyze energy poverty is essential to inform strategies and policies aimed at improving household living standards while advancing decarbonization objectives. The absence of a standardized framework to measure energy poverty limits our understanding of how socioeconomic factors – such as household characteristics like age, condition, and size – and income, education, and race, contribute to or influence energy poverty. Addressing these gaps will provide a more comprehensive understanding of energy poverty and its implications for policymaking in the context of Canada's decarbonization goals.

1.3 Research Objectives

The research objectives of this thesis are as follows:

- Establish a national and provincial baseline for existing energy hardship conditions using the 2019 and 2021 Canadian Survey of Household Spending (SHS).
- Examine the relation between household characteristics (e.g., dwelling characteristics, income levels, household composition etc.) and energy hardship, to gain a comprehensive understanding of the future drivers of energy hardship in Canada.
- Investigate the potential impact of energy efficiency measures and household electrification (e.g., replacing a gas furnace with an electric heat pump) on energy poverty in Ontario.

The scope of this project is limited to the available data from the SHS and the vetting rules from the Statistics Canada Research Data Centre (RDC). While energy hardship baselines are established nationally and for individual provinces, the analysis regarding the impact of climate change and household electrification on energy poverty is performed only for southern Ontario. Further limitations and assumptions will be addressed in detail throughout the thesis.

1.4 Thesis Organization

- Chapter 1 introduces the research and background and highlights research needs, objectives, and scope.
- Chapter 2 includes a detailed literature review on the definition of energy poverty, how it is measured, and existing policy or lack thereof in Canada, the USA, the UK, and Europe.
- Chapter 3 includes a detailed methodology to address the research objectives.
- Chapter 4 discusses the results obtained, and how the objectives were met.
- Chapter 5 concludes this thesis and provides recommendations for future research.

Chapter 2 : Literature Review

2.1 On Terminology for Energy Poverty

There have been multiple discussions about the definition of energy and/or fuel poverty. These terms are often used interchangeably but have different meanings depending on the context. It is agreed that energy poverty is experienced when there is a lack of access to energy sources or the inability to fulfill the financial costs of basic energy needs. J. Goldemberg [8] defines energy poverty as "*the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe, and environmentally benign energy services to support economic and human development*". The definition emphasizes the concept of fulfilling the demand for "*energy services.*" This does not refer to energy consumption but rather the delivery of energy services derived from diverse energy sources. This includes providing essential household energy services such as cooking, heating, cooling, lighting, transportation, work, and access to information and communication technologies (often referred to as "*connectivity*")[9]. This definition defines energy poverty as inadequate access to modern energy sources, which can be due to supply issues or inability to afford energy sources. Thus, this definition is applicable in countries that are not considered in the Organization for Economic Cooperation and Development (OECD) or developing regions and communities where access to fuel is limited. In OECD countries, where access to electricity and natural gas is not limited, energy poverty is defined through the household's ability to maintain adequate IEQ as well as the affordability of energy services.

In the United Kingdom (UK) and Ireland, energy poverty is referred to as "fuel poverty" in academic and policy discussions. In the initial discussions about energy poverty, the term "energy poverty" referred to energy access in less developed or industrialized nations [10], while "fuel poverty" was associated with energy affordability in the UK. The work of Brenda Boardman characterized households experiencing fuel poverty if 10 percent (10%) or more income is spent on energy services [11]. This was the initial metric for evaluating fuel poverty which was later developed into many other widely used indicators that include assessing the ability to maintain acceptable indoor environmental quality (IEQ). For example, the following four indicators are widely used to identify energy poverty:

i) **ten percent (10%)**: examines the percentage of a household's budget spent on energy and has been historically used. However, this measure is sensitive to energy prices and has limitations including the arbitrary selection of the 10% threshold level (representing twice the median expenditures in the UK in the 90s [12].

ii) **the double median (2M)**: it considers households to be in energy poverty if they spend a higher percentage of their income on energy expenditure than twice the national median [13].

iii) **the low-income, high-cost (LIHC)**: it considers households with low income and high energy costs, categorizing those with energy expenses above the median required energy costs and are low-income as energy poor [14].

iv) **minimum income standard (MIS)**: It considers households with a disposable income after deducting energy services and other necessary expenditures (i.e., rent, food, medicine) below the minimum income standards [15].

In Canada, while the term energy poverty is used instead of fuel poverty, the categorization of households as energy poor falls in line with the indicators derived from the UK definition of fuel poverty. Most Canadian studies categorize a home as energy-poor based on an expenditure analysis comparing energy expenditure to the total household income after tax. The indicator used to measure energy poverty is usually the ratio of energy expenditure (EER) which is the ratio of total energy expenditure including electricity and natural gas to income after tax. If a household spends more than a defined threshold the household (i.e., typically, 10% or 2M of the total household income after taxes) is considered energy poor [6], [16]. Despite the various definitions of energy poverty, the consensus is that it is caused by a complex combination of factors, including lack of physical availability of certain energy types, lack of income, and excessive costs associated with using energy. Considering the existing indicators and definitions of energy poverty[17], in this study, energy poverty is defined:

Energy Poverty (EP) Definition: A household experiences energy poverty if its energy expenditure ratio (EER) exceeds the defined thresholds, and the total household income (THI) is below low-income cut-offs (LICOs), as defined by Statistics Canada, based on community size and family size.

$$EP = \begin{cases} TRUE & if\ EER \geq THRESHOLD\ and\ THI \leq LICO \\ FALSE & otherwise \end{cases} \quad (2.1)$$

Canadian researchers tend to use the 10% and 2M (twice the median) thresholds because they utilize information that is available through Statistics Canada. Information on IEQ is not readily available. For this study, the 2M energy expenditure ratio was adopted as the main indicator of energy poverty.

2.2 On Terminology for Energy Burden

Energy burden quantifies the financial strain of energy expenses on households relative to total household income[18]. It is often used to describe the extent or depth of energy poverty. A high energy burden may contribute to energy poverty or indicate a risk of falling into energy poverty. However, not all households with a high energy burden are energy poor. For example, wealthier households with higher energy expenses might appear as energy poor when completing the analysis but might maintain a high standard of living and IEQ. These households may appear as energy poor in the analysis; however, the high energy costs may be due to overconsumption

rather than energy insecurity. In this study, there is a distinction between energy burden and poverty. Energy burden is defined as:

Energy Burden (EB) Definition: A household experiences energy burden if its energy expenditure ratio (EER) exceeds the defined thresholds, and the total household income (THI) is above low-income cut-offs (LICOs), as defined by Statistics Canada, based on community size and family size.

$$EB = \begin{cases} TRUE & if\ EER \geq THRESHOLD\ and\ THI \geq LICO \\ FALSE & otherwise \end{cases} \quad (2.2)$$

2.3 On Terminology for Energy Hardship

It is essential to establish a comprehensive definition that encompasses both energy poverty and energy burden. This distinction is necessary because previous studies have often examined energy hardship without considering household income, mistakenly labeling it as energy poverty. This misclassification dilutes the significance of identifying marginalized populations who experience both economic and energy poverty, highlighting the need for a more precise and inclusive approach.

Energy Hardship (EH) Definition: A household experiences energy hardship if its energy expenditure ratio (EER) exceeds the defined threshold, regardless of its total household income.

$$EH = \begin{cases} TRUE & if\ EER \geq THRESHOLD \\ FALSE & otherwise \end{cases} \quad (2.3)$$

2.3.1 Energy Hardship in Canada

A literature review was completed to identify all relevant studies over the past 34 years, from 1990 to 2024. The studies published have explored the impact of health [19], built environment [4], the prevalence of energy hardship [6], [16], [20], disparities in energy hardship and indoor environmental quality [21], and existing initiatives to alleviate it [22], [23]. The limited number of results further highlights that while energy hardship is gradually gaining recognition in Canada, energy poverty has been comparatively overlooked in policy discussions and domestic research. The following section provides an overview of existing literature and methodologies used to calculate energy hardship in Canada as well as the correlation between energy use, energy efficiency, and existing policy or lack thereof related to energy hardship.

The status quo of energy hardship in Canada is closely related to energy affordability challenges, inefficient housing, and low income. However, there is a lack of understanding about how these factors interact with other critical vulnerabilities, such as socio-demographics, neighborhood type, and racialization, which are associated with inequitable energy consumption [22]. Furthermore, there are limited resources to the information required to measure energy hardship holistically. Thus far, energy hardship in Canada is measured by an expenditure analysis examining the ratio of total household expenditure to total household income ratio. This has

been completed using Census data or SHS from Statistics Canada that include household income, and energy expenditure information. The information is usually limited to household spending which introduces limitations and challenges in understanding the building condition beyond the year built and maintenance requirements. Information related to occupant comfort, heating, and cooling is available in other surveys like the Canadian Housing Survey (CHS) but must be linked to the SHS survey for the analysis to be completed. While possible, this process presents a new set of challenges to data accessibility since linking the surveys requires months of work from Statistics Canada and is predicted to have missing information since both surveys have different sampling methods. Additionally, there is no known record of household square footage in correlation with income, energy spending, and demographics which would allow for a holistic analysis of existing energy hardship rates in Canada.

In detail, following the 2M threshold, the Canadian Urban Sustainability Practitioners (CUSP) used the 2016 Census data to evaluate energy hardship [24]. CUSP set the 2M threshold to six percent (6%) of their total income after tax as the threshold to determine the degree to which a household is under an energy hardship. This six percent (6%) is driven from the 2016 census data that most Canadian households spend less than 3% of their after-income tax on their energy bills. The results from the CUSP study completed in 2016 indicate that Canada had an energy hardship rate of 21%. Prince Edward Island faces the highest rate of energy hardship (41%), meanwhile, Ontario has the highest number of households struggling with energy hardship with about 1.1 M (22.5%) [24].

Following the CUSP study, Riva et al. investigated energy hardship using the 2017 SHS, under both the 10% and 2M benchmarks while applying different expense measures: one using only energy expenses, the second using energy expenses and housing costs. The 2M value used was six percent (6%) based on the CUSP study. A new median was not calculated for 2017. The study found that the percentage of households struggling with energy hardship ranges from 6% to 19% in Canada, and ~6% to 22% in Ontario. The range percentage of households in energy hardship is dependent on the threshold and energy expenditure used, in this case, six and ten percent, before and after housing costs [25].

In Canada, 33% of renter households spent more than 30% of their income on housing and utilities, exceeding the commonly accepted threshold of affordability. Furthermore, approximately 13% were in a state of severe housing cost burden, allocating over 50% of their income to these expenses, thereby facing a crisis of affordability[26]. In another study, Briot-Arthur et al. [20] addressed the lack of accessibility to information about income per housing, dwelling condition, and energy consumption by using a methodology that focused on energy modeling to identify energy hardship vulnerability. They developed an Energy Vulnerability Index (EVI) that ranges from 0 to 1, the closer the index is to 1, the more likely a building is vulnerable to energy hardship [20]. The use of building simulation models when evaluating

energy hardship is beneficial in addressing hidden energy hardship because it eliminates underconsumption patterns from surveys, energy bills, and occupant behavior. This is significant because it reduces the likelihood of missing vulnerable households when calculating energy hardship based on actual energy spending vs. expected. Especially when there are known trends that low-income households lower their energy consumption to reduce energy expenses. In 2013 Statistics Canada found that 14% of Canadian households kept their dwelling at an unsafe or uncomfortable temperature because of unaffordable heating and cooling costs, this was often the case for low-income households, 18% of which struggled to keep adequate indoor air temperatures [27]. The methodology used by Briot- Arthur et al. [20] further establishes a relationship between energy hardship and building conditions highlighting the impact of energy inefficiency cost burdens.

2.3.2 Energy Hardship & Socioeconomic Trends

Energy use, occupant comfort, and building efficiency are heavily connected to social practices, energy needs, and socio-economic and demographic factors, such as income, education, employment, disability, and race/ethnicity [16], [21]. In 2023, it was reported that 3% of Canadian households received a disconnection, shut off, or non-delivery notice concerning their energy bill because of overdue payments or the inability to pay the bills. In addition, 10% of Canadian households were late or unable to pay their energy bills. Approximately 15% had to reduce or forgo expenses for necessities, such as food and medicine, for at least 1 month, and 8% of households reported doing this for at least three months. It is also important to note that household composition also increases the risk of vulnerability to energy hardship. Single-parent families were 1.5 times as likely to face the risk of cutting back on basic needs to pay for their energy bills than couples with children, and over 3 times more than couples without children [27]. Geographic location also plays a role in determining energy poverty trends as geographic segregation at the neighborhood level has been observed, with income poverty being more prevalent in certain areas. This pattern is partly associated with the clustering of apartment housing, visible minority groups, and levels of racial diversity [16].

The link between socioeconomic factors and building energy efficiency is clear when assessing energy poverty, particularly in a household's energy source. The Canadian Social Survey found that electric heating was the most common energy source among the lowest-income households, with 47% relying on it. In 2023, 62% of households in low-rise apartment buildings and 41% in high-rise ones relied on electric heating, compared to only 23% in single-detached dwellings. Similarly, renters reported using electric heating more often (52%) than homeowners (27%) [27]. Section 2.7 Building Energy Efficiency and Energy Poverty will further explore the impact of energy efficiency and household electrification on energy hardship.

2.3.3 Existing Policies

In 2019, Canadians spent $29.8 billion on energy in their homes, where 81% was used for space and water heating[29]. The distribution of residential energy use by end-use, per Natural Resources Canada (NRCAN) is highlighted in Figure 1. Currently, in Canada, there are no energy hardship-specific policies that exist provincially or federally despite the high costs of energy use. However, several programs address energy hardship indirectly.

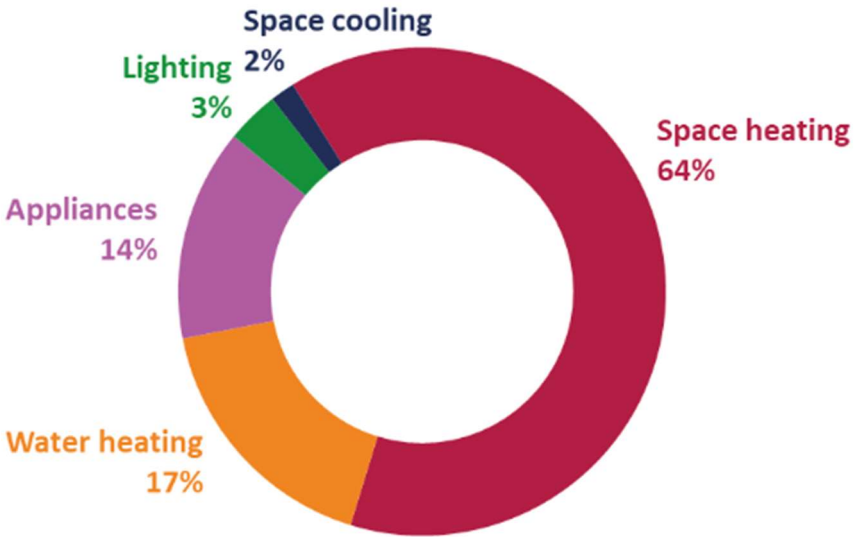


Figure 1. Canadian Residential Distribution of Energy Use by End-Use

Das et al. [22] completed a review to identify all the initiatives in Ontario that can mitigate risk factors associated with energy hardship. The results yielded a review of forty initiatives that can classify these support programs into three categories: financial support, energy efficiency and savings, and consumer protection. The Home Energy Loan Program [30], the Canada Greener Affordable Housing [31] , Canada Greener Homes Grant [32], the Energy-Efficient Housing Program [33], Better Homes Hamilton [34] and many more are examples of financing programs for homeowners that help improve energy efficiency in households regardless of household type. Most programs require significant capital investment from homeowners, making it difficult for low-income households to participate. Also, many of them target homeowners excluding renters when it comes to home improvements. The programs that are available for renters are energy assistance programs that support energy bill payments.

The Ontario Energy Board (OEB) has an electricity support program (OESP) where customers with low incomes can apply to assess their qualification for monthly on-bill credits to reduce their electricity bill. OESP is based on the number of people living at home and their combined household income. The program is open to all Ontario residents and is not limited to the type of housing. Additionally, the Low-income Energy Assistance Program (LEAP) by OEB has a list of intake agencies across a multitude of cities in Ontario that assist households if they are behind

on their energy bills or at risk of service disconnection [35]. Moreover, Enbridge offers a Smart Thermostat Program that provides rebates to households purchasing smart thermostats which can help reduce energy consumption and improve occupant comfort. These initiatives provide a short-term solution that offers rebates to reduce the financial burdens associated with energy hardship.

Financial solutions alone are often not enough to decrease energy hardship though. This is seen in CUSP's data where Ontario has the highest number of households experiencing energy hardship in Canada[24]. Subsequently, the implications of energy hardship are not limited to financial struggles as research indicates. Combined efforts to improve the efficiency of homes and lower energy costs are necessary. This includes heating system and building enclosure upgrades not limited to efficient boilers, improved airtightness, and double-glazed windows. The province of British Columbia has programs that consider building retrofits and are a step closer to holistic and long-term impact solutions. The BC Hydro program includes energy-saving kits with products like LED light bulbs, a high-efficiency showerhead, free energy-coaching service, and product installation. BC Hydro also provides free upgrades for non-profit housing providers and Indigenous communities. These upgrades include energy-saving products, high-efficiency gas furnace replacement, and insulation [36]. Québec also has energy efficiency and renovation programs like the Rénoclimat program. Participating in the Rénoclimat program allows homeowners to benefit from a home visit by an energy advisor who offers personalized advice to improve energy efficiency. The guidance helps reduce long-term energy consumption while enhancing indoor environment quality. The program also provides grants for improving insulation, enhancing airtightness, installing ENERGY STAR® certified doors and windows, or upgrading mechanical systems like heat recovery ventilators and drain water heat recovery systems [22] [37].

Although these programs were not explicitly implemented to reduce energy hardship but to improve energy efficiency and reduce financial burdens, they have a direct impact on reducing vulnerability to energy hardship. When considering policies to address energy hardship and thus, poverty, the first step is to establish a definition that would recognize energy poverty as an issue separate from hardship in Canada. Furthermore, a definition recognized by the government would help researchers identify and develop strategies and measures that encompass broader policy areas. This includes energy efficiency and savings, housing provision, poverty reduction, healthcare, and climate change mitigation [22]. The Canadian government would benefit from formally recognizing energy poverty as an existing and increasingly significant issue.

2.4 Energy Poverty in the US

The research on energy hardship in the U.S. is sparse, however, the research heavily links low-income households and need for energy efficiency improvements, racial disparities, and urban

vs. rural locations which are all indicators of energy hardship vulnerability [7], [38], [39], [40], [41]. Compared to Canada, the understanding of energy hardship in the U.S. is slightly more advanced because the U.S. federal government recognized energy hardship as a problem distinct from traditional poverty in 2021. In the Energy Poverty Prevention and Accountability Act (1 July 2021) energy hardship is defined as a "*condition in which individuals do not have access to affordable and reliable energy to maintain economic security*". This definition does not specify numeric values for energy hardship thresholds or specify socioeconomic conditions to meet energy hardship, allowing for researchers to specify these conditions based on the US population and energy sources. However, it specifies that minority, rural, elderly Native Americans as at-risk communities. In the most recent Energy Poverty Prevention and Accountability Act, enacted on September 14, 2023, specific tasks were mandated to address energy hardship[42]. A detailed report describing the analysis required to measure energy hardship, identifying at-risk communities (location and type), as well as measures. The energy hardship measures suggested in the act include, but are not limited to, increasing support for energy efficiency programs and requirements for utility companies to assist low-income households. Though recognizing energy poverty as a separate issue from hardship is a crucial step toward identifying vulnerable groups and addressing the problem.

Prior to the Energy Poverty Prevention and Accountability Act, the presence of energy hardship in the United States was evident through the implementation of two federally funded programs: the Low Income Home Energy Assistance Program (LIHEAP) and the Weatherization Assistance Program (WAP) [7]. Additionally, studies completed in the US used the same measures as Canadian ones. The 10% and 2M thresholds are commonly used due to the availability of information. Another strategy to measure energy hardship in the US is based on the number of households struggling to heat and cool their homes appropriately. These households are noted through their qualifications for a weatherization program [7]. This is because the qualification criteria for energy assistance programs are aligned with energy hardship indicators. For example, the qualification for WAP for each state depends on three factors: the percentage of low-income populations, residential energy expenditure by low-income households, and climate conditions through heating and cooling degree days. The prevalence of energy hardship is evident through other indicators, like poor energy efficiency, low incomes, and high energy bills [43]. In 2020, five million (4%) households reported that they could not use their heating equipment, and six million (nearly 5%) reported that they could not use their air-conditioning. Additionally, 1.4 million households (1%) reported that someone in the household needed medical attention because their home was kept at an unsafe temperature. Most of the evidence was published from the Residential Energy Consumption Survey (RECS) in 2020, indicating that 34 million US households (nearly 27%) could not afford their energy bills, and 12.5 million (10%) had received a disconnection notice from their energy providers. Additionally, 25 million households have had

to choose between paying their energy bills to heat their homes or forgoing food and medicine [44], [45]. WAP can significantly alleviate energy cost burdens for low-income households through cost-effective improvements in enclosure, air sealing, HVAC systems, lighting, and appliances [46]. This further solidifies the relation between building energy performance and energy hardship, and emphasizes the need to study the impact of electrification and decarbonization on energy hardship.

The most concerning consequence is the persistently high energy hardship rates, particularly those in the southern US (mostly rural states), and among minority households [44]. In a study completed using data from 2015, households with an annual income of less than US$ 22,929 were more likely to be in energy hardship. Compared with the poverty guidelines provided by the U.S Census Bureau (i.e., US$ 19,078), the energy hardship income level is higher [40]. Racial disparities are also often identified in energy hardship studies when comparing African American, Hispanic, Asian, and Caucasian households. African American households who are in energy hardship spend more on energy than poor non-African American households, with 35.4% of African American households considered in hardship. In comparison, the percentage for Caucasian households was 21.5%. Data from the United States Energy Information Administration (EIA) and the US Census Bureau reveal that an increasing number of households are threatened by energy hardship, which is becoming more common than economic poverty [40]. This further indicates that policymakers must accelerate their enforcement of methodologies and policies that identify at-risk households.

2.5 Energy Poverty in the UK

The UK nations (England, Scotland Wales, and Northern Ireland) have a refined energy poverty methodology compared to other countries. The concept of energy poverty has been studied in the UK for decades. What is known as energy poverty in Canada and the US is referred to as fuel poverty in UK. However, for this discussion and consistency in terminology, energy poverty will continue to be the term used throughout this thesis. The works of Brenda Boardman classified a household as energy poor if they spent more than 10% of their income on energy costs including electricity and natural gas to achieve a satisfactory indoor temperature[47]. The 10% threshold was chosen because at that time it was the value that yielded twice the median of energy expenditure. By 1997, energy poverty was recognized using this definition by the UK government [48].

In the energy poverty report from February 2024, it was stated that 13%, 20% 14%, and 24% of households in England, Scotland, Wales, and Northern Ireland, respectively, were classified as energy poor [49]. Note that there is a difference in how energy poverty is measured in each constituent country. This section explains the differences in methodologies and a summary is presented in Figure 2.2 on page 13from the UK Office for National Statistics [50]. In England and

Scotland, the energy poverty mitigation strategy focuses on prioritizing low-income households for energy efficiency support, distinct from strategies addressing income poverty. Additionally, households with high energy efficiency in their homes are not identified as fuel poor. To calculate energy poverty, household income, fuel cost, and household energy requirements are used. These estimates are based on the required energy to meet a satisfactory level of heating: 21 degrees Celsius for the living room and 18 degrees Celsius for any other room, 9 hours a day on a weekday and 16 hours a day during the weekend. This strategy accounts for varying household energy requirements, adjusting for the number of people per household and size. This is based on the standard heating guidelines by the World Health Organization (WHO)[51][37].

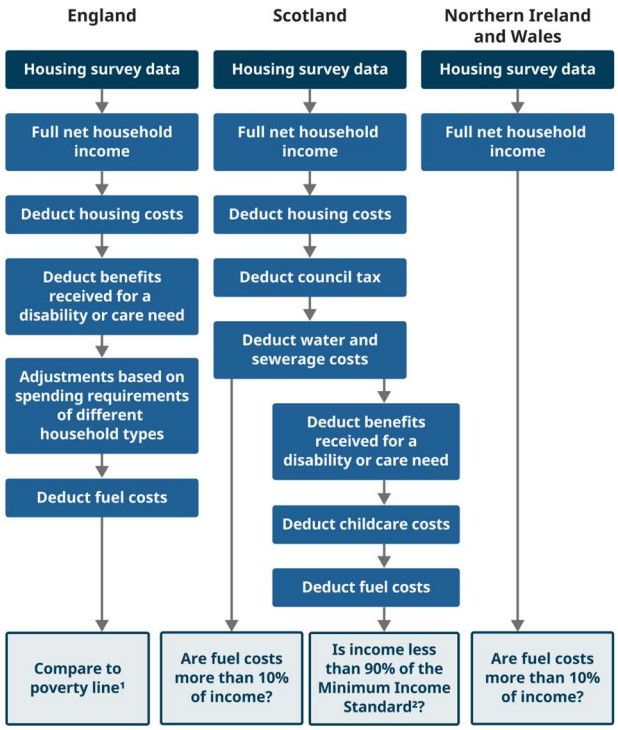


Figure 2.2. Measuring Energy Poverty in the UK *[51]*

England's current energy poverty standard was established in 2021 and is called the "Low Income Low Energy Efficiency" (LILEE) standard. It states that a household is considered energy poor in England if it meets two conditions:

1) Household has an energy efficiency rating (FPEER) of band D or below and,
2) The household disposable income after housing costs and energy needs is below the poverty line (i.e., in 2023 the poverty line was £17,300) [49]

Before the LILEE, the Low-Income High Cost (LIHC) measure was used to define energy poverty. It was the first measure to consider the energy poverty gap, which is defined as "*the reduction in*

fuel costs needed for a household to not be in energy poverty." LIHC determined that a household is energy poor if:

1) The amount a household would need to spend to maintain an "adequate standard of warmth" is above the national median level, and
2) if the household's leftover income after energy costs is below the official poverty line [49]

There are two major differences in these two definitions. First, the LILEE estimates EP based on required energy per household accounting for heating requirements. Meanwhile, LIHC relies on actual energy use. Second, LILEE classifies households that are low income as energy poor, meanwhile, LIHC evaluates if residual income falls below the official poverty line. This change from actual to modeled energy consumption was necessary due to occupants' low-income households reducing their energy consumption to reduce energy costs. The LIHC uses energy efficiency ratings, which are determined using information about the building's construction materials, heating systems, and insulation. The fuel costs are calculated using estimated energy requirements and cross-reference against relevant price data. This information is collected in the housing survey by asking for fuel type, location to correctly allocate regional fuel costs, and bill payments for gas and electricity. An energy auditor then inputs this data into government-approved software that generates an energy efficiency certificate (EPC) [52]. Notably, England targets achieving an energy efficiency rating of at least band C for fuel-poor households by 2030.

A study on English households found a significant discrepancy between modeled and actual energy use. On average, households spent 9.9% (£133) less on energy than predicted. This gap widens to 19.9% (£319) for households in energy poverty, compared to 8.6% (£110) for those not in energy poverty[53]. Factors like energy efficiency and household composition also influence this disparity. The results also show that the Fuel Poverty Energy Efficiency Rating (FPEER) rating band C and lower has a higher modeled vs. actual energy consumption. Interestingly, households with an FPEER of Band B have an average energy consumption that matches their modeled consumption. Figure 2.3 highlights the differences from the study.

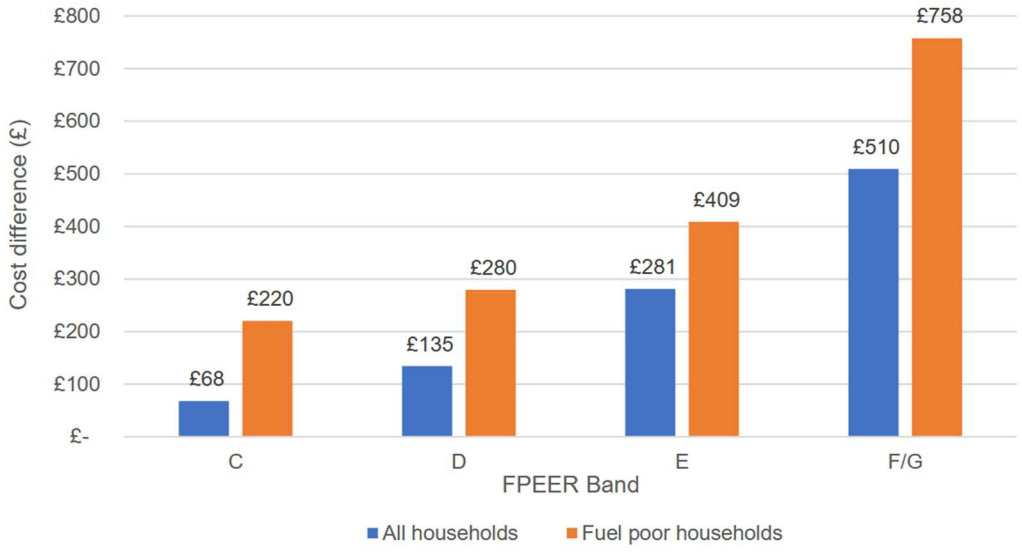


Figure 2.3. The Cost Difference Between Modeled and Actual Energy Consumption as FPPER Band Decreases [53]

Additionally, energy-poor households composed of single parents with children presented a discrepancy of £337 between modeled and actual household energy consumption while single parents with children who are not in energy poverty of £191. The analysis highlights that there is a negative correlation between energy consumption and household characteristics. Low-income households with low-efficiency housing under-consume energy when compared to higher-income and higher-efficiency households [53]. This is a common trend in low-income households since occupants try to reduce their reliance on heating and cooling systems to save on costs, energy modeling can help capture those households in the analysis and decrease the chances of hidden energy poverty. The relationship between energy poverty and energy efficiency is pivotal, with lower energy efficiency correlating with higher fuel costs and a greater likelihood of energy poverty.

Despite England using energy models to calculate energy poverty, charity organizations like National Energy Action (NEA) still use the 10% threshold to ensure that low-income, energy burdened households still qualify for weatherization programs [54]. They estimated that 6.5 million households in England are energy poor which is more than double the official government statement [49]. Similarly, Scotland's energy poverty definition considers a household to be energy poor if it meets both of these conditions [55]:

1) Total energy costs exceed 10% of the household's net income after housing costs while maintaining satisfactory heating conditions.

2) After deducting fuel costs, disability or care-related benefits, and childcare expenses, the remaining adjusted net income is below 90% of the UK Minimum Income Standard (MIS), making it insufficient for an acceptable standard of living.

On the other hand, Northern Ireland and Wales only use the 10% as a threshold, in which a household is considered energy-poor if they spend more than 10% of their income maintaining a satisfactory heating temperature, meanwhile Northern Ireland specifies the heating temperature of 21℃ in the main living room and 18℃ in other occupied rooms [49].

The drivers of energy poverty are household energy inefficiency, income, and energy prices. To address each of these drivers there are policies in place to help households with the cost of energy. For example, payment discounts for customers like the Winter Fuel Payment [56], Warm Homes discount [57], and Cold Weather Payments [58] are available to vulnerable customers to alleviate the energy burden.

2.6 Energy Poverty in Other Areas of the World

The academic and policy discussion on energy poverty has primarily concentrated in the UK, but within the last few decades, a plethora of reports and studies have emerged globally. In Europe and across the EU, Belgium [59], France [60], Germany [61], [62], Greece [63], [64], Hungary [65], Italy [66], Spain [67], [68], [69] as well many non-European countries such as China [70], [71], Japan [46], New Zealand [72] and Turkey [73] have started investigating energy poverty indicators. While many countries and regions follow the research completed in the UK, many do not have an accepted definition. For example, the EU does not have an agreed-upon definition of energy poverty, which hinders the development of effective policy. It is up to each nation to determine which methodology works best and determine "vulnerable" populations.

Studies completed in Germany use the 10% threshold, twice the median, and LHIC to understand dynamic energy poverty and determine whether a household is considered energy poor under each threshold [61], [62]. The study by Drescher et al. found that 78% of the energy poor households in the sample are temporarily facing energy poverty. The data was collected from 2013 to 2019 and noted that only 7.5% of the households that were energy poor remained in energy poverty the following year [62]. Italy on the other hand has limited studies on energy poverty with the energy poverty ratio defined as the ratio of required fuel cost divided by income. If the ratio is above 10% then the household is in energy poverty. Additionally, Italy mitigates energy poverty from a price reduction lens where the Italian Regulatory Authority for Electricity Gas and Water provides a subsidy for low-income households to help with energy costs [66].

Furthermore, Spain defines energy poor households as the ones that are unable to meet energy needs due to i) low income, and ii) energy-inefficient housing. They measure energy poverty using the 2M indicator, arrears on utility bills, and inability to keep home adequately warm [68].

Studies in Spain are not only identifying energy poverty but also 'hidden energy poverty.' In 2019, a study identified 25% of households that had "low" energy expenditure as energy poor. Hidden energy poverty refers to households that are under-consuming to save on energy costs while compromising their thermal comfort. Those households are often missed in energy poverty studies because they are not spending more than the defined indicator (10%, 2M etc.…) but they are sacrificing comfort [69].

Additionally, other Spanish studies adjust total household income before and after housing costs (mortgage or rent) and for household size to reflect different household needs [74]. The MIS methodology is also used where when net residual income – covering housing and minimum living costs – is insufficient to cover energy costs then a household is considered energy poor [75]. The UK approach of using the LIHC is also used. However, it is often criticized as it could exclude energy burdened households that might need to spend more than 10%. As a result many organizations still use the 10% indicator to qualify households for their energy assistance programs [49], [74]. Finally, the European Commission in 2015 highlighted five indicators that can help gauge the extent of energy poverty [76]:

1) Income
2) Energy Consumption
3) Energy Prices
4) Tenure status and other housing characteristics including but not limited to dwelling type, age, and the use of heating and cooling systems
5) Well-being and material deprivation

The above indicators were a consistent theme throughout all the methodologies used to measure energy poverty regardless of location. These indicators were also considered when creating the methodology for this investigation given the data availability from Statistics Canada. The UK and other countries have many studies addressing energy poverty and now strive towards enhancing their methodologies, and policies and understanding the relationship between energy poverty and building efficiency. Canada is behind in recognizing the issue at hand.

2.7 Building Energy Efficiency and Energy Poverty

Improving the energy efficiency of energy-poor households is one of the few long-term sustainable solutions because by improving the overall energy performance of a building may result in reduced energy bills and improved thermal comfort, which also results in improved physical and mental health[19]. This section investigates the role of energy retrofits in mitigating energy poverty in low-income households. There are many challenges to energy efficiency upgrades in the residential sector such as high capital costs, long payback periods, and lack of awareness about improved indoor environment conditions [77]. Inadequate dwelling

performance indicators like insufficient heating and poor insulation were used to assess energy poverty in Belgium, Spain, France, Italy, and the UK through the 'European Fuel Poverty and Energy Efficiency program (EPEE) [78]. Leaky roofs, damp walls/floors/foundations or mold noted on window frames and floors are all signs that the dwelling is energy inefficient and requires upgrades. Those signs are also indicators of energy poverty vulnerability; 1 in 7 households in Europe is experiencing or is at risk of energy poverty due to low household incomes, insufficient heating, poor insulation, and high energy prices [78]. In Greece, it was noted that low-income households live in poor-quality dwellings with no insulation and single-glazed windows. This results in households spending double the energy quantity in comparison to non-low-income households for heating and cooling per square meter to satisfy basic energy needs [79]. Another study completed a holistic retrofit analysis of a low-income apartment building in Athens by introducing scenarios with different interventions: improved envelope insulation, efficient windows, photocatalytic coating, and LED lighting. Compared to its pre-renovation performance, the retrofitted building achieved an 81.6% reduction in energy consumption, resulting in an annual electricity use of 25.4 kWh/m^2 [80]. Upgrading the building envelope can resolve energy poverty by reducing the total energy needed to maintain a reasonable indoor temperature. Upgrading the building enclosure is not the only way to improve energy efficiency; fuel switching and upgrading to a fully electric HVAC system can also significantly reduce energy costs. However, adding solar panels as an additional step is often financially out of reach for energy-poor households due to the high upfront costs. Thus, reducing the energy cost through programs aimed at improving dwelling conditions is the most accessible to low-income households. A 2004 English House Condition Survey study revealed the cost and scale of improving energy performance for energy-poor households in England. Energy efficiency measures were applied to 2.5 million energy-poor households to reduce their energy expenditure ratio to below 10%. The total cost of applying the measures was estimated to be £4.6 billion, without accounting for future servicing and replacement costs for heating and cooling. A simulation study was then performed estimating that 29.1% of the households that were energy poor, remained in energy poverty due to low income. An additional £1.4 billion annually would be needed to remove the remaining households from energy poverty [81]. This highlights that income is a primary indicator of energy poverty.

Canada has some programs that could help homeowners improve their dwellings energy efficiency. The Greener Home Loan offers up to $40,000 in interest-free financing to help homeowners make the necessary upgrades to make their homes energy-efficient [32]. While this initiative can reduce emissions and energy costs, it excludes renters who are more likely to fall under energy poverty. Additionally, the budget covers less than 7% of Canada's single-family homes, and in 2022, energy retrofits accounted for only 6.1% of all grants awarded [77]. Heidari et al. [82] performed a simulation study for single detached houses in the City of Guelph to

create an accessible roadmap for retrofitting houses in Ontario. The study used energy modeling calibrated with historical utility data to assess energy performance, showing that air-source heat pumps (ASHP) reduced natural gas consumption by 84%. The evaluation applied upgrades progressively, accounting for their cumulative effects, with the recommended retrofit order being appliance upgrades, followed by building envelope improvements, fuel switching by replacing a gas furnace with ASHP for space heating, and finally, photovoltaic installations. However, a study completed for the Region of Waterloo [77], noted that targeted deep energy retrofits are more likely to help meet the emissions reduction goals by 2030. The study used a database of 38,607 home energy audits from the Waterloo Region to model the energy-related emission reduction when applying deep retrofit measures. It was noted that houses built before 1980s are more likely to benefit from a building enclosure upgrade due to higher heat losses (GJ/m^2) [83]. It was noted that deep envelope upgrades have the potential to have a 2.5 times greater impact on heat loss reductions than in homes built after 1980 [77]. Houses built post-1980 significantly reduced emissions when switching to heat pumps and eliminating the use of natural gas.

In Canada, the most common type of dwelling improvement to reduce energy consumption were replacing water heating equipment, followed by space heating equipment and windows[84]. Since 6.1 million households made home improvements that could have improved the dwelling conditions and reduced energy consumption. In 2023, only 7% of all Canadian households used heat pumps and approximately 9% of households in the highest-income quintile reported using heat pumps, meanwhile only 5% of households in the lowest-income quantile used heat pumps [23]. Furthermore, the most common source of heating in low-income households is electric heating, 47% of households in the low-income quantile. In the summer it was reported that 26% of Canadian households did not have air conditioning or other cooling equipment which further exacerbates hidden energy poverty because electricity use may decrease but indoor temperatures are still uncomfortable. Additionally, a study completed in Germany with a very similar methodology to this one, highlighted that from the households that were classified as energy poor, 2.5% of German households were not able to keep their homes adequately warm, and 12.0% faced poor housing conditions, including leaking roofs, damp walls, foundation or floors, or rot in window frames [62].

While deep energy retrofits and improving energy performance through enhancing HVAC and building enclosures are crucial to reducing energy consumption, indoor air quality (IAQ) is also important since it affects health and occupant comfort. Poor indoor air quality is often exacerbated by inadequate ventilation, damp conditions, and inefficient heating systems, and can lead to chronic respiratory illnesses like asthma. These trends are exacerbated in low-income households since they tend to be older with a higher normalized leakage than conventional

homes [85] [86]. Additionally, low-income residents tend to live in smaller dwellings in multi-unit residential buildings (MURBs) which might increase the influence of indoor pollutants due to shared walls [87].

Outside of the USA and Canada, studies have highlighted the relationship between poor-performing homes and indoor air quality [88]. In addition, many studies reported that low-income populations are already disproportionately impacted by poor IAQ [89], [90], [91], [92], [93]. Thus, it is urgently needed to review the impact of poor-performing homes on IEQ for low-income populations in the USA and Canada. Furthermore, the impact of specific challenges experienced by low-income populations, such as energy poverty, should be further examined.

2.8 Health Impact

Energy hardship notably manifests in physical and mental health. Riva et al. demonstrated a negative association between energy hardship and the health of Canadians, with those facing energy hardship being significantly more likely to report poorer general and mental health [19]. Additionally, one million households in Canada were affected by energy hardship, with direct effects on health and incidences of eviction and homelessness [94]. The relationship between energy poverty and health is closely tied to factors such as occupant discomfort and exposure to thermal stressors[95]. These thermal stressors are amplified by climate change and the heat island phenomenon prevailing in major urban centers, as extremely hot or cold outdoor temperatures create a challenge to maintain appropriate indoor temperatures. Especially when households cannot afford to heat or cool their homes adequately. Thermal stressors are more common to occur in older residential housing where individuals may not be aware of required upgrades and most importantly, might not be able to afford them. These extreme climate events have been increasing in frequency and severity due to climate change. They will continue to increase in the years to come further exacerbating health consequences due to challenges to heating and cooling houses adequately and cost-effectively [96].

The consequences of cold homes on health have been researched widely. Respiratory infections, strokes, and inflammatory diseases increase in low temperatures. The Department of Epidemiology & Public Health at University College London completed a review on the health impacts of cold homes on children, adults, and the elderly, known as the Marmot Review. The review identified that cold homes are a factor in the increase in respiratory, circulatory, and mental illnesses [97]. The review also concluded the following for indoor temperature when it comes to vulnerable populations such as kids and the elderly:

- Temperatures that are lower than 16°C appear to impair respiratory functions
- Temperatures below 12°C place strain on the cardiovascular system
- Temperatures below 6°C people are at risk of hypothermia

This is because inhaling cold air and the cooling of the body surface, which lowers the core body temperature, can suppress the immune system, increasing susceptibility to infections [98]. The most common illnesses that are associated with the cold are usually the common flu and cold. However, children living in damp, moldy homes are between 1.5 and 3 times more prone to asthma and respiratory conditions than children in homes with no mold [97]. Further studies with larger sample groups need to be completed to determine the impact of prolonged exposure to cold indoor temperatures.

A study completed in Germany identified an increase in stroke risk factors for extreme temperature drops within 24 hours. The study was completed in conjunction with Jena University Hospital where over 1500 patients were screened to determine the cause of their strokes [99]. The American Journal of Stroke and Cerebrovascular Disease also noted a similar correlation between lower temperature and stroke hospitalizations [100]. It is important to note that the cold is not the only risk factor, but it can increase the likelihood of strokes due to the physiological effects of the cold on the human body.

The impact of cold homes is not limited to physical health. Mental health is largely impacted by energy poverty due to financial stressors, productivity, and overall lack of positive well-being. Since mental health is not systematically measured in children, most of the research is focused on adults and the elderly. The impacts of energy poverty on mental health are usually associated with anxiety, depression, and social isolation. Studies across Africa, Scotland, and China all show a negative impact on mental health due to energy poverty, where individuals living in cold homes reported episodes of anxiety and/or depression [71]. Similarly, indoor overheating also has a negative impact on the health and well-being of households. The increase in outdoor temperature and frequency of heat waves are increasing the likelihood of occupants experiencing indoor overheating. Further studies need to be established for evaluating the heat on health and its relevance in Canada as well as methods to measure it. This is because most households do not have cooling equipment (e.g., ceiling fans, air conditioners, and heat pumps) and are most likely experiencing indoor overheating, a condition expected to become more frequent in the coming decades.

Finally, a few studies investigated the holistic impacts of energy poverty on occupants' health (physical and mental). A study across 32 European countries examined the relationship between energy poverty, general health, and mental well-being. The indicator used in this study to determine energy poverty was the affordability of energy [101]. To measure physical and mental wellbeing a self-reporting health status tool that is commonly used in public health and epidemiology research was used. Thomson et al. found that countries with a higher number of households struggling with energy poverty have a higher poor health score. Similarly, the World Health Organization index score (WHO-5) was used to measure mental well-being. The results identified a similar trend, where countries with individuals that were considered energy poor

scored lower on the well-being scale. This further highlights the relationship between energy poverty and physical and mental health. This study is important because it is one of the few studies that have a large sample size (~40,000) across multiple countries, removing any potential socioeconomic, cultural and technical (e.g., construction practices) bias.

To summarize, the relationship between climate change, energy hardship, and health underscores the urgency to address energy inefficiency and affordability challenges, particularly in low-income and vulnerable populations. Buildings account for a significant portion of global greenhouse gas emissions, making retrofitting and energy efficiency improvements essential to achieving net-zero goals. However, the capital-intensive nature of electrification and retrofitting disproportionately affects low-income households, rural communities, and Indigenous populations, exacerbating associated social inequities. Current methodologies for assessing energy hardship in Canada are fragmented and inconsistent, often relying on expenditure-based measures that fail to capture the complexities of household energy needs, building conditions, and socioeconomic factors. This research aims to establish a standardized approach to energy poverty measurement using national datasets while exploring the impact of electrification and energy efficiency measures on Canadian households, with a focus on Ontario. This is achieved by addressing these gaps, the study seeks to provide actionable insights to inform equitable climate policies, potentially reduce energy poverty, and enhance climate resilience in the built environment.

Chapter 3 : Methodology

The methodology used to address the objectives of this study utilizes the energy poverty, burden, and hardship definitions presented under the literature review to ensure clarity and consistency with past studies and practices (eq 2.1, eq 2.2 and eq. 2.3, respectively). It is important to reiterate that energy hardship serves as a general term encompassing both energy poverty and energy burden.

The indicators that were focused on establishing energy hardship rates were income after tax, energy expenditure (electricity, natural gas, and other fuel sources), and housing cost (rent or mortgage). The energy hardship rates (including energy poverty and burden) were calculated using three thresholds: 2M, 6%, and 10%. This established a baseline for existing energy hardship conditions and allows for a comparison with previous studies that used 6% and 10% as a threshold.

The analysis was completed in two phases. Phase 1 aims to understand how household characteristics, including dwelling type and age, influenced energy burden and poverty in Canada and Ontario. Since energy poverty is a socio-economic issue, demographic information such as education and household type were also considered. Phase 2 was prompted by the lack of information in the surveys about dwelling conditions to determine energy efficiency. Hence calibrated numerical energy models were used to estimate current and future energy consumptions and assess how household envelope and HVAC upgrades can potentially impact energy poverty in the short- and long-term, considering climate change.

3.1 Statistical Input Data

The data used in this project was requested from Statistics Canada. After submitting the proposal in April of 2023, approval and security clearance were completed in December of 2023. All the data analysis was completed at the Southwestern Ontario Research Data Centre (RDC) at the University of Waterloo and the Toronto RDC at the University of Toronto. The RDC is a secure physical location, available only to accredited researchers to access disaggregated and anonymized data. The surveys requested were:

- Canadian Housing Survey (CHS) for 2018
- Canadian Housing Survey (CHS) for 2021
- Canadian Housing Survey (CHS) for 2022
- Survey of household spending (SHS) for 2019
- Survey of household spending (SHS) for 2021

Statistics Canada granted us access to CHS for 2018 and 2021, and SHS for 2019 and 2021. It is important to note that each survey has a unique data sampling methodology. The surveys are not linked, and each presents a different information set. CHS collects information about

housing needs and experiences, which applies to occupant health and comfort [102]. The SHS is focused on collecting data on household expenditures. This includes the total annual income of households from personal income tax data as well as demographic, dwelling characteristics, and energy costs: electricity, natural gas, and other fuel sources. While it is important to include occupant comfort in the study and understand how it affects energy poverty, linking the two datasets presented many limitations due to Statistics Canada's lengthy process and the CHS has strict output vetting rules [103]. Thus, to address the objectives and stay within the scope of this thesis, only the SHS was used to complete the data analysis.

The SHS survey sampling that was made available to the researchers includes two steps: an interview conducted in-person with a questionnaire and a spending reporting diary. The interview collects expenditures such as housing costs, energy costs, and less frequent expenditures such as furniture and dwelling repairs. Demographic, dwelling characteristics, and household equipment information are also collected during the interview. In conjunction with the interview, the survey data is combined with tax data to collect household income for the previous year of the reference period. For example, the 2019 survey uses household income and tax information from 2018.

After the interview, the participants are asked to complete a spending diary to report on all spending excluding household costs and vehicle purchases. The data set in the RDC is presented in four separate files: household interview, household diary, person interview, and person diary. As a result, the data set used contains the results from the household interview since it includes all the required information to calculate energy poverty. The data from SHS is collected continuously during the entire reference year, from January to December. The target population includes the 10 provinces and the three territorial capitals of Whitehorse, Yellowknife, and Iqaluit. The survey excludes Indigenous communities, people living in military camps, residences for dependent seniors, school residences, work camps, and members of religious and other communal colonies. The excluded communities make up less than 0.5% of the target population and to ensure the data set is representative of the population weights are assigned to each household that participated in the survey [104]. These weights are applied to the data analysis to abide by Statistics Canada’s vetting rules and data release from the RDC. The rules state that the minimum required frequency is 5 households for any descriptive results and the outputs must be rounded to the nearest multiple of 50. The vetting rules are enforced to protect the confidentiality of individual respondent data, but it does not correspond to any measure of the quality of the analysis. Additionally, the output must be on the province level or in major cities like Toronto, Vancouver, and Montreal [105].

3.2 Phase 1: Household Characteristics and Energy Burden and Poverty Assessment for Canada and Ontario

3.2.1 Data Clean-up and Aggregation

The data aggregation and clean-up process were driven by the vetting rules and consideration for user input errors during data collection. These considerations included errors in both the income and yearly tax entries, as there were numerous entries with zero values. To abide by the vetting rules, some categories in the data set columns had to be combined. The new groups created to complete the analysis are presented in Appendix A – National Statistical Results and Appendix B – Ontario Statistical Results . From those columns, the total household income and total energy spending were filtered to exclude values below or equal to zero. Errors noted in the data set were likely due to user-input inconsistencies, and information extracted from the Canadian Revenue Agency (CRA). Additionally, the vetting rules presented many limitations in how the results were presented, and in many cases, results were not extracted because the unweighted frequency of households was below 5 households.

Rows with non-positive income or energy spending were removed, Additionally, rows with codes indicating "none stated" answers were eliminated. Dwelling types of motels, hotels, and others were also eliminated as they do not need to be included in this analysis. Finally, the duplex category was merged with the townhouses category to accommodate the vetting count rules.

3.2.2 Calculating Energy Burden and Poverty Rates

All the energy poverty and burden rates were calculated using expenditure data from the SHS. The energy expenditure ratio (EER) represents the ratio of household income spent on total energy consumption, including electricity, natural gas, and other household fuels.

$$Total\ Energy\ Consumption\ (\$) = Electricity(\$) + Natural\ Gas(\$) + Other\ Household\ Fuels(\$) \quad (3.1)$$

Four different EER definitions were used to account for varying household expenses:

Basic EER, including only income after taxes.

$$EER_{it} = \frac{Total\ Energy\ Consumption\ (\$)}{Total\ Income(\$) - Income\ Tax\ (\$)} \quad (3.2)$$

EER excluding housing costs, since rent and mortgage payments are essential

$$EER_{hctax} = \frac{Total\ Energy\ Consumption\ (\$)}{Total\ Income(\$) - [Income\ Tax(\$) + Housing\ Costs(\$)]} \quad (3.3)$$

EER excluding housing, food, and health care costs, recognizing that food and health care are also necessities affecting disposable income.

$$EER_{hcf} = \frac{Total\ Energy\ Consumption\ (\$)}{Total\ Income(\$) - [Income\ Tax(\$) + Housing\ Costs(\$) + Food\ \&\ Health\ Care\ Costs(\$)]} \quad (3.4)$$

EER excluding housing, food, health care, and additional heating/cooling costs, accounting for inefficient homes that require extra heating or cooling.

$$EER_{hchac} = \frac{Total\ Energy\ Consumption\ (\$)}{Total\ Income(\$) - [Income\ Tax(\$) - Housing\ Costs(\$) - Food\ \&\ He \quad Care\ Costs(\$) - Additional\ Heating\ and\ Cooling\ Costs\ (\$)]} \quad (3.5)$$

Property taxes, condominium fees, and transportation fuel costs are excluded from all EER calculations. Since energy hardship depends on a household's ability to afford adequate heating and cooling with their disposable income, these variations in EER definitions help capture different financial constraints. E.g., older, inefficient homes may require energy efficiency upgrades or supplemental heating/cooling devices, further influencing energy affordability.

Once EERs were calculated, they were compared against three energy hardship thresholds. The thresholds were twice the national median (2M, calculated from the data set), six percent (6%) and ten percent (10%). To distinguish between energy burden and energy poverty, households with Low-income cut-offs per Statistics Canada [106] were used in Eq. 2.1 and Eq. 2.2, as shown in Table 3.1.

Table 3.1. Low-income cut-offs (LICOs) after tax by family size, in current dollars *[106]*

Community size	Family size	2019	2021
Population 500,000 and over	1 person	$ 21,899	$ 22,801
	2 persons	$ 26,653	$ 27,750
	3 persons	$ 33,189	$ 34,555
	4 persons	$ 41,406	$ 43,110
	5 persons	$ 47,148	$ 49,090
	6 persons	$ 52,289	$ 54,442
	7 persons or more	$ 57,429	$ 59,794

Finally, statistical weights were applied, and averages and percentiles were calculated, to estimate the total energy cost under the three energy poverty (EP) thresholds (i.e., 6%, 10% and 2M). The analysis was performed nationally, then for Ontario.

3.2.3 Key Metrics for Assessing Energy Burden and Poverty

The study examines how factors such as dwelling and household characteristics such type, dwelling age, maintenance, household income, household size, education level, and energy cost,

influence energy poverty in Canada and Ontario. These parameters were selected based on the data available from the SHS. By analyzing these individual metrics, the study identifies which factors are most strongly associated with energy poverty and the extent to which they contribute to household energy burden.

However, a key limitation of this approach is that it examines the individual impact of each factor in isolation, rather than assessing how multiple factors may interact to influence energy poverty. Energy poverty is often the result of a combination of economic, demographic, and housing-related factors acting together. Future research should consider multivariate analyses or machine learning approaches to better understand how these variables interact and compound energy vulnerability.

3.3 Phase 2: Energy Modeling for Efficiency and Climate Adaptation for Energy Poor Households in Toronto, Ontario

A numerical energy simulation model was developed using Rhino and Climate Studio to represent a median detached household in Toronto based on the 2019 SHS dataset. The methodology follows a structured approach that can be applied to other regions and dwelling types to evaluate energy poverty and the effectiveness of energy retrofits.

1) 3.2.1 Baseline Model Development

A baseline energy model was created to simulate the energy consumption of a typical energy-poor household. The model represents a median detached dwelling in Toronto and was calibrated using household energy expenditures from the SHS 2021 dataset, under typical meteorological weather conditions (TMY3). Details on the selection of housing characteristics used in the model are provided in Section 4.3.1. The baseline scenario was evaluated under projected future climate conditions using 2.5 Global Warming Potential (GWP) and 3.5 GWP scenarios. This analysis determines whether a business-as-usual scenario will remain resilient to energy poverty as climate conditions shift.

2) Energy Retrofit Scenarios

To assess the potential for energy poverty alleviation, retrofit scenarios were applied to the baseline model in a staggered approach:

a. Lighting Upgrades
b. Roof Assembly Upgrade
c. Envelope Upgrade Model
    i. Focuses on building enclosure improvements (e.g., increased insulation, and reduced air leakage).
    ii. Evaluate whether envelope upgrades alone can lift an energy-poor household out of energy poverty under current climate conditions.
d. Envelope + HVAC Upgrade Model
    i. Replace the existing natural gas furnace with an air source heat pump (ASHP) for heating and cooling.
    ii. Provides additional insights into the electrification of residential heating and its role in Canada's decarbonization commitments.

3.4 Methodological Limitations

While the methodology is scalable and adaptable to different geographic locations and household types, it does not account for future changes in energy costs or household income. This exclusion was intentional, as projecting these variables over the next 50 years remains highly uncertain given global economic instability. For similar reasons, while the study evaluates energy efficiency measures in current and future climates, it excludes capital and maintenance costs.

This framework provides a repeatable and accessible approach for researchers to assess energy poverty and the impact of retrofits across various regions and climate conditions.

Chapter 4 : Results & Discussion

4.1 National Statistical Results

To reiterate, three key thresholds were used to evaluate existing energy burden and poverty (i.e., 2M, 6%, and 10%) applied to four energy expenditure ratios (i.e., EER_{it}, EER_{hctax}, EER_{hcfh}, and EER_{hchac}). Initially, the analysis was completed nationally to understand the extent of energy hardship for Canadian households. Next, the impact of individual household characteristics on energy poverty and burden was evaluated to assess how each factor influences the extent of energy burden before and after housing costs.

Note that this study focuses on using the twice-the-median (2M) energy expenditure threshold. The preference of 2M over fixed percentages like 6% or 10% comes from its ability to adjust dynamically based on actual energy spending patterns. Unlike fixed thresholds, which apply universally, the relative measure accounts for regional differences in climate, energy costs, and housing efficiency, making it more adaptable to varying economic and social conditions.

Another key advantage is that the 2M approach avoids rigid cutoffs that may not reflect actual affordability challenges. Instead of imposing a universal standard, it adjusts in response to changes in average energy use and economic shifts. Furthermore, this method aligns with other relative poverty measures, ensuring consistency with broader economic assessments. By capturing energy poverty in a way that reflects real-world conditions, it provides a more accurate and context-sensitive tool for policymakers.

When applying this approach to the data from the SHS for 2019 and 2021, the calculated twice median thresholds for Canada listed in Table 4.1.

Table 4.1. Calculated Twice the Median (2M) Thresholds for Energy Expenditure Ratios

Energy Expenditure Ratio (EER)	2019	2021
EER after income tax ($EER_{it)}$	5.48%	5.22%
EER after housing cost (EER_{hctax})	6.23%	5.96%
EER after food & medical expenses (EER_{hcfh})	7.14%	6.74%
EER after additional heating and cooling expenses (EER_{hchac})	7.17%	6.76%

Depending on the EER definition, the 2M threshold ranges from 5.22% to 7.17%, centering around 6%. In 2021, 4.6% of Canadian households fell under energy poverty (dark orange) before housing cost, while 13% experienced a high energy burden (light orange). These percentages change to 4.2% and 13.6%, after housing cost, then 3.9%, and 15.8% when other basic household expenses (e.g., housing, health food) are included. There was a notable increase in energy hardship rates when including other household expenses because disposable income is decreasing, resulting in a larger EER.

Overall, the percentage of Canadian households in energy hardship increased when evaluating the 6% threshold, especially after deducting necessary expenses from income, 5.1% and 21.6% of households were energy poor and burdened. The percentage of households decreased at the 10% threshold, only 2.7% and 2.4% are energy poor and burdened. This is because the 10% threshold is an extreme case of energy hardship, the dwelling must be extremely inefficient, or occupants are likely to decrease their energy use to save on costs. Figure 4.1 summarizes the changes in energy hardship rate in 2019 and 2021 across all three thresholds. The initial analysis and results also present the 6% and 10% thresholds. This choice allowed for a comparison with findings from a study conducted by Riva et al. in 2017 who used the same survey from 2017 and to provide readers with a perspective on how the energy hardship has changed over the years. These results will be addressed in further detail in Section 4.1.1 Comparison with Past Energy Hardship Studies in Canada.

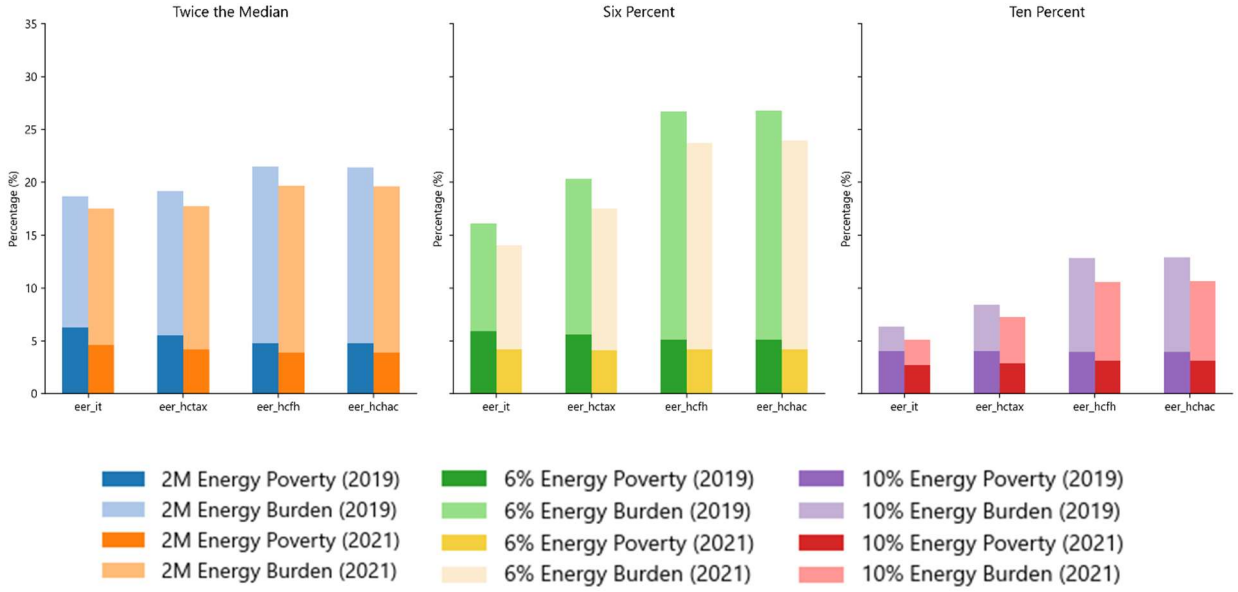


Figure 4.1. Percentage of Canadian Households in Energy Hardship based on four EERs

The figure above demonstrated that between 2019 and 2021, there was a decrease in overall energy hardship as presented in Figure 4.1. The 2M results indicate that 12.4% and 13% of households in Canada were experiencing energy hardship before housing costs (EER_{it}) in 2019 and 2021. After housing costs (EER_{hctax}), 13.6% of households were in energy hardship, in 2019 and 2021. The decrease was prominent in energy poverty rates from 2019 to 2021. In 2019, 6.2% were energy poor, followed by a reduction to 4.6% in 2021 before housing costs (EER_{it}). Similarly, after housing costs (EER_{hctax}) energy poverty in Canada decreased from 5.5% to 4.2%.

Subsequently, energy hardship is most prevalent in Atlantic Canada, particularly in New Brunswick, Newfoundland and Labrador (NL), Nova Scotia, and Prince Edward Island (PEI) before and after housing costs. Atlantic Canada is predominantly rural, with most residents living in

single detached dwellings, which are characteristics noted in energy burdened and poor households [107]. In 2021, PEI had the highest energy poverty rates (7.1% and 7.3%) before and after housing costs, while Alberta had the lowest (4.4% and 4.2%). Moreover, Newfoundland and Labrador had the highest energy burden rates (36.4% and 34.9%), while British Columbia had the lowest energy burden (9.2%) before housing cost, Quebec had the lowest energy burden after housing cost (10.2%). Overall, energy hardship is below the Canadian median in only British Columbia(~14%), Ontario(~17%), and Quebec(~15%). Meanwhile, New Brunswick had the greatest reduction in energy hardship from 2019 to 2021 (~5%) while Newfoundland and Labrador (~40%) had the highest energy hardship in 2021 as presented in Figure 4.2.

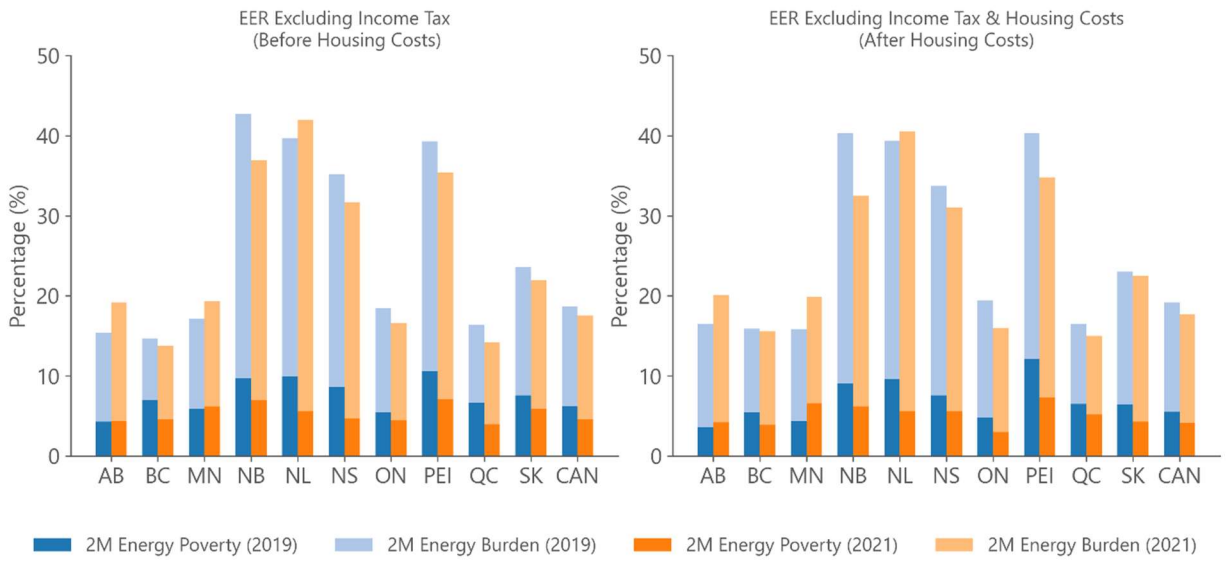


Figure 4.2. Per Province Analysis of Energy Burden and Poverty using the 2M, before and after Housing Costs

The different sources of heating likely influence the difference in energy hardship rates across provinces. For instance, western provinces like Alberta, British Columbia, and Ontario rely more on natural gas for heating, whereas eastern provinces, including Quebec and the Atlantic region, use diverse heating fuels such as electricity, heating oil, and biomass[108]. As fuel prices continue to rise and deprivation and political pressure grow, the plight of the energy poor will require greater attention [109]. Ontario-specific results will be discussed in section 4.2 Ontario Statistical Results.

It is extremely evident that when disposable income decreases, the percentage of households in energy hardship increases. Food and medical costs were included to analyze necessary household expenses holistically. Often, energy-poor households compromise their comfort, food, and medical needs to afford energy bills. Thus, it is important to gain an understanding of

how much the EER increase impacts the rates of energy burden and poverty. Few households had additional costs for additional heating or cooling equipment, which explains the small increase in EER_{hchac}. Figure 4.3. Per Province Analysis of Energy Burden and Poverty Using the 2M, after Food, Medicine, Additional Heating and Cooling Costs highlights the increase in energy burden and poverty rates when adding food and medicine costs. After including housing costs, food, and medicine costs, the prevalence of energy poverty increased in most provinces but increased in PEI and NL by ~1%. However, energy burden increased across all provinces.

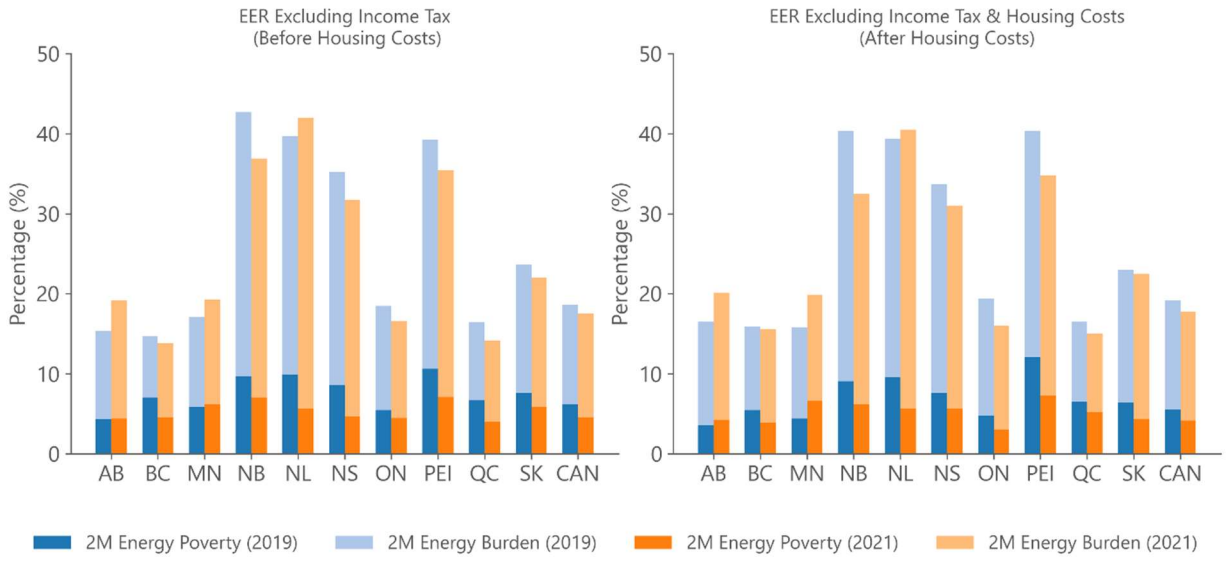


Figure 4.3. Per Province Analysis of Energy Burden and Poverty Using the 2M, after Food, Medicine, Additional Heating and Cooling Costs

For each EER, before housing costs, after housing costs, and after additional food, medicine, heating, and cooling costs. Energy poverty increased from 2019 to 2021 by 1.7%, 1.4% and 0.9% across each EER measure, respectively. However, the energy burden decreased by 0.5%, 0.1%, and 0.9%. Nationally, these reductions are very modest and could be attributed to a minor reduction in energy consumption or income increase. Furthermore, the prevalence of energy poverty in PEI and NL increased in 2021. The results from this analysis are consistent with the trends from previous Canadian studies which will be discussed in detail in the following section.

4.1.1 Comparison with Past Energy Hardship Studies in Canada

In a study completed in 2017, Riva et al. [6] concluded that per the 6% threshold, the prevalence of energy hardship was 18.1% and 19.2% before and after housing costs; using the 10% threshold the sum was 6.2% and 10.4% before and after housing costs. The energy hardship results from 2017 to 2021 are compared in Table 4.2.

Table 4.2. Prevalence of National Energy Hardship Based on the 6% and 10% Thresholds from 2017 to 2021.

Year	6%		10%	
	Before Housing Cost (%)	After Housing Cost (%)	Before Housing Cost (%)	After Housing Cost (%)
2017[6]	18.1	19.2	6.2	10.4
2019	16.1	20.3	6.3	8.4
2021	14.0	17.5	5.1	7.3

Despite the challenges posed by the COVID-19 pandemic, energy hardship has clearly declined over the last three survey periods. The initial hypothesis suggested that the pandemic would increase household energy hardship, raising both energy burden and poverty rates due to higher residential energy consumption from widespread telework [44]. However, national data from 2017 to 2021 indicate a consistent decline in both energy burden and poverty rates.

This decline may be attributed to factors like implementing energy efficiency measures, climate change, and hidden energy poverty. In 2019, residential energy consumption in Canada totaled 90.5 GJ, decreasing to 85.4 GJ in 2021, largely due to energy efficiency measures and green initiative programs [110]. Additionally, 6.1 million households undertook home improvements aimed at reducing energy consumption, including replacing water heating equipment, space heating systems, and windows [84]. These upgrades likely contributed to the overall decline in energy burden and poverty in 2021. Among these households, approximately 934,000 received government grants as part of home energy programs, supporting efficiency improvements. Another contributing factor could be a reduction in heating degree days from 2017 to 2021, influenced by climate change. Figure 4.4 illustrates the decline in heating degree days from 2019 to 2021.

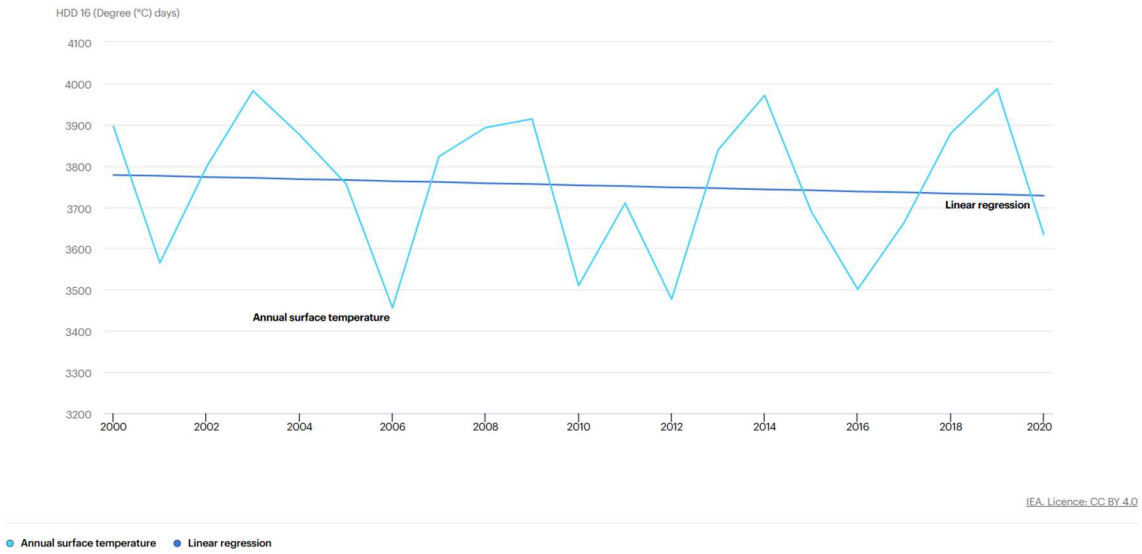


Figure 4.4. Heating Degree-Days in Canada, 2000 – 2020 *[111]*.

Moreover, in 2023, 14% of Canadian households reported that they kept their dwellings at unsafe temperatures for at least one month in the past 12 months because of unaffordable heating or cooling [27]. These households may not be accurately represented in the SHS data. While their energy consumption appears reduced, this reduction results from sacrificing occupant comfort rather than efficiency measures. Although many of these households experience energy poverty, the SHS data does not allow for their identification, further exacerbating hidden energy poverty.

4.1.2 National: Characteristics of Households Experiencing Energy Hardship

The following section investigates the characteristics of Canadian households experiencing energy hardship, the metrics used moving forward will be the 2M threshold with the result before housing costs (EER_{it}). All other completed results for all three thresholds 2M, 6%, and 10% as well as after housing cost (EER_{hctax}) can be found in Appendix A – National Statistical Results, along with the syntax used to conduct the analysis in Appendix D – Syntax used in the RDC for Statistical Analysis.

4.1.2.1 Impact of Household Income

Household income directly influences the calculation of EERs and energy hardship, making its impact fundamental. Figure 4.5 presents that low-income households are more likely to experience energy poverty, underscoring the importance of distinguishing between energy burden and energy poverty. The analysis indicates that nearly 40% of Canadian households with an income of CAD$29,000 fall under energy poverty. However, approximately 30% of households with an income of CAD$30,000- 59,000 are energy burdened and less than 5% are energy poor. The percentage of energy poor households rapidly decreases as income increases. An important observation is energy poverty is eliminated for all households above CAD$60,000, but some households may still be energy burdened. This is due to the initial definition of energy poverty as defined in 2.1 On Terminology for Energy Poverty. Low-income households are more likely to prolong or reduce the use of heating or cooling to manage energy costs, prioritizing affordability over comfort. The Canadian Social Survey reveals that foregoing basic needs was most prevalent in households in the lowest income quintile in 2023. Nearly one in five households reported forgoing necessities such as food and medicine. This is also the reality for middle-income households, where approximately 16% reported sacrificing basic needs to afford energy bills. While it is less common, 8% of households in the highest quintile reported cutting back on essentials to cover their energy costs [27]. These trends are also noted in the US, 35 million out of 118.2 million households reported skipping meals or medication to afford energy bills [7].

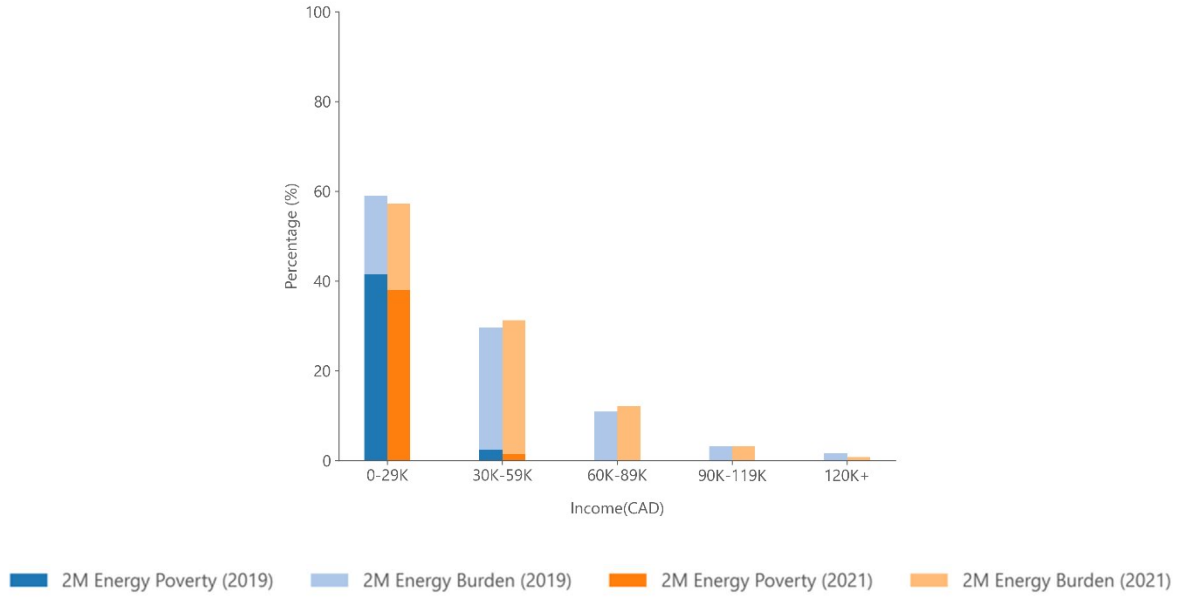


Figure 4.5. Percentage of Canadian Households in Energy Burden and Poverty based on Income, for 2019 and 2021.

4.1.2.2 Impact of Employment and Education

Education and employment are linked to household income, with employment status being a key determinant. Figure 4.6 highlights that full-time employment helps reduce energy hardship. In 2019, 20.2% of households where the primary earner was unemployed experienced energy burden, while 11.3% were classified as energy poor. By 2021, these figures shifted to 21.9% and 9.5%, respectively, indicating modest changes in energy burden and poverty levels during the pandemic.

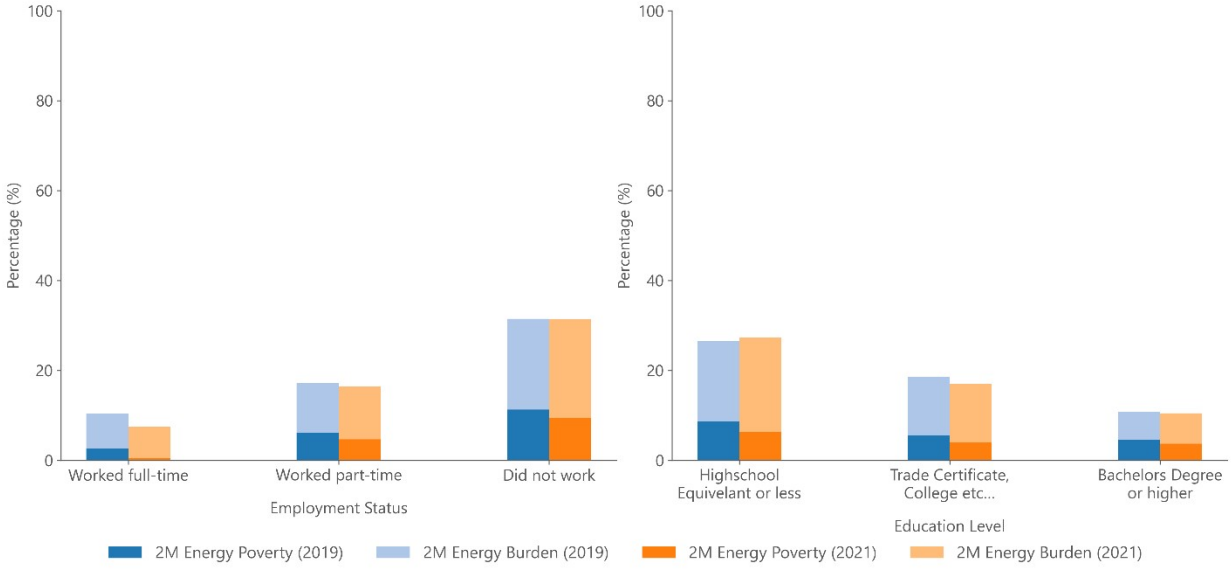


Figure 4.6. National Energy Burden and Poverty as a Function of Employment and Education Status, Before Housing Cost, using 2M Thresholds, for 2019 and 2021.

The analysis also identified that education level significantly influences energy burden and poverty rates in Canada. Households where the primary earner holds a bachelor's degree or higher are less likely to experience energy hardship compared to those with lower educational attainment, as shown in Figure 4.6. Unemployment is one of the major characteristics that impacts energy burden and poverty since it directly influences income which heavily influences the EER calculations.

4.1.2.3 Impact of Dwelling Age and Type

High energy costs can be attributed to a combination of factors, including building characteristics like dwelling age and type, HVAC system, and occupant behavior. Figure 4.7 presents energy hardship as a function of the dwelling type and age. The analysis indicates that dwellings built before 1960 are more likely to experience energy poverty and burden, due to poor building conditions and outdated HVAC equipment. The analysis confirms that single-detached dwellings are more likely to experience energy hardship than other household types due to their lower energy efficiency compared to townhouses and apartments. In 2021, 21.2% of

single detached households were in energy hardship, with the majority being in energy burden (17.1%) in comparison to high-rise apartments that were predominantly energy poor (2.9%). The National Building Code of Canada (NBCC) was updated in 1977 to include HVAC requirements and minimum performance standards for enclosures [80].

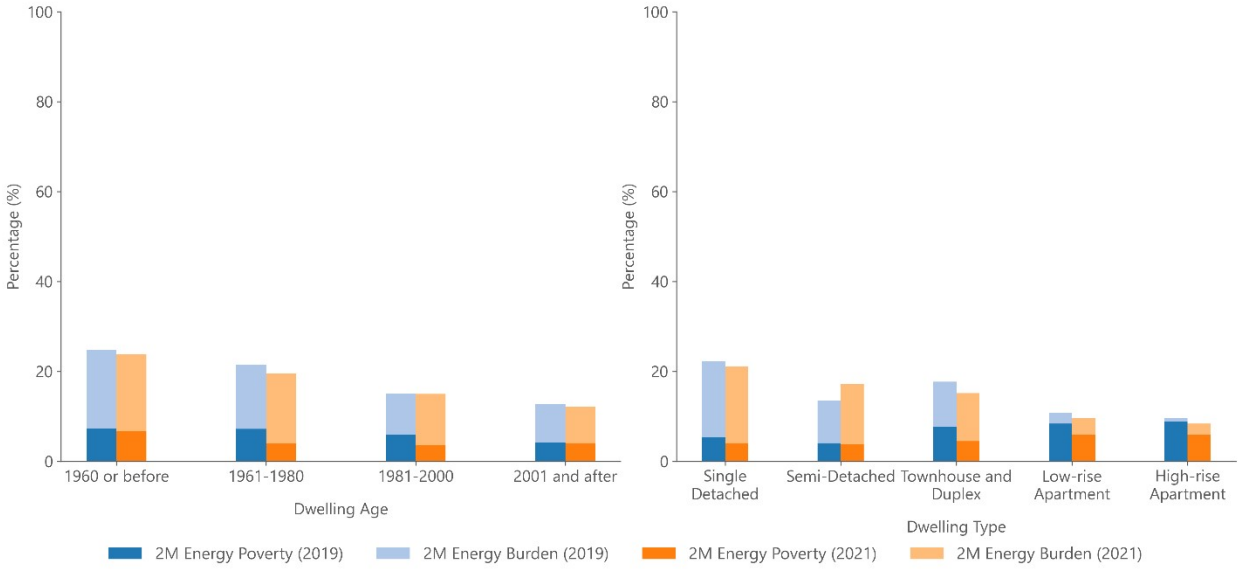


Figure 4.7. Percentage of Canadian Households in Energy Burden and Poverty as a Function of Dwelling Age and Type, for 2019 and 2021

Furthermore, single detached dwellings have greater exposure to outdoor conditions, higher heating and cooling demands, and lower insulation levels contribute to increased energy costs, making energy poverty more prevalent among these households. Single-detached dwellings tend to have a larger exterior surface area, including walls, roofs, and windows, leading to greater heat loss, air leakage, and thus, higher energy consumption per dwelling [64]. Single-detached homes also tend to have a significantly larger conditioned surface area compared to non-detached dwellings, such as more compact apartments. This larger space requires more energy for space conditioning, further contributing to higher energy consumption and increased vulnerability to energy hardship.

4.1.2.4 Impact of Household Size

Energy poverty is most prevalent among single-person households, with one in three experiencing energy hardship. In 2021, energy poverty among one person households was 10.5%, while it was significantly lower for households with two or more people, ranging from 1% to 2%. The researchers speculate that this pattern may be driven by the number of employed individuals in a household or the number of occupants in one-bedroom apartments. Figure 4.8 highlights energy hardship is inversely proportional to the number of people in a household

(referred to as household size). Interestingly, the relationship between the number of bedrooms and energy hardship is not straightforward. Households with two or three bedrooms had the highest rates of energy hardship, with one in five experiencing it. Note that the 2019 SHS did not include data on the number of bedrooms per household, thus, only the 2021 results are presented.

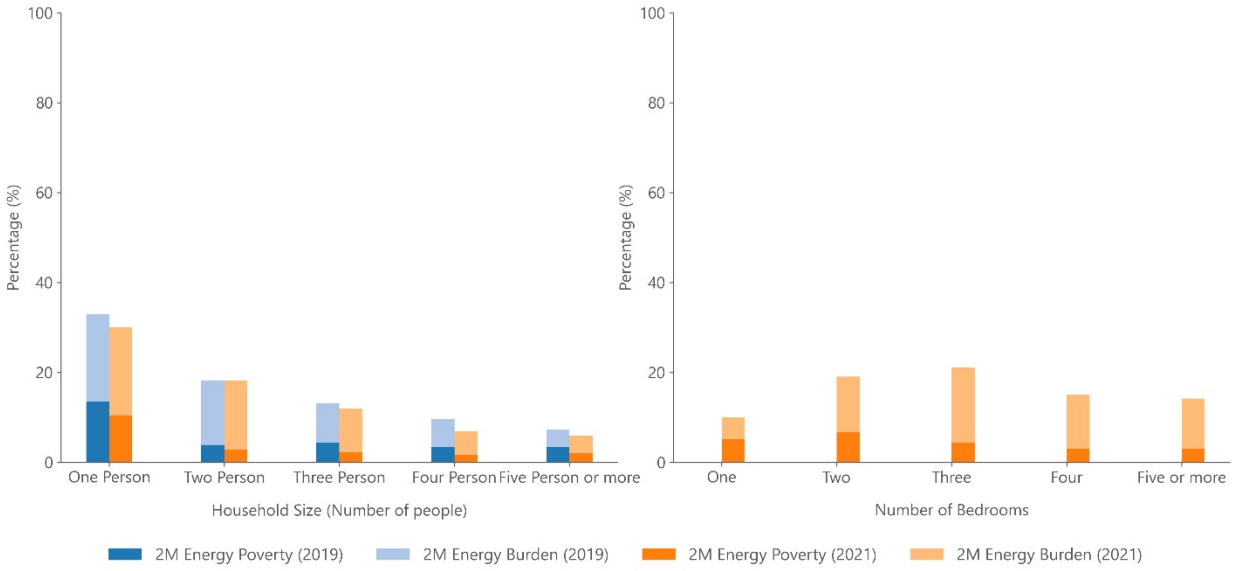


Figure 4.8. Percentage of Households in Energy Burden or Poverty as a Function of Household Size (Number of People) and Number of Bedrooms, for 2019 and 2021.

The researchers further speculate that one-bedroom households often refer to apartments, which tend to be more compact and may be more energy efficient due to shared walls that reduce heat loss. These buildings also benefit from centralized heating and cooling systems, which can lead to lower individual energy costs. On the other hand, households with four or more bedrooms are typically larger single-detached houses, which are more expensive to heat and cool. However, these households may have higher disposable incomes, allowing them to maintain their homes, potentially invest in energy-efficient upgrades, and better absorb energy costs. Households with two or three bedrooms may represent a middle ground where energy hardship is more pronounced. These households could be older, less energy-efficient single-family houses or townhouses occupied by families with moderate incomes, where financial resources are stretched across multiple expenses.

4.1.2.5 Impact of Household Tenure Type and Maintenance

This study found that renters often face unique challenges, as they typically lack control over energy efficiency upgrades and are disproportionately impacted by rising energy costs. This reinforces the strong connection between housing conditions and energy poverty. Figure 4.9 shows that in 2021, 11.2% of renters experienced energy poverty, the highest percentage among

tenure types, while 6.3% of households that required major repairs were in energy poverty. Additionally, owned households without a mortgage had the highest rates, with one in five experiencing an energy burden. Meanwhile, homeowners – whether with or without a mortgage – were more likely to experience energy burden than energy poverty. Furthermore, the study found that households in dwellings needing major repairs were significantly more likely to experience energy hardship, with over one in three affected, compared to less than one in five for those requiring minor or regular maintenance.

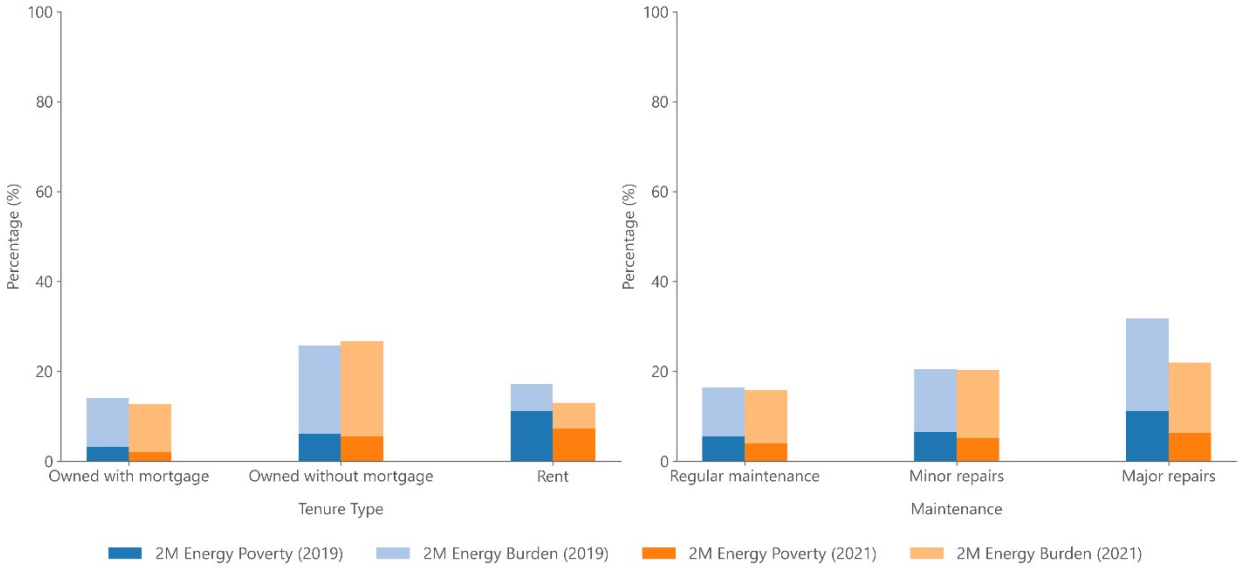


Figure 4.9. Percentage of Canadian Households in Energy Burden and Poverty as a Function of Tenure Type and Maintenance, for 2019 and 2021.

This finding aligns with existing literature indicating that households renting or occupying a home without paying rent are more likely to experience a high energy burden [40]. This further suggests that poor housing conditions directly contribute to higher energy burden and poverty, as dwelling envelope deficiencies and aged HVAC equipment can lead to increased energy consumption. This will ultimately impact renters more than homeowners.

4.1.2.6 Impact of Family and Marital Status

Energy hardship is influenced not only by economic and dwelling factors but also by socioeconomic characteristics, which play a critical role in shaping household vulnerability. The study identified consistent socioeconomic trends among energy-poor households, highlighting the impact of household's family marital status on energy hardship. Household composition appears to be a significant determinant of energy hardship. Figure 4.10 illustrates the distribution of household types and marital status among energy-burdened or energy-poor households. Single-person(10.5%) and lone-parent(5%) households are the most likely to

experience energy poverty, whereas couples without children and other multi-person households(including those with related or unrelated individuals) exhibit lower rates(2.1%). In Addition, marital status further influences energy hardship. In 2019, separated, divorced, and widowed individuals reported higher rates of energy hardship and burden. While these figures showed a slight decline in 2021, energy burden among widowed individuals increased by 20.3% percentage points.

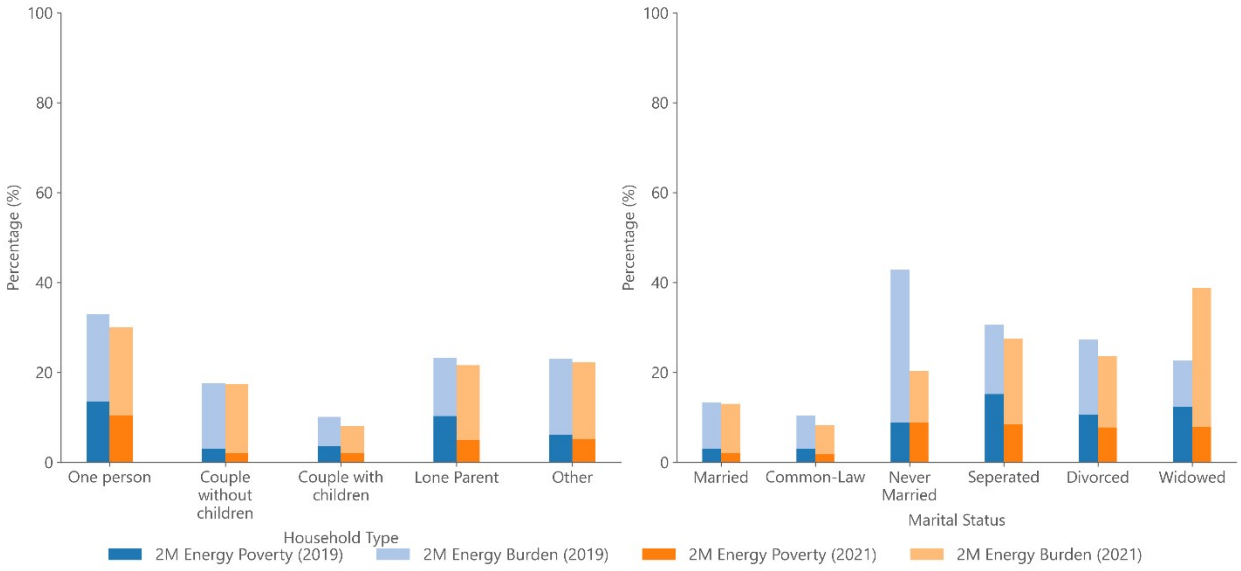


Figure 4.10. Percentage of Canadian Households in Energy Burden and Poverty as a Function of Family and Marital Status, for 2019 and 2021.

It is important to note that the literature has established that seniors are vulnerable to energy poverty [78]. While the SHS survey collects data on age and gender, it is limited to the household representative who participated in the survey, restricting broader demographic analysis. Future research should prioritize examining the age distribution within households, as those with children under five, elderly individuals, or people with disabilities are considered particularly vulnerable to energy poverty [7]. Expanding SHS data collection on these factors will provide a more comprehensive understanding of household energy vulnerability and inform targeted policy interventions.

4.2 Ontario Statistical Results

Ontario was selected for an in-depth analysis due to its higher-than-average household energy consumption, reaching 89.3 gigajoules in 2021, which exceeds the national average [110]. Single-detached houses comprised 53.6% of all occupied dwellings, while apartments in buildings with five or more storeys accounted for 17.9% of privately occupied dwellings in the province [112]. The analysis found that in 2019, Ontario's EERs were higher than the national

average, but by 2021, most had dropped below the national EERs, except for those measured after housing costs as demonstrated in Table 4.3.

Table 4.3. Calculated Twice the Median (2M) Thresholds for Energy Expenditure Ratios for Ontario

Energy Expenditure Ratio (EER)	Ontario		Canada	
	2019	2021	2019	2021
EER after income tax (EER_{it})	5.56%	5.14%	5.48%	5.22%
EER after housing cost (EER_{hctax})	6.56%	5.96%	6.23%	5.96%
EER after food & medical expenses (EER_{hcfh})	7.46%	6.54%	7.14%	6.74%
EER after additional heating and cooling expenses (EER_{hchac})	7.50%	6.64%	7.17%	6.76%

Figure 4.11 highlights these trends for 2M, 6%, and 10% thresholds. Despite this decline, Ontario households still faced significant energy burdens. Notably, in 2019, 14.27% of households experienced energy burden before housing costs, and 3.69% fell into energy poverty. By 2021, the proportion of households spending more than 10% on energy had decreased, though a substantial number continued to allocate between 5.5% and 6.5% of their residual income to energy. Like the national results the percentage of households with energy burden and poverty increases after including food, and health costs.

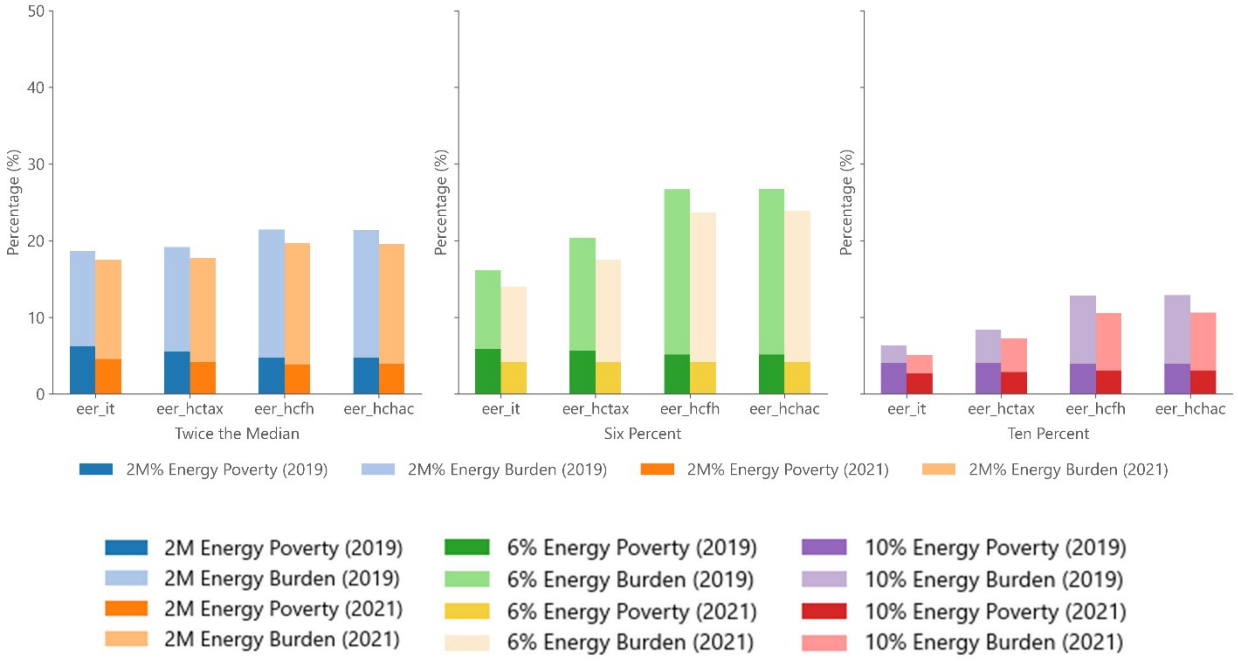


Figure 4.11. Percentage of Households in Ontario under Energy Burden and Poverty, for 2019 and 2021.

4.2.1 Ontario: Characteristics of Households Experiencing Energy Hardship

The following section investigates the characteristics of Ontario households experiencing energy hardship, the metrics used to move forward will be the 2M threshold with the result before housing costs (EERit). All other completed results for all three thresholds 2M, 6%, and 10% as well as after housing cost (EER_{hctax}) can be found in Appendix B – Ontario Statistical Results. Note that many of the results in this section were reacted due to the RDC vetting rules, which is why in some characteristics energy poverty is not shown.

4.2.1.1 Impact of Household Income

The household income trends in Ontario exceeds the national results. Figure 4.12 presents that low-income households are more likely to experience energy poverty, than energy burden further emphasizing the importance of distinguishing between energy burden and energy poverty. The analysis indicates that more than 40% of Ontario households with an income of CAD$29,000 fall under energy poverty. Nearly 40% of households with an income of CAD$30,000- 59,000 are energy burned and less than 5% are energy poor. The percentage of energy poor households rapidly decreases as income increases. An important observation is energy poverty is eliminated for all households above CAD$60,000, but some households may still be energy burdened, due to the definition of energy poverty identified in Section 2.1 On Terminology for Energy Poverty. This is consistent with previous studies where Ontario has consistently had the highest number of households struggling with energy hardship [24]. Households in Ontario also have a higher air conditioning and energy consumption rate relative to the national median, which would justify the higher prevalence in energy hardship.

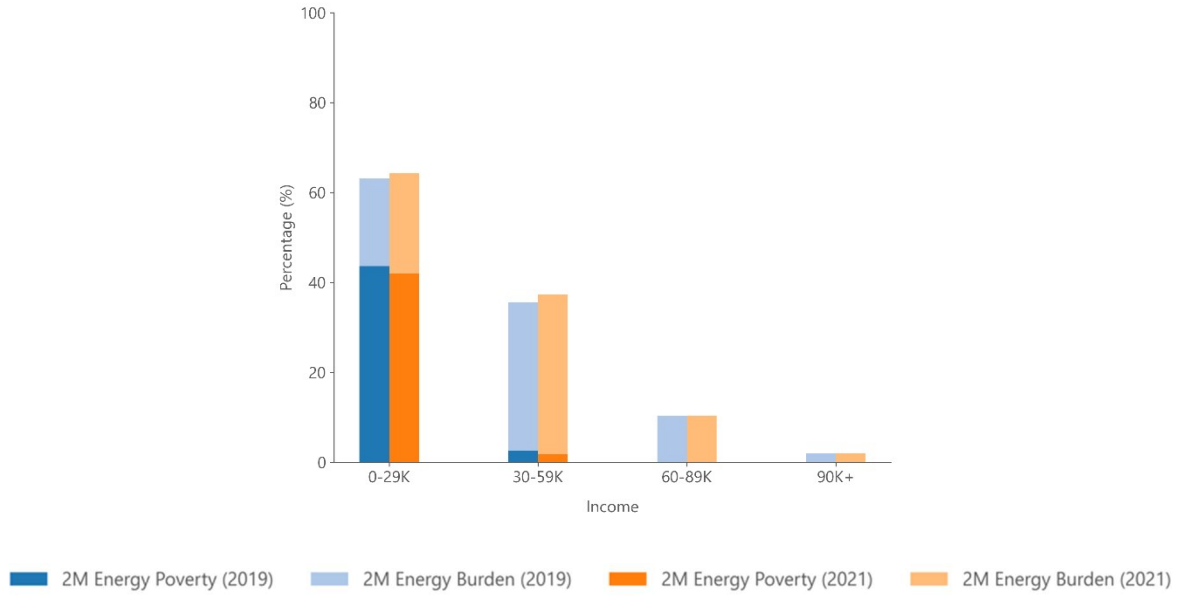


Figure 4.12. Percentage of Households in Ontario in Energy Burden or Poverty based on Income, for 2019 and 2021.

4.2.1.2 Impact of Employment and Education

Education and employment play a significant role in shaping household income, with employment status being a major factor. Figure 4.13 illustrates that full-time employment helps alleviate energy hardship. In 2019, 21.3% of households where the primary earner was unemployed faced energy burden, while 9.8% fell into energy poverty. Meanwhile, in 2021, 32.8% were in energy burden. The energy poverty percentage for 2021 was too small to meet the RDC vetting rules, thus the researchers are unable to present it. However, it can be assumed that the number of households that were energy poor are not energy burdened due to the increase in energy burden rates in 2021.

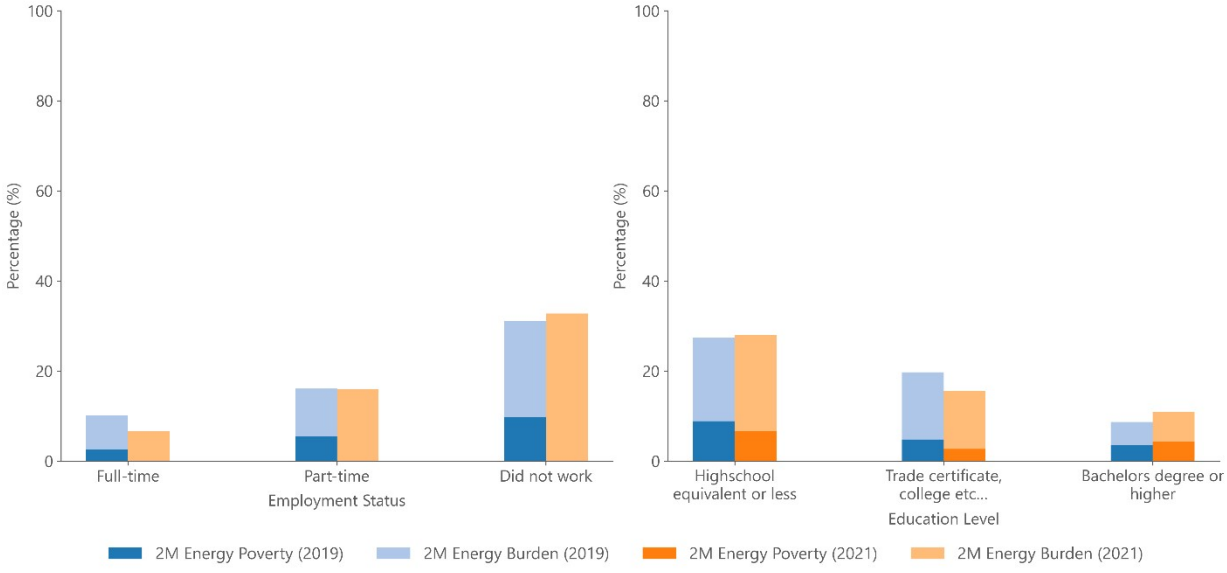


Figure 4.13. Percentage of Households in Ontario in Energy Burden or Poverty based Employment Status and Education Level, for 2019 and 2021.

The analysis reinforces the strong link between education level and energy hardship. Consistent with national trends, households where the primary earner has a bachelor's degree or higher are half as likely to experience energy burden and poverty compared to those with lower educational attainment.

4.2.1.3 Impact of Living in a City

Ontario's energy burden was more pronounced in rural areas and municipalities with populations under 30,000. In 2019, 21% of households were in energy burden, 5.5% were in energy poverty and in 2021 17% were energy burdened. On the contrary, population centers with 500,000 or larger were less likely to experience energy hardship. In 2019, 8% were energy burdened, 5% were energy poor and in 2021, 14% were energy burdened. Figure 4.14

demonstrates the percentage of households in Ontario based on population size and city. The results from the analysis on the city level are also comparable to the population. Cities present a lower percentage of energy hardship than the other category which includes rural areas. The trends are consistent with previous Canadian studies where households living in rural areas are more likely to experience energy poverty [6], [77].

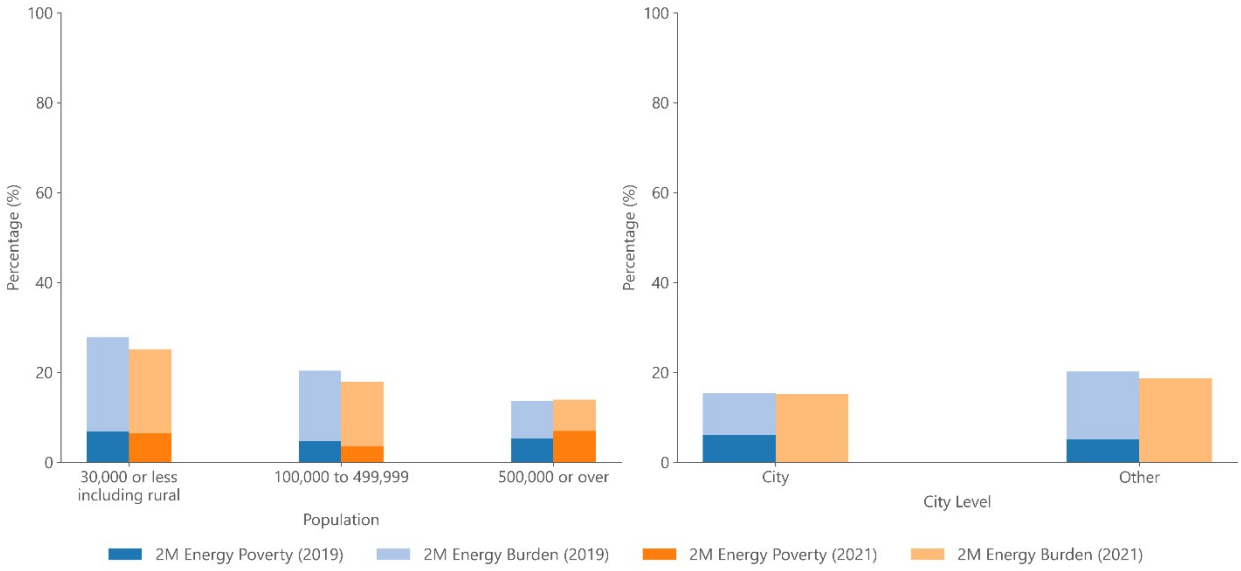


Figure 4.14. Percentage of households in Energy Burden and Poverty as a Function of Population Size and City, for 2019 and 2021.

4.2.1.4 Impact of Dwelling Age and Type

Energy burden and poverty trends varied significantly by housing type and the age of dwellings in Ontario. Figure 4.15 demonstrates these trends from 2019 to 2021. The analysis revealed a clear relationship between dwelling age and energy burden, with older homes facing higher rates. In 2019, 16% of dwellings built before 1960 were energy burdened, which decreased to 14% in 2021. For dwellings built between 1961 and 1990, there was a significant drop in energy poverty but an increase in energy burden from 12.6% to 16%. In contrast, there were no notable changes in energy burden or poverty rates for dwellings built after 1991 between 2019 and 2021. These findings highlight the critical role of housing type and age in shaping energy burden and poverty outcomes. In addition, houses (referring to non-apartment dwellings such as detached and townhouses) experienced a decrease in energy burden and poverty, apartments saw an increase in energy burden during this period. Despite this, houses remained more likely to experience energy hardship, consistent with national trends.

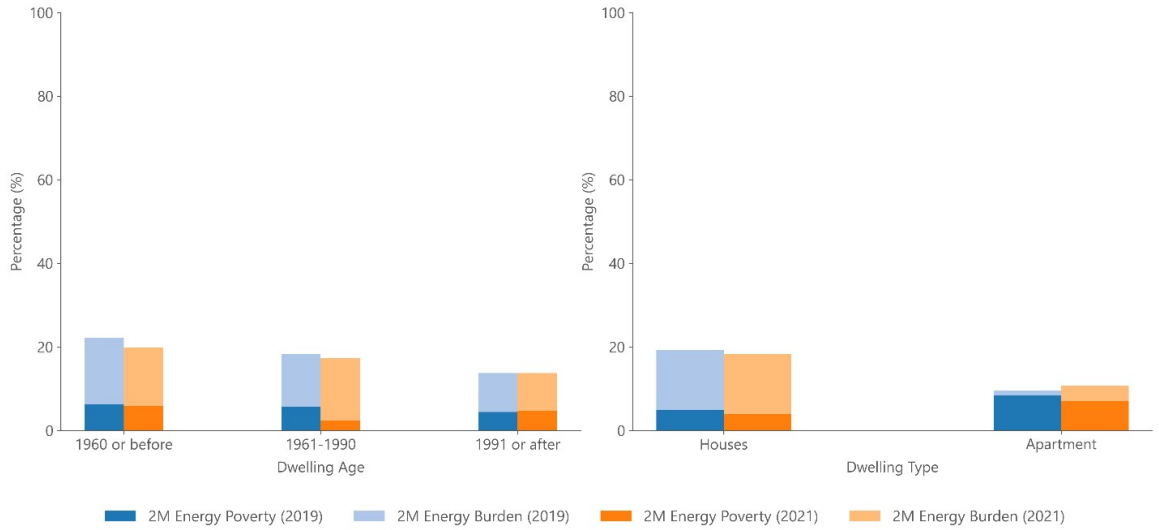


Figure 4.15. Percentage of Households in Ontario in Energy Burden or Poverty based on Dwelling Age or Type, for 2019 and 2021

4.2.1.5 Impact of Household Size

Household size had a prominent impact on energy hardship in Ontario, in particular one person households face the highest energy hardship in Ontario. Figure 4.16 illustrates that in 2019 and 2021, nearly 22% were energy burdened, 12.5% and 10.5 %, were energy poor. Notably, there is a large decrease in energy hardship rates as soon as a household has two or more occupants. Energy poverty drops below 5%. This is likely due to the higher total household income among multiple occupants compared to single-person households, reducing their overall financial strain from energy costs.

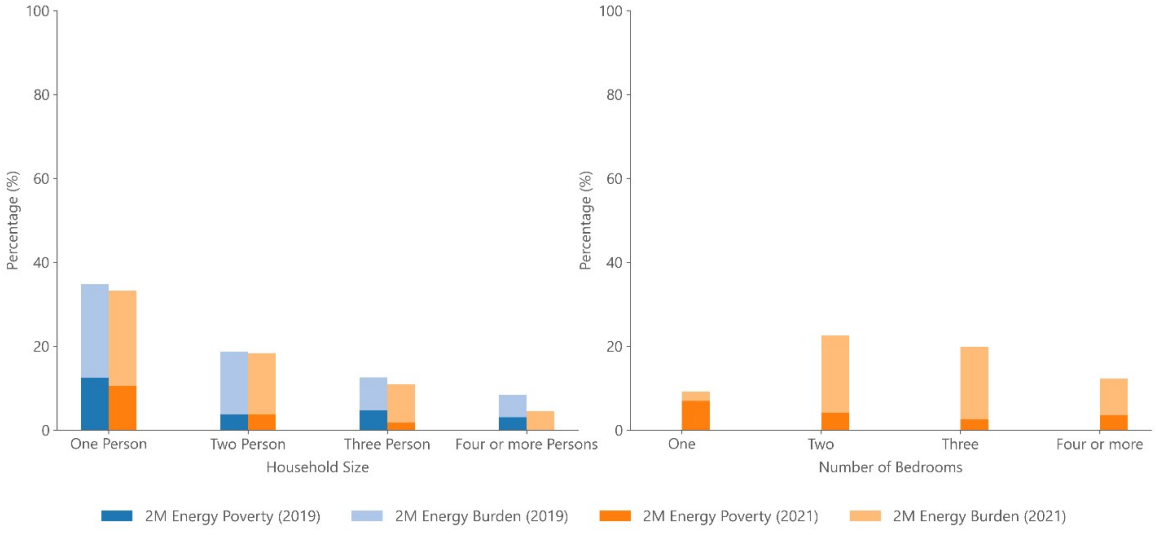


Figure 4.16. Percentage of Households in Ontario in Energy Burden or Poverty based on Household Size and Number of Bedrooms, for 2019 and 2021.

Similar to the national trend, the link between the number of bedrooms and energy hardship does not follow a clear pattern. Households with two or three bedrooms showed the highest levels of energy hardship, affecting one in five. One-bedroom households, often in energy-efficient apartments, benefit from compact designs and shared heating, reducing energy costs. Larger homes with three or more bedrooms typically have higher-income occupants who can afford maintenance and energy upgrades. In contrast, two- or three-bedroom households may face energy hardship due to higher energy needs but limited financial resources for efficiency improvements.

4.2.1.6 Impact of Household Tenure Type and Maintenance

Renters in Ontario are more likely to experience energy burden or poverty because they have less control over their appliances, building renovations, and rent increases. In 2019, 12% were energy poor, and 7% were energy burdened. Meanwhile, in 2021 there was a small decrease to 8% and 6.5%, respectively. Energy burden is more prevalent in households that were owned without mortgage 10% in 2019 and 2021. Additionally, 22% of households reported that major maintenance was required and were in an energy burden, and 12% were energy poor. Figure 4.17 presents the percentage of households in Ontario that are in energy burden or poverty based on tenure and maintenance requirements.

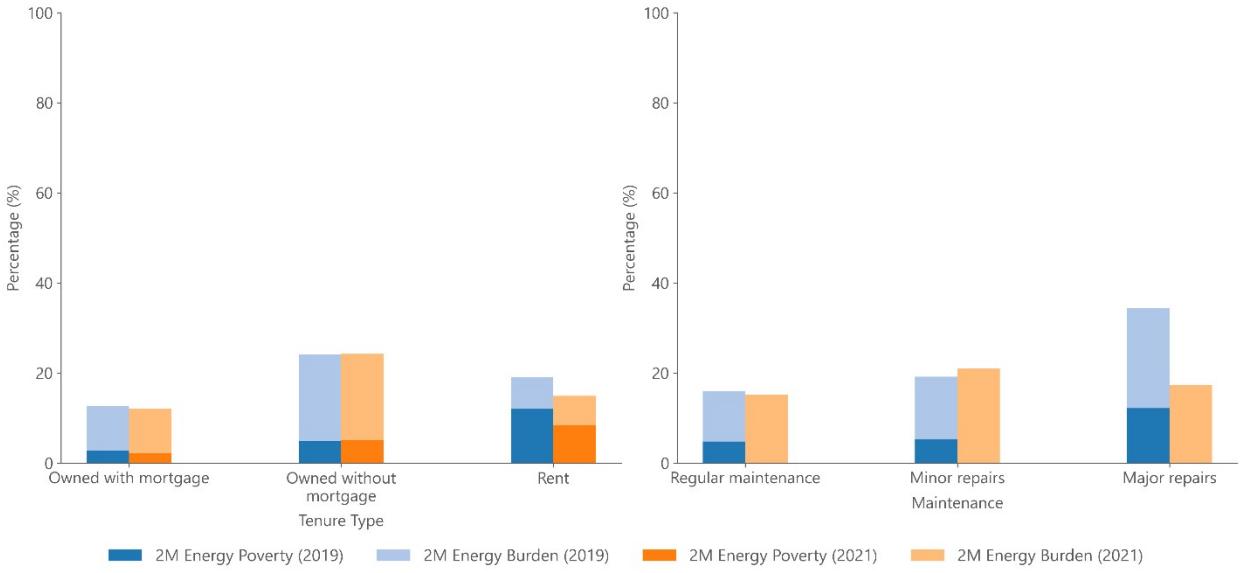


Figure 4.17. Households in Ontario in Energy Burden as Poverty as a function of Tenure Type and Maintenance Requirements, for 2019 and 2021.

4.2.1.7 Impact of Family and Marital Status

Like the national results, households categorized as one-person (22%)or lone parent (15%) households are more likely to be in energy burden in both 2019 and 2021. Figure 4.18 shows that in 2019, 36.3% of households with never-married occupants experienced energy burden,

which decreased to 11.5% in 2021. Energy poverty in this group increased from 7.3% to 10.5% over the same period. The researchers speculate that this group primarily consists of younger individuals who choose to live alone or with roommates. However, without specific provincial data, determining the exact age distribution of never-married individuals in Ontario remains challenging. Households categorized as separated, divorced, and widowed had an increase in energy burden(13% to 23%) but a decrease in energy poverty(12% to 6.6%) from 2019 to 2021.

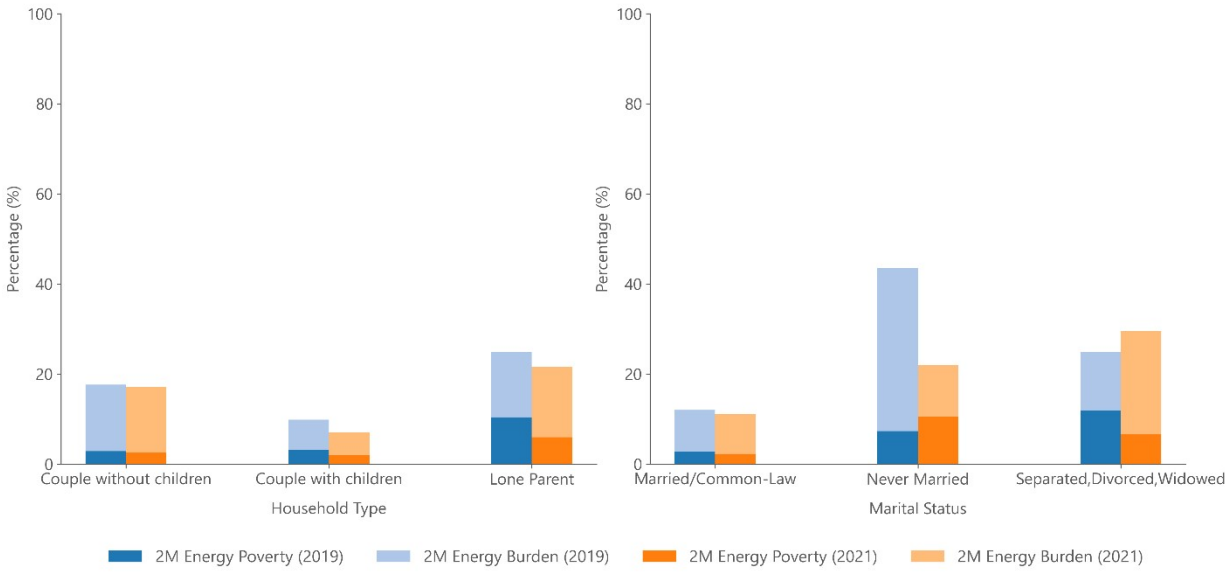


Figure 4.18. Percentage of households in Energy Burden and Poverty based on Household Type and Marital Status, for 2019 and 2021.

Other Canadian surveys also support these results for Ontario. The 2017 Canadian Community Health Survey (CCHS) and 2017 Households and the Environment Survey (HES) reported that Ontario stands out, with 85% of households reporting access to air conditioning; a rate higher than many regions in Canada [113]. However, significant disparities persist within the province, particularly among vulnerable populations. Older adults living alone, considered a heat-vulnerable group, as reported much lower air conditioning rates at 56%, compared to the Ontario average of 85% and the national average of 81%. The lack of air conditioning access among older adults living alone is particularly concerning, as this group faces higher health risks from heat exposure due to difficulty accessing cooler environments due to limited mobility and social support.

4.3 Ontario Modelling Results

4.3.1 Modelling Baseline

The findings from the statistical analysis suggest two primary energy hardship scenarios in Ontario. One scenario involves renters in urban areas living in apartments with limited energy control. The second scenario includes single-detached homeowners in rural areas with higher energy demands, possibly over-consuming due to inefficient dwellings. However, using the data available for release from the 2019 and 2021 SHS surveys, an annual household energy consumption profile was developed for a house in Ontario. Table 4.4 presents the median energy expenditure for households experiencing energy burden and poverty in Ontario, during these years.

Table 4.4. Median Energy Consumption and Income Breakdown for Ontario, in Canadian Dollars.

Median Household Profile		**2019**	**2021**
Energy Burdened	Electricity Consumption	$1,440	$1,440
	Natural Gas and Other	$1,520	$1,330
	Total Energy Consumption	$3,180	$2,975
	Total Income	$38,305	$40,245
	EER_{it}	8.30%	7.39%
Energy Poor	Electricity Consumption	$1,200	$1,200
	Natural Gas and Other	$1,035	$1,100
	Total Energy Consumption	$2,470	$2,300
	Total Income	$18,045	$19,570
	EER_{it}	13.69%	11.75%

A baseline energy model was built based on the results found using the SHS of the characteristics of a "typical" household under energy poverty in Ontario. The results show that detached dwellings, built pre-1960, are likely to be in energy poverty, with an annual estimated total energy cost of CAD$2,300. The electricity cost was estimated at CAD$1,200 and natural gas at CAD$1,100.

A numerical simulation model of a two-storey detached house was developed in Climate Studio – a Rhino plugin interface of Energyplus – to capture the energy behavior of the median energy poor household in Ontario that falls under extreme energy poverty (i.e., 10% EER or more). The total conditioned floor area of 144 $m^2$with a window-to-wall ratio was 30%. Note that while the survey did not provide information on the size of the household, the total area was established based on the average residential living space for Canada in 2019 which was estimated to be 146 m^2 [114]. The assumed HVAC system provides both heating using a natural gas furnace and air conditioning. The choice of including air conditioning was driven by the fact that in the households and the environment survey of 2021, it was reported that 64% of Canadians have at

least one type of air conditioning. Ontario has the most reported air conditioning units, ranging from ~80 – 90%, depending on the census metropolitan region [115]. Additionally, in 2019 77.3% of low-income households reported having an air conditioner [116].

The Energyplus simulation engine was used to calibrate the baseline model to match the energy expenditure and estimate its end-use breakdown and energy use intensity (EUI). Standard schedules and occupancy were used based on the National Energy Code of Canada for Buildings (NECB) 2020. Table 4.5 below summarizes the assumptions for the baseline model, which achieves a total energy expenditure within +/- 15% per the ASHRAE Guideline 14 [117] when compared to a median energy-poor household in Ontario.

Table 4.5. Baseline Model Assumptions

	Kitchen/ Bathroom	**Living Room / Bedroom**
Power Loads		
Lighting (W/m^2)	7	7
Electric Equipment (W/m^2)	35	4
Hot Water Peak Flow Rate (m^3/s)	1.66×10^{-6}	6.26×10^{-7}
Enclosure Details		
Operable Window U-factor ($W/(m^2K)$)	2.48 (U-0.44)	
Wall Insulation ($(m^2K)/W$)	1.75 (R-10)	
Roof Insulation ($(m^2K)/W$)	2.64 (R-15)	
Infiltration @4Pa ($m^3/s/m^2$)	6×10^{-4}	
HVAC Details		
Cooling System	Air Conditioning	COP 3.5 [118]
Heating System	Natural Gas Furnace	UEF 0.95
Other		
Number of Occupants (P/m^2)	0.025	

Once the costs and parameters were established, an annual energy simulation was performed using the typical meteorological weather file (TMY3) for Toronto Pearson. The final baseline model energy costs are highlighted in Table 4.6.

Table 4.6. Final Baseline Model Energy Expenditure, EER and Energy Poverty Status

Electricity Cost	$ 1370
Natural Gas Cost	$ 1328
Total Cost	$ 2619
EER	13.4%
Energy Poverty Status	**Energy Poor**

The above energy costs were calculated by estimating the electricity ($/kWh) and natural gas ($/m^3) for Ontario in 2021. These estimates were determined based on a Hydro-Quebec report that compares electricity prices across main cities in Canada [119]. For residential customers in Toronto, the average reported electricity rate of $0.1343/kWh was adjusted to $0.15/kWh to account for taxes. This value also includes any additional surcharges such as delivery charges and Ontario Electricity Rebate (OER). For natural gas, the Ontario Energy Board (OEB) "estimated bill calculator" and the historical natural gas rates were used to estimate 0.38 $/$m^3$ in 2021, for residential customers, including surcharges [120], [121].

4.3.2 Baseline Modelling Results

The EUI for the baseline was 316 kWh/m^2, which is higher than the average EUI for a detached household in Toronto (i.e.,204 kWh/m^2) [122]. Since the baseline represents an energy poor and inefficient household, the EUI is expected to be higher. Natural gas consumption yielded 80% – 71% for space heating and 9% for water heating – while space cooling (3%), lighting (3%), and appliances (14%) were all within expected ranges, and are comparable to the national average [114], as illustrated in Figure 4.19.

To better understand the existing conditions and the need to address energy consumption in vulnerable households, a business-as-usual analysis was conducted assuming no efficiency upgrades for the baseline model. The model's performance was evaluated under global warming potential (GWP) of 2.5°C and 3.5°C. The simulations indicate that failing to financially support struggling households will further exacerbate energy poverty driven by climate change. Table 4.7 highlights an overall increase in electricity costs across all scenarios. Compared to the baseline, electricity costs are estimated to rise by +19.8% under a GWP 2.5°C scenario and by +25.6% under a GWP 3.5°C scenario. In contrast, natural gas costs decrease significantly – by -15.6% and -26.5%, respectively. Although the EER_{it} remains between 13–14%, these households continue to be classified as energy poor.

Table 4.7. Energy Performance of the Baseline Model under Current Climate Conditions (2021), GWP2.5 and GWP3.5.

Baseline Model Performance	2021	GWP 2.5°C	GWP 3.5°C
Electricity Cost	$ 1370	$1,641	$1,720
Natural Gas Cost	$ 1328	$1,121	$976
Total Cost	$ 2619	$2,762	$2,696
EER	13.4%	14.1%	13.7%
Energy Poverty Status	**Energy Poor**	**Energy Poor**	**Energy Poor**

The large increase in electricity cost is attributed to the dependency on cooling systems as temperatures continue to increase due to climate change. As the weather gets warmer there is an expected decrease in the use of heating systems. There was a decrease of -17.5% (GWP 2.5°C) and 30% (GWP 3.5°C) in space heating across, when compared to the baseline. Additionally, there was a notable increase in space cooling from 11 kWh/m^2 to 23 kWh/m^2 (GWP 2.5°C) and 27 kWh/m^2 (GWP 3.5°C). This is also reflected in the energy use breakdown for both the GWP 2.5°C and GWP 3.5°C scenarios highlighted in Figure 4.19.

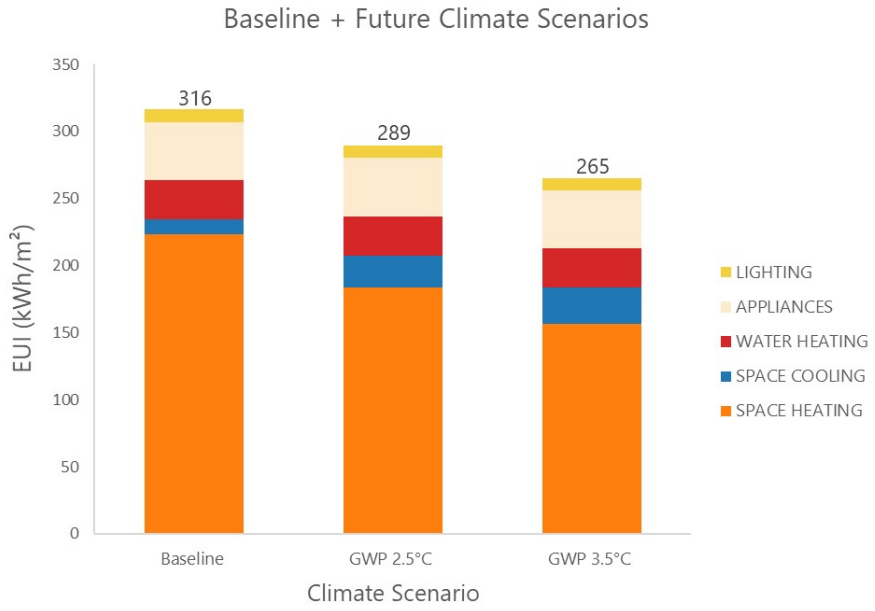


Figure 4.19. EUI and End Use Breakdown for the Baseline and GWP 2.5°C and 3.5°C

The above figures also indicate a significant decrease in EUI across the three scenarios. This is due to climate change leading to more cooling than heating demand due to continuously rising temperatures. A reminder that for this first analysis, no energy efficiency measures were considered. Even if the overall energy demand for heating and cooling are the same, the consumption will be different due to different equipment efficiencies. Air conditioners are more

efficient than natural gas furnaces. The reduction of the EUI heavily emphasizes (overall 16.1% for 2021) the need for cooling systems in the near future as temperatures approach and are expected to surpass GWP 2.5°C. The next question that arises here is whether energy efficiency upgrades can help alleviate the financial hardship of energy costs for the median energy poor household in Ontario.

4.3.3 Energy Efficiency Measures

This section investigates the implementation of cost-effective Energy Efficiency Measures (EEMs) to alleviate energy poverty among households. Rather than applying all possible measures until a household is entirely removed from energy poverty, we assess whether cost-effective or subsidized measures can achieve this goal by reducing operational energy costs. This analysis quantifies the financial depth ($) of the investment required for such interventions. For this simulation, the basic EER (EER_{it}) of 5.14% was determined as a threshold to establish the minimum required measures to relieve energy poverty.

Energy efficiency measures were applied in a staggered approach, and then total energy consumption, EUI, and EER were calculated to understand the impact of each improvement on energy poverty. Figure 4.20 illustrates the approach used to apply the EEMs within the selected framework and Appendix C – Modelling Results includes a summary of all the modelling results.

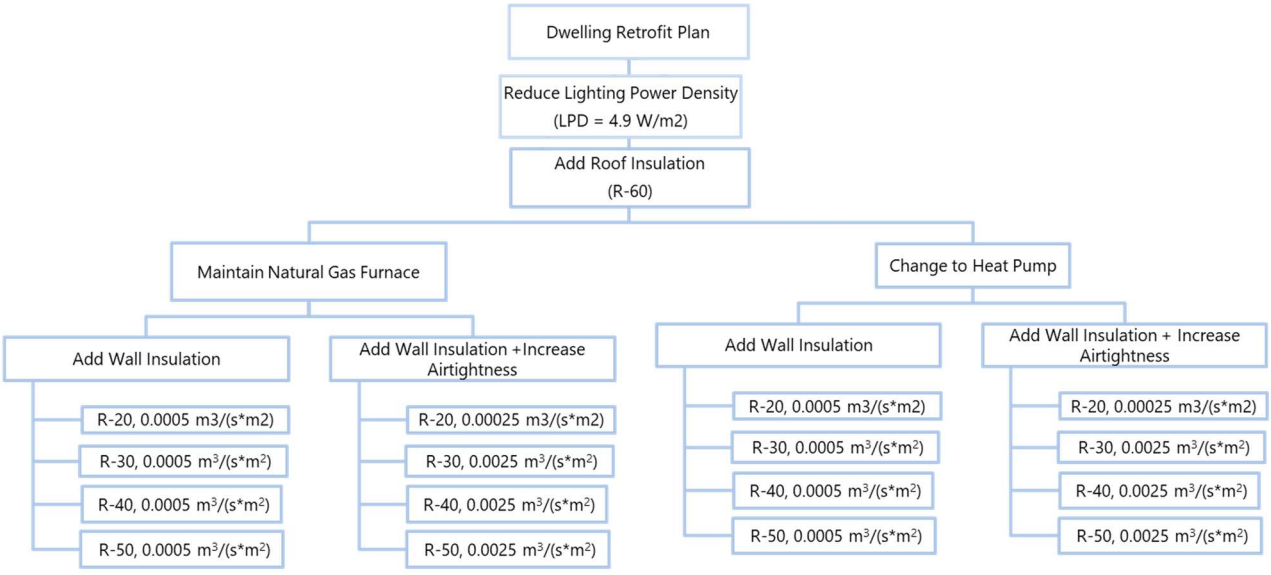


Figure 4.20. Energy Efficiency Measures Analysis Pedagogy

The first energy efficiency measure implemented was a reduction in lighting power density (LPD) by ASHRAE 90.1. The LPD was lowered to 4.9 W/m^2 across all conditioned zones, leading to a 30% decrease in lighting consumption from the baseline. However, the impact on EUI was minimal since lighting is only 3% of the baseline's EUI. Lighting upgrades are often households' first step to reduce electricity costs, as they are both accessible and cost-effective. Additionally, 8.5%-10% of households in energy poverty in Ontario are renters, who often do not have much control over their home maintenance. As a result, plug loads were not included in the analysis since they are usually not replaced unless they are irreparable.

The application order for the energy efficiency measures highlighted in Figure 4.20 is driven by the grants available in the Greener Home Initiative and Ontario's Efficiency programs [123]. Following the lighting upgrade, the roof insulation was enhanced to R-60, leading to a modest 2.6% reduction in annual natural gas costs and a 3% decrease in EUI.

Four iterations were completed with wall insulation upgrades ranging from R-20 to R-50. Window improvements were not included in this analysis due to higher capital costs and limited subsidies (approximately $125 or $250 per opening). Further envelope improvements were implemented to the natural gas furnace scenario with an infiltration rate of 0.005 $m^3/(s \cdot m^2)$ and then 0.00025 $m^3/(s \cdot m^2)$ at 4Pa, annotated as INF in Figure 4.21. It is important to note that the 0.00025 $m^3/(s \cdot m^2)$ infiltration rate was coupled with a heat recovery ventilator (HRV) to maintain adequate IEQ. Enhancing airtightness resulted in a pronounced reduction in EUI between each infiltration rate change. These changes are highlighted in Figure 4.21 with blue vertical lines. There was an up to 35.4% reduction in EUI from the baseline, due to airtightness measures. However, the energy savings between R-20 to R-50 were minimal for both infiltration rates, emphasizing even further the importance of airtightness in a dwelling. The reduction in EUI is largely due to the decrease in space heating (color orange) by an average of 25.1% and 57% across all wall assemblies proposed. However, space cooling (color blue) doubled for an infiltration rate of 0.00025 $m^3/(s \cdot m^2)$. This increase does not account for any natural cooling methods (e.g., opening windows, night cooling), representing a worst-case scenario where the household relies solely on mechanical cooling. Even with these improvements, the dwelling remained in energy poverty. For both infiltration rates and a R-50 wall assembly, the EER was 12%.

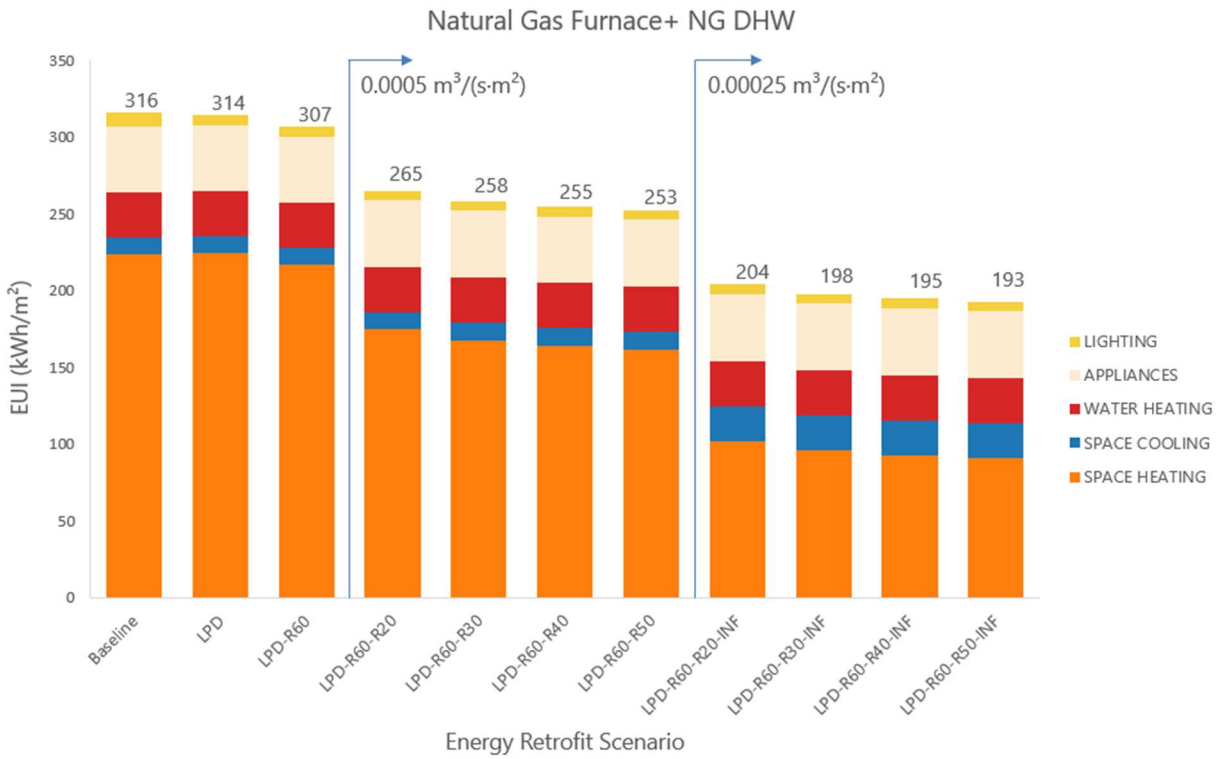


Figure 4.21. EUI and End-Use breakdown for Natural Gas Furnace and Domestic Hot Water Scenarios

The analysis was repeated, this time incorporating fuel switching from natural gas to electricity for heating using an electric heat pump with a $COP_{heating}$ of 2.14 [118], while maintaining the natural gas water heater. A heat pump was evaluated, due to the subsidy and loan programs available from the government. It is also a common practice to fuel the switch at the end of the service life of a natural gas furnace. Figure 4.22 shows that the adoption of a heat pump significantly reduced EUI by 41.1% and cut natural gas consumption by 50%, eliminating associated emissions, resulting in an EUI of 186kWh/m^2. Additionally, decreasing the infiltration rate to 0.0005m^3/(s·m^2) reduced energy consumption by 45.3% (EUI of 173 kWh/m^2). Further decreasing the infiltration rate to 0.00025 m^3/(s·m^2) resulted in 53.48% decrease (EUI of 147 kWh/m^2) as highlighted with the vertical blue lines in Figure 4.22, which summarizes the outcome of this EEM scenario. The lowest EUI achieved was 142 kWh/m^2. Like the previous scenario, the energy savings due to wall insulation measures between R-20 to R-50 were minimal for both infiltration rates. The reduction in EUI is largely due to the decrease in space heating (color orange) by an average of 66.4% and 81.2% across all wall assemblies proposed. However, space cooling (color blue) doubled for an infiltration rate of 0.00025 m^3/(s·m^2). This resulted in doubling electricity consumption, causing the EER to rise to 20.6% keeping the households in energy poverty. While heat pumps improve significantly energy efficiency (and

reduce drastically emissions), they can also increase overall energy expenditures, exacerbating energy poverty rather than alleviating it.

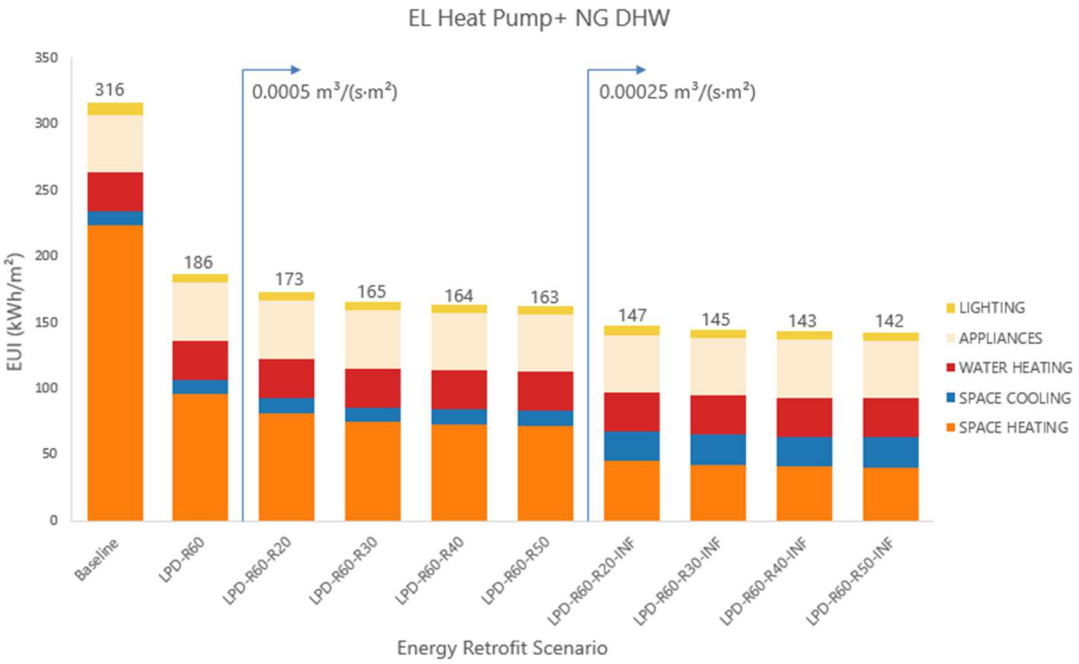


Figure 4.22. EUI and End-Use breakdown for Electric Heat Pump and Domestic Hot Water Scenarios

Despite all the proposed energy efficiency improvements, the household remains in energy poverty regardless of the level of retrofit. In the last iteration (i.e., LPD-R60-R50-INF), the EER was 11.2% when maintaining a natural gas furnace, and 14.3% when using a heat pump. Figure 4.23 highlights that regardless of the degree of proposed EEM, in all investigated scenarios the household remained energy poor. The grey line across the graph indicates the energy poverty threshold, For both the natural gas furnace (orange dots) and electric heat pump (blue dots), the EERs fell above the threshold as indicated by the grey arrow on the right. This is because regardless of the HVAC system's efficiency, the cost of electricity is higher than the cost of natural gas per unit energy. The electric heat pump deepened energy poverty, maintaining the EER at approximately 17%. It was noted in the increased electricity consumption to an average of $2,924.

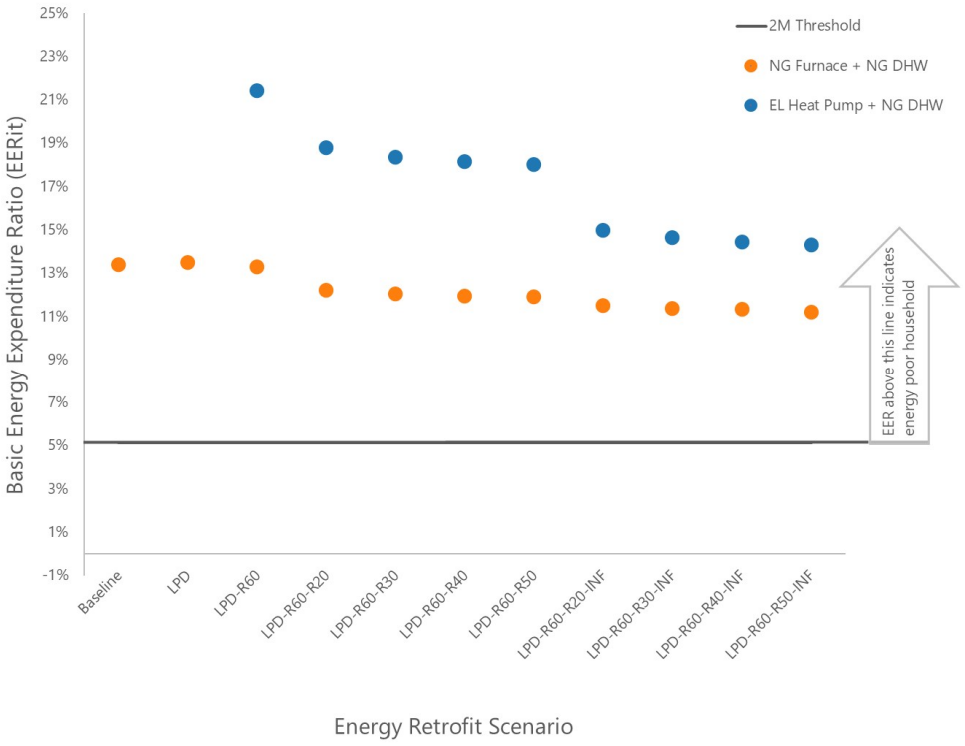


Figure 4.23. Basic Energy Expenditure Ratio and Energy Retrofit Scenarios

4.3.4 Impact of Household Income

In the simulation study, the primary objective in addressing energy poverty was to reduce the EER by lowering a household's operational energy costs. However, it is evident that energy efficiency improvements alone are not sufficient to lift a household out of energy poverty; increasing household income is also necessary. Figure 4.24 demonstrates how an increase in income removes households from energy hardship at different EEM levels for the natural gas furnace scenario. At an income of $50,000 after tax (yellow dots), the EER starts to decrease after completing lighting and roof upgrade. Once the R-20 wall and an infiltration of 0.0005 $m^3/(s \cdot m^2)$ was established, a household with $50,000 income after tax is not energy poor. If the household size is smaller than 5 people per LICO table they are also not energy burdened. However, households who make $60,000 or more after tax are not in energy hardship since they do not meet the conditions of a low-income household and are below the EER threshold.

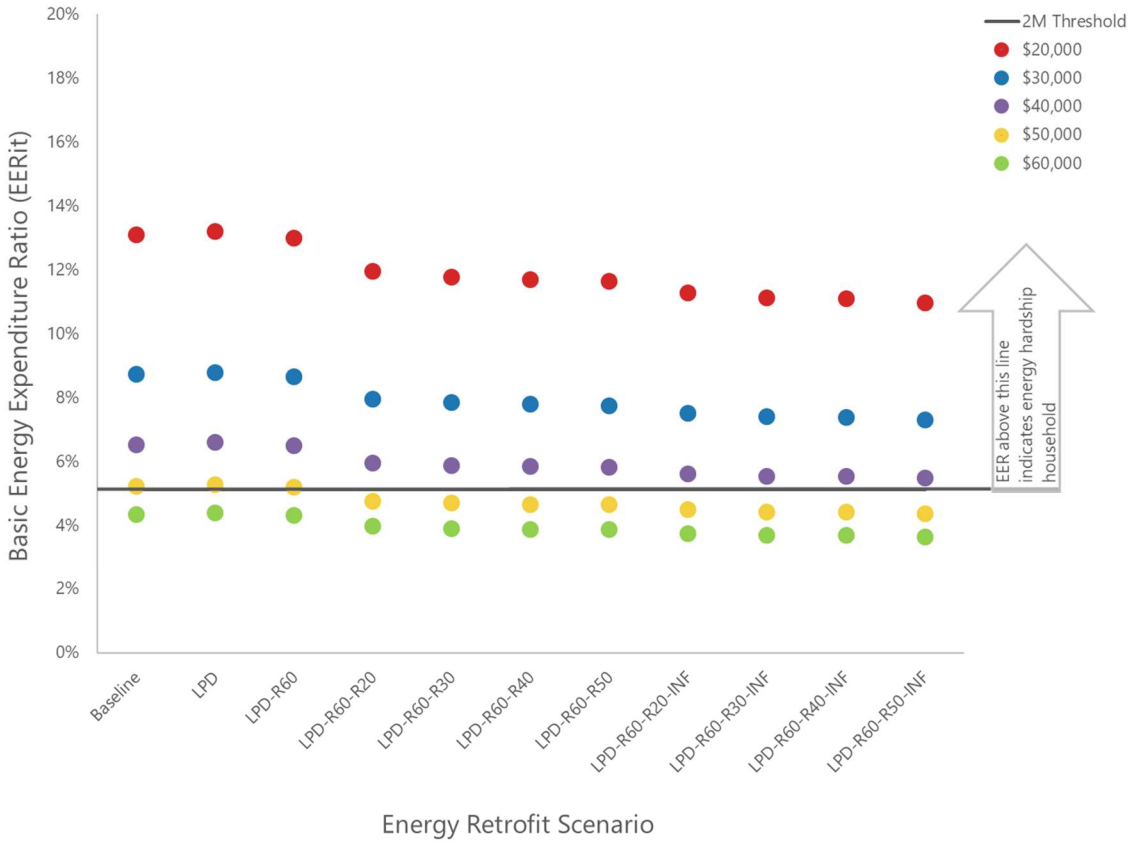


Figure 4.24. The Relationship of Income to EER for a Household using a Gas Furnace, under various retrofit scenarios.

The contrary occurs when evaluating the heat pump scenarios as presented in Figure 4.25. Only after decreasing infiltration to 0.00025 $m^3/(s \cdot m^2)$ and completing a wall assembly retrofit does the EER decrease below the grey energy poverty line. Since the energy consumption costs are high for this series of retrofits, a higher income range was also investigated. Figure 4.25 demonstrates that energy burden can be eliminated from households with an income greater than $70,000 by upgrading lighting and the roof assembly (navy blue, orange and pink points). Households with an income below $50,000 remained in energy poverty.

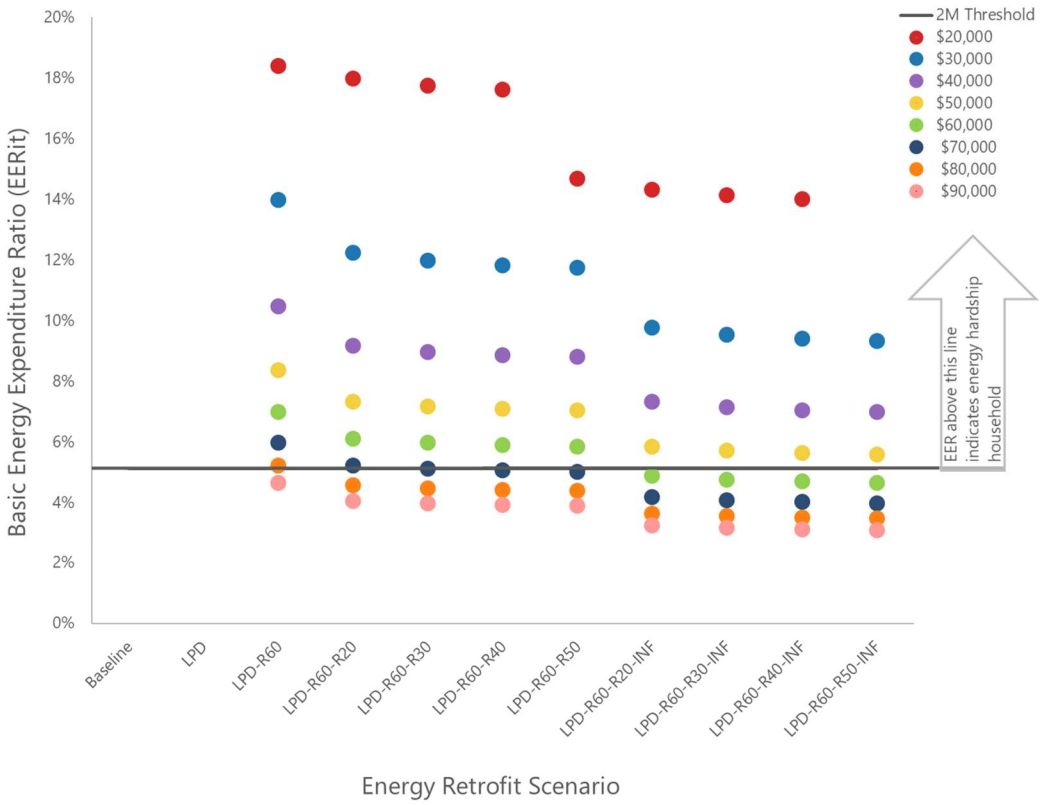


Figure 4.25. The relationship of income to EER and Heat Pump Retrofits

This further emphasizes that to remove households from energy poverty in Ontario, a comprehensive approach needs to be considered. Energy efficiency policies and incentives alone are not enough to address energy poverty in Ontario.

Chapter 5 : Conclusions and Future Work

5.1 Summary and Conclusions

A detailed literature review on energy hardship, its prevalence, effects on energy consumption, and socioeconomic impact in Canada was completed to understand the existing condition of energy poverty and burden. In this study, a household experiences energy hardship if its Energy Expenditure Ratio (EER) exceeds the defined threshold, regardless of its total household income. Energy hardship encompasses both energy poverty and energy burden. Thus, a household experiences energy poverty if its EER exceeds the defined thresholds, and the total household income is below low-income cut-offs, and energy burden if it exceeds the defined thresholds, and the total household income is above low-income cut-offs.

To establish baseline energy hardship conditions using in Canada, the 2019 and 2021 SHS from Statistics Canada were used to complete a national statistical analysis to estimate the prevalence of energy hardship across all provinces and the household characteristics associated with both energy burden and energy poverty. This study identified key indicators of energy poverty and burden. It confirms that household income is the most detrimental indicator of energy hardship. Nearly 40% of households earning CAD$29,000 or less, experience energy poverty. Energy poverty is nearly eliminated for those earning above CAD$60,000, due to the definition of energy poverty. Dwellings built before 1960's are likely to be inefficient (e.g., leaky with poor insulation and outdated HVAC system) resulting in increased energy consumption. This was more evident in single-detached homes as they tend to have higher energy burden due to larger conditioned spaces, higher heat loss, and greater heating and cooling demand. Additionally, households that needed major repairs were most vulnerable with one in three experiencing energy hardship.

Indicators of energy poverty were not limited to income and dwelling characteristics but also socioeconomic factors. Single-person and lone-parent households were most affected by energy hardship. Education and employment – which directly influence income – play a major role; households with higher levels of education and full-time employment are less likely to experience energy hardship.

The analysis was repeated for Ontario to establish a profile for a typical energy consumption use for a median household in energy poverty. The indicators of energy hardship in Ontario were consistent with national trends. It was noted that energy burden was more pronounced in rural areas and municipalities with populations under 30,000 people.

To examine the relation between household electrification (e.g., replacement of a gas furnace with a heat pump) and energy poverty, an energy simulation study was completed for an

median energy poor household in Ontario. An EER_{it} of 5.14% was the threshold to determine when a household is no longer considered to be in energy poverty, determined based on the SHS 2021 data. Lighting power density (LPD) was reduced as the first measure, cutting lighting consumption by 30%, but had minimal impact on energy poverty since lighting represents only 3% of total energy use. Then the roof insulation was upgraded to R-60, reducing natural gas costs by 3% and EUI by 1%, but still did not eliminate energy poverty. Further envelope improvements (i.e., R-20 to R-50) including reduced infiltration rates of 0.0005 and 0.00025 $m^3/(s \cdot m^2)$ were applied for both a natural gas furnace and electric heat pump lowering household EUI significantly but did not remove households from energy poverty. In this analysis, airtightness was the most impactful measure to reduce energy poverty. Scenarios that included electric heat pumps increased the depth of energy poverty due to the higher electricity rates (per unit energy), when compared to natural gas. The energy modelling also emphasized the importance of income levels on alleviating energy hardship; households earning $50,000 CAD after tax were not in energy hardship after insulation and airtightness upgrades, resulting in an equitable transition to household electrification.

To summarize, there are three ways to alleviate energy hardship:

1) by improving a household's income,
2) energy rebate programs to help households pay bill
3) Reduce operational energy costs by reducing their energy consumption

Addressing energy hardship effectively requires recognizing the long-term benefits of energy efficiency and savings measures. Green home incentives alone will not solve energy poverty, the issue needs to be recognized at hand to implement inclusive and effective combination of energy efficiency improvements and income support policies.

5.2 Recommendations for Future Work

Future studies should further explore:

- A dedicated survey on energy usage, expenditure, dwelling conditions, and household characteristics is needed to fully evaluate energy hardship in Canada.
- A sensitivity analysis on the weight of different indicators influences on energy hardship
- Objective and subjective indicators need to be investigated to identify hidden energy hardship. The objective indicators would include expenditure-based metrics (annual energy costs and consumption). Subjective indicators include a household's direct assessment of their living condition to examine IEQ
- Conduct a socioeconomic study that projects future energy costs (electricity and natural gas) and household income to better assess the long-term dynamics of energy poverty.

References

[1] "Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach - 2023 Update".

[2] "Buildings - Energy System," IEA. Accessed: Jun. 12, 2024. [Online]. Available: https://www.iea.org/energy-system/buildings

[3] E. and C. C. Canada, "Setting the next milestone to building a cleaner, stronger economy." Accessed: Jan. 16, 2025. [Online]. Available: https://www.canada.ca/en/environment-climate-change/news/2024/12/setting-the-next-milestone-to-building-a-cleaner-stronger-economy.html

[4] Environment and Climate Change, "Pan-Canadian Framework on Clean Growth and Climate Change." Accessed: Jan. 16, 2025. [Online]. Available: https://www.canada.ca/en/services/environment/weather/climatechange/pan-canadian-framework/introduction.html

[5] S. Canada, "A healthy environment and a healthy economy." Accessed: Jan. 16, 2025. [Online]. Available: https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/healthy-environment-healthy-economy.html

[6] M. Riva, S. Kingunza Makasi, P. Dufresne, K. O'Sullivan, and M. Toth, "Energy poverty in Canada: Prevalence, social and spatial distribution, and implications for research and policy," *Energy Research & Social Science*, vol. 81, p. 102237, Nov. 2021, doi: 10.1016/j.erss.2021.102237.

[7] D. J. Bednar and T. G. Reames, "Recognition of and response to energy poverty in the United States," *Nat Energy*, vol. 5, no. 6, pp. 432–439, Jun. 2020, doi: 10.1038/s41560-020-0582-0.

[8] J. Goldemberg, United Nations Development Programme, United Nations, and World Energy Council, Eds., *World energy assessment: energy and the challenge of sustainability*. New York, NY: United Nations Development Programme, 2000.

[9] M. González-Eguino, "Energy poverty, An Overview," *Renewable and Sustainable Energy Reviews*, vol. 47, pp. 377–285, Mar. 2015, doi: https://doi.org/10.1016/j.rser.2015.03.013.

[10] P. Nussbaumer, M. Bazilian, and V. Modi, "Measuring energy poverty: Focusing on what matters," *Renewable and Sustainable Energy Reviews*, vol. 16, no. 1, pp. 231–243, Jan. 2012, doi: 10.1016/j.rser.2011.07.150.

[11] B. Boardman, "Fuel poverty is different," *Policy Studies*, vol. 12, no. 4, pp. 30–41, Dec. 1991, doi: 10.1080/01442879108423600.

[12] Brenda Boardman, *Fuel poverty : from cold homes to affordable warmth*. 1991.

[13] John Hills, "Fuel Poverty: The problem and its measurement," *IDEAS Working Paper Series from RePEc*.

[14] R. Moore, "Definitions of fuel poverty: Implications for policy," *Energy Policy*, vol. 49, pp. 19–26, Oct. 2012, doi: 10.1016/j.enpol.2012.01.057.

[15] H. Thomson, S. Bouzarovski, and C. Snell, "Rethinking the measurement of energy poverty in Europe: A critical analysis of indicators and data," *Indoor and Built Environment*, vol. 26, no. 7, pp. 879–901, Aug. 2017, doi: 10.1177/1420326X17699260.

[16] R. R. Das, M. Martiskainen, and G. Li, "Quantifying the prevalence of energy poverty across Canada: Estimating domestic energy burden using an expenditures approach," *The Canadian Geographer*, vol. 66, no. 3, pp. 416–433, Sep. 2022, doi: 10.1111/cag.12750.
[17] I. Siksnelyte-Butkiene, D. Streimikiene, V. Lekavicius, and T. Balezentis, "Energy poverty indicators: A systematic literature review and comprehensive analysis of integrity," *Sustainable Cities and Society*, vol. 67, p. 102756, Apr. 2021, doi: 10.1016/j.scs.2021.102756.
[18] S. Cong, D. Nock, Y. L. Qiu, and B. Xing, "Unveiling hidden energy poverty using the energy equity gap," *Nat Commun*, vol. 13, no. 1, p. 2456, May 2022, doi: 10.1038/s41467-022-30146-5.
[19] M. Riva *et al.*, "Energy poverty: an overlooked determinant of health and climate resilience in Canada," *Can J Public Health*, Feb. 2023, doi: 10.17269/s41997-023-00741-0.
[20] S. Briot-Arthur, V. Fournier, and B. Lee, "Quantifying energy poverty vulnerability with minimal data – A building energy simulation approach," *Energy and Buildings*, vol. 309, p. 114062, Apr. 2024, doi: 10.1016/j.enbuild.2024.114062.
[21] P. Nojedehi *et al.*, "Examining disparities in energy poverty and indoor environmental quality satisfaction among Canadian households," *Energy Policy*, vol. 194, p. 114319, Nov. 2024, doi: 10.1016/j.enpol.2024.114319.
[22] R. R. Das, M. Martiskainen, L. M. Bertrand, and J. L. MacArthur, "A review and analysis of initiatives addressing energy poverty and vulnerability in Ontario, Canada," *Renewable and Sustainable Energy Reviews*, vol. 165, p. 112617, Sep. 2022, doi: 10.1016/j.rser.2022.112617.
[23] K. M. F. Cairney, "ENERGY POVERTY AS IDEOLOGICAL POVERTY IN CANADA," 2009.
[24] Canadian Urban Sustainability Practitioners, "Energy Poverty in Canada: a CUSP Backgrounder," Oct. 2019.
[25] C. E. R. Government of Canada, "CER – Market Snapshot: Household energy expenditures vary significantly by province and territory." Accessed: Jul. 15, 2024. [Online]. Available: https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2020/market-snapshot-household-energy-expenditures-vary-significantly-province-territory.html
[26] "2023-CRHI-Media-Backgrounder." Accessed: Apr. 14, 2025. [Online]. Available: https://bcnpha.ca/wp-content/uploads/2023/06/2023-CRHI-Media-Backgrounder.pdf
[27] Statistics Canada, "Canadian Social Survey: Energy use," Statistics Canada. [Online]. Available: https://www150.statcan.gc.ca/n1/daily-quotidien/231030/dq231030b-eng.htm#shr-pg0
[28] I. Antepara, L. Papada, J. P. Gouveia, N. Katsoulakos, and D. Kaliampakos, "Improving Energy Poverty Measurement in Southern European Regions through Equivalization of Modeled Energy Costs," *Sustainability*, vol. 12, no. 14, p. 5721, Jul. 2020, doi: 10.3390/su12145721.
[29] N. R. C. Government of Canada, "Energy Use in Canada: Trends Publications." Accessed: Apr. 07, 2025. [Online]. Available: https://oee.nrcan.gc.ca/publications/statistics/trends/2019/residential.cfm
[30] C. of Toronto, "Home Energy Loan Program," City of Toronto. Accessed: Sep. 15, 2024. [Online]. Available: https://www.toronto.ca/services-payments/water-environment/environmental-grants-incentives/home-energy-loan-program-help/

[31] "Canada Greener Affordable Housing | CMHC." Accessed: Sep. 15, 2024. [Online]. Available: https://www.cmhc-schl.gc.ca/professionals/project-funding-and-mortgage-financing/funding-programs/all-funding-programs/canada-greener-affordable-housing-program
[32] N. R. Canada, "Canada Greener Homes Grant." Accessed: Sep. 15, 2024. [Online]. Available: https://natural-resources.canada.ca/energy-efficiency/homes/canada-greener-homes-initiative/canada-greener-homes-grant/canada-greener-homes-grant/23441
[33] "Energy Efficient Housing Program," Sagen. Accessed: Sep. 15, 2024. [Online]. Available: https://www.sagen.ca/products-and-services/energy-efficient-housing/
[34] "Better Homes Hamilton Program | City of Hamilton." Accessed: Sep. 15, 2024. [Online]. Available: https://www.hamilton.ca/home-neighbourhood/environmental-stewardship/environmental-plans-strategies/hamiltons-climate-2
[35] "Ontario Electricity Support Program | Ontario Energy Board." Accessed: Mar. 13, 2024. [Online]. Available: https://www.oeb.ca/consumer-information-and-protection/bill-assistance-programs/ontario-electricity-support-program
[36] "Energy Conservation Assistance Program • CleanBC Better Homes," CleanBC Better Homes. Accessed: Mar. 13, 2024. [Online]. Available: https://www.betterhomesbc.ca/rebates/energy-conservation-assistance-program/
[37] "Rénoclimat Program - Residential." Accessed: Jul. 28, 2024. [Online]. Available: https://transitionenergetique.gouv.qc.ca/en/residential/programs/renoclimat
[38] D. L. Goldwyn, "Addressing energy poverty," *Geopolitics of Energy*, vol. 32, no. 10–11, pp. 11–19, 2010.
[39] E. Dogan, M. Madaleno, R. Inglesi-Lotz, and D. Taskin, "Race and energy poverty: Evidence from African-American households," *Energy Economics*, vol. 108, p. 105908, Apr. 2022, doi: 10.1016/j.eneco.2022.105908.
[40] Q. Wang, M.-P. Kwan, J. Fan, and J. Lin, "Racial disparities in energy poverty in the United States," *Renewable and Sustainable Energy Reviews*, vol. 137, p. 110620, Mar. 2021, doi: 10.1016/j.rser.2020.110620.
[41] B. Goldstein, T. G. Reames, and J. P. Newell, "Racial inequity in household energy efficiency and carbon emissions in the United States: An emissions paradox," *Energy Research & Social Science*, vol. 84, p. 102365, Feb. 2022, doi: 10.1016/j.erss.2021.102365.
[42] "BILLS-118hr5482ih." Accessed: Jul. 25, 2024. [Online]. Available: https://www.congress.gov/118/bills/hr5482/BILLS-118hr5482ih.pdf
[43] L. Tozer, H. MacRae, and E. Smit, "Achieving deep-energy retrofits for households in energy poverty," *B&C*, vol. 4, no. 1, Jun. 2023, doi: 10.5334/bc.304.
[44] D. S. Pereira and A. C. Marques, "Are dynamic tariffs effective in reducing energy poverty? Empirical evidence from US households," *Energy*, vol. 282, p. 128848, Nov. 2023, doi: 10.1016/j.energy.2023.128848.
[45] "In 2020, 27% of U.S. households had difficulty meeting their energy needs - U.S. Energy Information Administration (EIA)." Accessed: Jul. 25, 2024. [Online]. Available: https://www.eia.gov/todayinenergy/detail.php?id=51979
[46] Office of Energy Effeciency and Renewable Energy, "WAP-fact-sheet_final.pdf," US Department of Energy, Feb. 2018. Accessed: Jul. 25, 2024. [Online]. Available: https://www.energy.gov/sites/prod/files/2018/03/f49/WAP-fact-sheet_final.pdf

[47] Janet Rudge and Fergus Nicol, Eds., *Cutting the Cost of Cold: Affordable Warmth for Healthier Homes*. CRC Press, 2005.
[48] K. Primc, M. Dominko, and R. Slabe-Erker, "30 years of energy and fuel poverty research: A retrospective analysis and future trends," *Journal of Cleaner Production*, vol. 301, p. 127003, Jun. 2021, doi: 10.1016/j.jclepro.2021.127003.
[49] Suzan Hinson and Paul Bolton, "Fuel Poverty.pdf," House of Common Library, 8730, Feb. 2024. Accessed: Mar. 27, 2024. [Online]. Available: https://researchbriefings.files.parliament.uk/documents/CBP-8730/CBP-8730.pdf
[50] "How fuel poverty is measured in the UK - Office for National Statistics." Accessed: Sep. 05, 2024. [Online]. Available: https://www.ons.gov.uk/peoplepopulationandcommunity/housing/articles/howfuelpovertyismeasuredintheuk/march2023#what-is-fuel-poverty
[51] Office for National Statistics (ONS), "How fuel poverty is measured in the UK: March 2023," ONS website. [Online]. Available: https://www.ons.gov.uk/peoplepopulationandcommunity/housing/articles/howfuelpovertyismeasuredintheuk/march2023
[52] "Energy Performance Certificate (EPC)." Accessed: Sep. 15, 2024. [Online]. Available: https://assets.publishing.service.gov.uk/media/5a748d20ed915d0e8bf19346/1790388.pdf
[53] Jennifer Arthur, "Comparison of theoretical energy consumption with actual usage," Department for Energy Security and Net Zero and Department for Business, Energy & Industrial Strategy, Energy Statistics, Mar. 2019. Accessed: Sep. 06, 2024. [Online]. Available: https://assets.publishing.service.gov.uk/media/5c9b4b1c40f0b633fc95f79c/Comparison_of_theoretical_energy_consumption_with_actual_usage.pdf
[54] "Energy crisis," National Energy Action (NEA). Accessed: Sep. 15, 2024. [Online]. Available: https://www.nea.org.uk/energy-crisis/
[55] *Fuel Poverty (Targets, Definition and Strategy) (Scotland) Act 2019*. 2023. [Online]. Available: https://www.legislation.gov.uk/asp/2019/10/section/3/enacted
[56] "Winter Fuel Payment," GOV.UK. Accessed: Sep. 04, 2024. [Online]. Available: https://www.gov.uk/winter-fuel-payment/eligibility
[57] "Warm Home Discount Scheme," GOV.UK. Accessed: Mar. 13, 2024. [Online]. Available: https://www.gov.uk/the-warm-home-discount-scheme
[58] "Cold Weather Payment," GOV.UK. Accessed: Sep. 04, 2024. [Online]. Available: https://www.gov.uk/cold-weather-payment
[59] S. Bouzarovski, S. Petrova, and R. Sarlamanov, "Energy poverty policies in the EU: A critical perspective," *Energy Policy*, vol. 49, pp. 76–82, Oct. 2012, doi: 10.1016/j.enpol.2012.01.033.
[60] B. Legendre and O. Ricci, "Measuring fuel poverty in France: Which households are the most fuel vulnerable?," *Energy Economics*, vol. 49, pp. 620–628, May 2015, doi: 10.1016/j.eneco.2015.01.022.
[61] "Measuring Fuel Poverty: General Considerations and Application to German Household Data," *FA*, vol. 71, no. 2, p. 178, 2015, doi: 10.1628/001522115X14285723527593.
[62] K. Drescher and B. Janzen, "Determinants, persistence, and dynamics of energy poverty: An empirical assessment using German household survey data," *Energy Economics*, vol. 102, p. 105433, Oct. 2021, doi: 10.1016/j.eneco.2021.105433.

[63] "Measuring energy poverty in Greece | Elsevier Enhanced Reader." Accessed: Sep. 20, 2022. [Online]. Available: https://reader.elsevier.com/reader/sd/pii/S0301421516301720?token=99CC00DCEC0B8C7CEB33B3593A537769AB363C642F04754E8476BDE0A0886CEB7A93789F693776B51FA7F6F39AE205B2&originRegion=us-east-1&originCreation=20220920201909
[64] A. Dagoumas and F. Kitsios, "Assessing the impact of the economic crisis on energy poverty in Greece," *Sustainable Cities and Society*, vol. 13, pp. 267–278, Oct. 2014, doi: 10.1016/j.scs.2014.02.004.
[65] B. Menyhért, "Energy poverty in the European Union. The art of kaleidoscopic measurement," *Energy Policy*, vol. 190, p. 114160, Jul. 2024, doi: 10.1016/j.enpol.2024.114160.
[66] K. Fabbri, "Building and fuel poverty, an index to measure fuel poverty: An Italian case study," *Energy*, vol. 89, pp. 244–258, 2015, doi: 10.1016/j.energy.2015.07.073.
[67] O. Aristondo and E. Onaindia, "Inequality of energy poverty between groups in Spain," *Energy*, vol. 153, pp. 431–442, Jun. 2018, doi: 10.1016/j.energy.2018.04.029.
[68] P. Palma, R. Barrella, J. P. Gouveia, and J. C. Romero, "Comparative analysis of energy poverty definition and measurement in Portugal and Spain," *Utilities Policy*, vol. 90, p. 101770, Oct. 2024, doi: 10.1016/j.jup.2024.101770.
[69] R. Barrella, J. C. Romero, J. I. Linares, E. Arenas, M. Asín, and E. Centeno, "The dark side of energy poverty: Who is underconsuming in Spain and why?," *Energy Research & Social Science*, vol. 86, p. 102428, Apr. 2022, doi: 10.1016/j.erss.2021.102428.
[70] T. Wei, Z. Duan, and P. Xie, "Spatial disparities and variation sources decomposition of energy poverty in China," *Journal of Cleaner Production*, vol. 421, p. 138498, Oct. 2023, doi: 10.1016/j.jclepro.2023.138498.
[71] X. Li, H. Yang, and J. Jia, "Impact of energy poverty on cognitive and mental health among middle-aged and older adults in China," *Humanit Soc Sci Commun*, vol. 9, no. 1, p. 253, Aug. 2022, doi: 10.1057/s41599-022-01276-4.
[72] K. C. O'Sullivan, P. L. Howden-Chapman, and G. M. Fougere, "Fuel poverty, policy, and equity in New Zealand: The promise of prepayment metering," *Energy Research & Social Science*, vol. 7, pp. 99–107, May 2015, doi: 10.1016/j.erss.2015.03.008.
[73] E. Dogan, M. Madaleno, and D. Taskin, "Which households are more energy vulnerable? Energy poverty and financial inclusion in Turkey," *Energy Economics*, vol. 99, p. 105306, Jul. 2021, doi: 10.1016/j.eneco.2021.105306.
[74] A. Maxim, C. Mihai, C.-M. Apostoaie, C. Popescu, C. Istrate, and I. Bostan, "Implications and Measurement of Energy Poverty across the European Union," *Sustainability*, vol. 8, no. 5, p. 483, May 2016, doi: 10.3390/su8050483.
[75] D. Hirsch, M. Padley, J. Stone, and L. Valadez-Martinez, "The Low Income Gap: A New Indicator Based on a Minimum Income Standard," *Soc Indic Res*, vol. 149, no. 1, pp. 67–85, May 2020, doi: 10.1007/s11205-019-02241-6.
[76] Steve Pye, Audrey Dobbins, and Claire Baffet, "Energy poverty and vulnerable consumers in the energy sector across the EU: analysis of policies and measures: Appendices to main report."

[77] H. McDiarmid, A. Bonner Septien, and P. Parker, "Achieving rapid decarbonisation of Canada's residential sector requires a strategic approach," *Energy and Buildings*, vol. 308, p. 113999, Apr. 2024, doi: 10.1016/j.enbuild.2024.113999.
[78] S. Bouzarovski, "Energy poverty in the European Union: landscapes of vulnerability," *WIREs Energy and Environment*, vol. 3, no. 3, pp. 276–289, Apr. 2014, doi: 10.1002/wene.89.
[79] M. Santamouris, K. Kapsis, D. Korres, I. Livada, C. Pavlou, and M. N. Assimakopoulos, "On the relation between the energy and social characteristics of the residential sector," *Energy and Buildings*, vol. 39, no. 8, pp. 893–905, Aug. 2007, doi: 10.1016/j.enbuild.2006.11.001.
[80] A. Synnefa *et al.*, "Minimizing the energy consumption of low income multiple housing using a holistic approach," *Energy and Buildings*, vol. 154, pp. 55–71, Nov. 2017, doi: 10.1016/j.enbuild.2017.07.034.
[81] S. Roberts, "Energy, equity and the future of the fuel poor," *Energy Policy*, vol. 36, no. 12, pp. 4471–4474, Dec. 2008, doi: 10.1016/j.enpol.2008.09.025.
[82] M. Heidari, M. H. Rahdar, A. Dutta, and F. Nasiri, "An energy retrofit roadmap to net-zero energy and carbon footprint for single-family houses in Canada," *Journal of Building Engineering*, vol. 60, p. 105141, Nov. 2022, doi: 10.1016/j.jobe.2022.105141.
[83] N. R. C. Canada, "Historical editions of Codes Canada publications (1941-1998)." Accessed: Oct. 17, 2024. [Online]. Available: https://nrc.canada.ca/en/certifications-evaluations-standards/codes-canada/codes-canada-publications/historical-editions-codes-canada-publications-1941-1998
[84] N. R. C. Government of Canada, "Survey of Household Energy Use, 2019." Accessed: Dec. 30, 2024. [Online]. Available: https://oee.nrcan.gc.ca/publications/statistics/sheu/2019/index.cfm
[85] W. R. Chan, J. Joh, and M. H. Sherman, "Analysis of air leakage measurements of US houses," *Energy and Buildings*, vol. 66, pp. 616–625, Nov. 2013, doi: 10.1016/j.enbuild.2013.07.047.
[86] B. Stephens and J. A. Siegel, "Penetration of ambient submicron particles into single-family residences and associations with building characteristics," *Indoor Air*, vol. 22, no. 6, pp. 501–513, 2012, doi: 10.1111/j.1600-0668.2012.00779.x.
[87] L. J. Underhill *et al.*, "Modeling the resiliency of energy-efficient retrofits in low-income multifamily housing," *Indoor Air*, 2018, [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85041105507&doi=10.1111%2fina.12446&partnerID=40&md5=075dd2be27c3b7e51c4accd5c8ab9298
[88] S. Al Humidi and T. Li, "Assessing the Impact of Poor- Performing Homes on Indoor Air Quality Pre- and Post-Energy Retrofits in Low-Income Populations," Jan. 2024.
[89] L. E. Escobedo, W. M. Champion, N. Li, and L. D. Montoya, "Indoor air quality in Latino homes in Boulder, Colorado," *Atmospheric Environment*, 2014, [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84898647342&doi=10.1016%2fj.atmosenv.2014.03.043&partnerID=40&md5=b75cafbdee3972953ad5787cc502c8b9
[90] T. Brown *et al.*, "Relationships between socioeconomic and lifestyle factors and indoor air quality in French dwellings," *Environmental Research*, vol. 140, pp. 385–396, Jul. 2015, doi: 10.1016/j.envres.2015.04.012.

[91] E. Diaz Lozano Patino and J. A. Siegel, "Indoor environmental quality in social housing: A literature review," *Building and Environment*, vol. 131, pp. 231–241, Mar. 2018, doi: 10.1016/j.buildenv.2018.01.013.
[92] J. E. Storm, K. A. Mazor, S. J. Shost, J. Serle, K. M. Aldous, and B. C. Blount, "Socioeconomic disparities in indoor air, breath, and blood perchloroethylene level among adult and child residents of buildings with or without a dry cleaner," *Environmental Research*, 2013, [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84875059150&doi=10.1016%2fj.envres.2013.02.001&partnerID=40&md5=732aa5d137f51ac7958e4303d8164e46
[93] D. Vakalis *et al.*, "Quantifying thermal comfort and carbon savings from energy-retrofits in social housing," *Energy and Buildings*, vol. 241, p. 110950, Jun. 2021, doi: 10.1016/j.enbuild.2021.110950.
[94] F. Tardy and B. Lee, "Building related energy poverty in developed countries – Past, present, and future from a Canadian perspective," *Energy and Buildings*, vol. 194, pp. 46–61, Jul. 2019, doi: 10.1016/j.enbuild.2019.04.013.
[95] S. Jessel, S. Sawyer, and D. Hernández, "Energy, Poverty, and Health in Climate Change: A Comprehensive Review of an Emerging Literature," *Front. Public Health*, vol. 7, p. 357, Dec. 2019, doi: 10.3389/fpubh.2019.00357.
[96] B. Ostro, S. Rauch, R. Green, B. Malig, and R. Basu, "The Effects of Temperature and Use of Air Conditioning on Hospitalizations," *American Journal of Epidemiology*, vol. 172, no. 9, pp. 1053–1061, Nov. 2010, doi: 10.1093/aje/kwq231.
[97] M. Marmot, "Health equity in England: the Marmot review 10 years on," *BMJ*, p. m693, Feb. 2020, doi: 10.1136/bmj.m693.
[98] E. G. Mourtzoukou and M. E. Falagas, "Exposure to cold and respiratory tract infections," p. 6.
[99] F. Rakers *et al.*, "Rapid weather changes are associated with increased ischemic stroke risk: a case-crossover study," *Eur J Epidemiol*, vol. 31, no. 2, pp. 137–146, Feb. 2016, doi: 10.1007/s10654-015-0060-3.
[100] J. H. Lichtman, E. C. Leifheit-Limson, S. B. Jones, Y. Wang, and L. B. Goldstein, "Average Temperature, Diurnal Temperature Variation, and Stroke Hospitalizations," *Journal of Stroke and Cerebrovascular Diseases*, vol. 25, no. 6, pp. 1489–1494, Jun. 2016, doi: 10.1016/j.jstrokecerebrovasdis.2016.02.037.
[101] H. Thomson, C. Snell, and S. Bouzarovski, "Health, Well-Being and Energy Poverty in Europe: A Comparative Study of 32 European Countries," *IJERPH*, vol. 14, no. 6, p. 584, May 2017, doi: 10.3390/ijerph14060584.
[102] S. C. Government of Canada, "Canadian Housing Survey (CHS)." Accessed: Aug. 11, 2024. [Online]. Available: https://www.statcan.gc.ca/en/survey/household/5269
[103] S. C. Government of Canada, "Survey of Household Spending (SHS)." Accessed: Aug. 11, 2024. [Online]. Available: https://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&Id=1204699
[104] Statistics Canada, "User Guide for the Survey of Household Spending, 2019," no. 62, 2019.
[105] Statistics Canada, "SHS_vetting_rules.pdf." Apr. 04, 2021.

[106] S. C. Government of Canada, "Low income cut-offs (LICOs) before and after tax by community size and family size, in current dollars." Accessed: Sep. 15, 2024. [Online]. Available: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1110024101
[107] S. C. Government of Canada, "Occupied private dwellings by structural type of dwelling, percentage distribution 2021: Canada, provinces and territories." Accessed: Dec. 20, 2024. [Online]. Available: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=9810004701
[108] C. E. R. Government of Canada, "CER – Market Snapshot: Household expenditures on energy are highest in Atlantic Canada." Accessed: Dec. 20, 2024. [Online]. Available: https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2019/market-snapshot-household-expenditures-energy-are-highest-in-atlantic-canada.html
[109] B. Boardman, "Energy Poverty in Eastern Europe—Hidden Geographies of Deprivation, Stefan Buzar. Ashgate, UK (2007)," *Energy Policy*, vol. 37, no. 7, pp. 2836–2837, Jul. 2009, doi: 10.1016/j.enpol.2008.10.004.
[110] S. C. Government of Canada, "The Daily — Households and the Environment Survey: Energy use, 2021." Accessed: Dec. 21, 2024. [Online]. Available: https://www150.statcan.gc.ca/n1/daily-quotidien/240319/dq240319d-eng.htm
[111] "Heating degree days in Canada, 2000-2020 – Charts – Data & Statistics," IEA. Accessed: Dec. 21, 2024. [Online]. Available: https://www.iea.org/data-and-statistics/charts/heating-degree-days-in-canada-2000-2020
[112] S. C. Government of Canada, "Focus on Geography Series, 2021 Census - Ontario." Accessed: Sep. 12, 2024. [Online]. Available: https://www12.statcan.gc.ca/census-recensement/2021/as-sa/fogs-spg/page.cfm?lang=E&topic=3&dguid=2021A000235
[113] S. C. Government of Canada, "The prevalence of household air conditioning in Canada." Accessed: Jan. 06, 2025. [Online]. Available: https://www150.statcan.gc.ca/n1/pub/82-003-x/2023007/article/00002-eng.htm
[114] N. R. C. Government of Canada, "Energy Use in Canada: Trends Publications." Accessed: Feb. 07, 2025. [Online]. Available: https://oee.nrcan.gc.ca/publications/statistics/trends/2019/residential.cfm
[115] S. C. Government of Canada, "Air conditioning: More Canadians keep cool, but costs heat up." Accessed: Feb. 07, 2025. [Online]. Available: https://www.statcan.gc.ca/o1/en/plus/4034-air-conditioning-more-canadians-keep-cool-costs-heat
[116] S. C. Government of Canada, "The prevalence of household air conditioning in Canada." Accessed: Feb. 07, 2025. [Online]. Available: https://www150.statcan.gc.ca/n1/pub/82-003-x/2023007/article/00002-eng.htm
[117] *Measurement of Energy and Demand Savings*, Guideline 14, Jun. 27, 2002. Accessed: Feb. 10, 2025. [Online]. Available: https://www.eeperformance.org/uploads/8/6/5/0/8650231/ashrae_guideline_14-2002_measurement_of_energy_and_demand_saving.pdf
[118] he Toronto and Region Conservation Authority's Sustainable Technologies, "Performance Assessment of Heat Pump Systems.pdf." Accessed: Feb. 07, 2025. [Online]. Available: https://sustainabletechnologies.ca/app/uploads/2015/12/ASHP-GSHP_TechBrief_Final.pdf
[119] "Comparison of Electricity Prices in Major North American Cities 2024," 1927.

[120] Ontario Energy Board, "Historical Natural Gas Rates." Accessed: Feb. 07, 2025. [Online]. Available: https://www.oeb.ca/sites/default/files/qram-union-20211001-en.pdf
[121] "Gas Bill Calculator (contract | residential)." Accessed: Feb. 07, 2025. [Online]. Available: https://www.oeb.ca/_html/calculator/gasbillcalc.php
[122] D. Jermyn and R. Richman, "A process for developing deep energy retrofit strategies for single-family housing typologies: Three Toronto case studies," *Energy and Buildings*, vol. 116, pp. 522–534, Mar. 2016, doi: 10.1016/j.enbuild.2016.01.022.
[123] N. R. Canada, "Eligible retrofits and grant amounts." Accessed: Feb. 09, 2025. [Online]. Available: https://natural-resources.canada.ca/energy-efficiency/home-energy-efficiency/canada-greener-homes-initiative/eligible-retrofits-grant-amounts

Appendix A – National Statistical Results

National EB and EP Results for 2019 and 2021

Description	Province	2M_EB_2019	2M_EP_2019	6_EB_2019	6_EP_2019	10_EB_2019	10_EP_2019	2M_EB_2021	2M_EP_2021	6_EB_2021	6_EP_2021	10_EB_2021	10_EP_2021
eer_it	AB	11.10	4.30	8.90	4.10	2.60	2.80	14.80	4.40	11.30	4.40	1.70	3.20
	BC	7.70	7.00	6.50	6.80	1.50	4.50	9.20	4.60	6.80	4.10	1.80	3.00
	MN	11.20	5.90	9.10	5.80	2.40	3.90	13.10	6.20	9.90	6.10	2.20	3.80
	NB	33.00	9.70	28.60	9.50	8.90	6.80	29.90	7.00	22.50	6.10	5.70	3.90
	NL	29.80	9.90	26.30	9.70	8.70	7.00	36.40	5.60	29.80	5.30	9.80	4.40
	NS	26.60	8.60	23.20	8.30	6.10	6.80	27.00	4.70	22.40	4.30	6.40	3.50
	ON	13.00	5.50	10.50	5.10	2.00	3.90	12.10	4.50	9.40	4.10	2.40	2.60
	PEI	28.70	10.60	23.90	10.60	6.50	8.20	28.30	7.10	22.50	6.90	6.10	5.90
	QC	9.70	6.70	7.60	6.30	1.40	3.40	10.20	4.00	6.90	3.70	1.50	1.70
	SK	16.00	7.60	13.90	7.30	3.50	5.60	16.10	5.90	14.20	5.30	4.60	3.80
	CAN	12.43	6.23	10.21	5.90	2.28	4.03	12.97	4.57	9.82	4.20	2.37	2.70
eer_hctax	AB	12.90	3.60	14.10	3.80	5.80	2.70	15.90	4.20	15.70	4.20	3.90	3.00
	BC	10.40	5.50	11.70	5.50	3.50	4.10	11.70	3.90	11.50	3.90	3.90	2.90
	MN	11.40	4.40	12.00	4.40	3.70	3.00	13.30	6.60	13.10	6.60	3.50	4.80
	NB	31.20	9.10	33.60	9.20	11.90	7.50	26.30	6.20	26.30	6.00	8.20	4.20
	NL	29.80	9.60	31.30	9.80	11.20	7.80	34.90	5.60	34.80	5.60	13.30	5.20
	NS	26.10	7.60	28.60	7.60	8.30	6.00	25.40	5.60	25.20	5.50	10.00	4.10
	ON	14.60	4.80	15.40	4.80	4.40	3.70	13.00	3.00	13.00	3.00	5.20	2.10
	PEI	28.20	12.10	29.40	12.10	9.00	9.60	27.50	7.30	27.20	7.30	9.00	6.40
	QC	10.00	6.50	11.10	6.70	2.60	4.00	9.80	5.20	9.40	5.00	2.00	3.10
	SK	16.60	6.40	17.40	6.40	5.50	5.80	18.20	4.30	17.90	4.30	6.50	2.80
	CAN	13.64	5.52	14.75	5.60	4.38	4.02	13.57	4.17	13.39	4.12	4.41	2.85
eer_hcfh	AB	15.80	3.10	19.50	3.30	9.30	2.90	17.50	2.50	22.30	2.60	8.10	1.70
	BC	12.90	4.60	17.10	4.80	6.80	3.90	13.10	3.30	16.30	3.50	7.00	3.00
	MN	14.60	3.70	19.40	4.10	7.10	3.00	15.80	5.30	19.80	5.30	8.70	4.80
	NB	33.30	8.50	42.00	8.50	19.00	7.60	30.50	5.70	37.00	5.90	15.20	4.50
	NL	31.70	10.00	40.10	10.30	18.10	8.70	38.30	4.90	43.40	5.00	19.00	4.60
	NS	28.20	6.40	37.20	6.60	16.20	6.10	29.00	5.80	34.00	5.80	15.50	4.80
	ON	17.80	3.70	22.60	4.20	9.00	3.30	14.70	3.30	18.20	3.60	6.90	2.60
	PEI	30.50	10.70	38.60	11.10	16.90	9.00	30.40	6.60	34.70	6.80	16.70	6.40
	QC	13.60	6.20	18.20	6.50	7.10	4.50	12.80	5.10	16.00	5.70	5.20	3.70
	SK	18.50	5.60	25.50	5.90	10.60	4.80	20.90	3.90	25.60	4.20	10.20	3.40
	CAN	16.69	4.77	21.58	5.13	8.87	3.97	15.77	3.89	19.49	4.21	7.47	3.10
eer_hchac	AB	15.90	3.10	19.70	3.30	9.40	2.90	17.40	2.50	22.30	2.60	8.10	1.70
	BC	12.90	4.60	17.10	4.80	7.00	3.90	13.00	3.30	16.30	3.50	7.00	3.00
	MN	14.50	3.70	19.40	4.10	7.10	3.00	15.80	5.30	19.80	5.30	8.70	4.80
	NB	33.10	8.50	42.10	8.50	19.00	7.60	30.60	5.70	37.10	5.90	15.20	4.50
	NL	31.60	10.00	40.10	10.30	18.10	8.70	38.10	4.90	43.40	5.00	19.40	4.60
	NS	28.10	6.40	37.20	6.60	16.40	6.10	29.10	5.80	34.10	5.80	15.60	4.80
	ON	17.80	3.70	22.70	4.20	9.10	3.30	14.70	3.30	18.70	3.60	7.00	2.60
	PEI	30.30	10.70	38.70	11.10	16.90	9.00	30.80	6.60	34.70	6.80	16.90	6.40
	QC	13.40	6.10	18.20	6.50	7.20	4.50	12.60	5.10	16.10	5.70	5.30	3.70
	SK	18.30	5.60	25.40	5.90	10.60	4.80	20.90	3.90	25.60	4.20	10.20	3.40
	CAN	16.65	4.75	21.63	5.13	8.93	3.98	15.71	3.90	19.72	4.21	7.53	3.10

National EB and EP Characteristics : EERit													
		2019						2021					
Characteristic	Description	2M_EB	2M_EP	6_EB	6_EP	10_EB	10_EP	2M_EB	2M_EP	6_EB	6_EP	10_EB	10_EP
Household Type	One person	19.40	13.5	16.60	12.9	5.00	9.3	19.5	10.5	16.0	9.9	4.6	6.7
	Couple without children	14.50	3.1	11.70	2.9	1.60	2	15.3	2.1	11.0	1.8	2.6	1.2
	Couple with children	6.50	3.6	4.60	3.4	0.50	2	5.9	2.1	4.0	1.9	0.8	0.7
	Lone Parent	13.00	10.3	11.10	10.2	3.90	5.8	16.6	5	12.0	4.3	1.7	3.8
	Other	7.70	3.1	6.52	2.8	1.89	2	7.6	2.5	5.7	2.4	0.9	1.2
Marital Status	Married	10.4	3	8.1	2.9	1.2	2	10.9	2.1	7.7	1.9	1.7	0.9
	Common-Law	7.3	3.1	5.6	3	0.4	1.4	6.5	1.8	4.3	1.7	1.0	1.1
	Never Married	34	8.9	29.4	8.7	9.9	7.2	11.4	8.9	9.2	8.2	3.1	5.6
	Seperated	15.5	15.2	13.4	14	4.4	9.9	19.0	8.5	13.8	7.6	2.1	5.9
	Divorced	16.7	10.6	13.2	9.7	3.2	5.5	15.8	7.8	12.3	7.7	2.2	3.5
	Widowed	10.3	12.4	9.3	11.9	2.7	8.3	30.9	7.9	25.8	7.7	7.0	6.2
Employment	Worked full-time	7.8	2.6	6	2.6	1.3	2.1	7.0	0.5	4.9	0.5	0.9	0.4
	Worked part-time	11	6.2	9	5.9	1.5	4.2	11.8	4.7	8.8	4.2	2.1	1.9
	Did not work	20.2	11.3	16.9	10.6	4.3	6.6	21.9	9.5	17.1	9	4.7	6.4
Number of Bedrooms	One	0	0	0	0	0	0	4.8	5.2	3.8	4.3	0.8	2.3
	Two	0	0	0	0	0	0	12.3	6.8	8.5	6.4	1.9	3.6
	Three	0	0	0	0	0	0	16.8	4.3	13.6	3.9	3.4	2.8
	Four	0	0	0	0	0	0	12.0	3.1	8.6	2.9	2.1	2
	Five or more	0	0	0	0	0	0	11.1	3.1	8.3	3.1	2.1	2.1
City	City	8.5	6.5	7.1	6.1	1.4	4.3	9.6	4	6.7	4	1.3	2.9
	Other	16.9	6.1	13.7	5.9	3.2	3.9	17.2	5.1	13.5	4.6	3.4	3
Urban Size	1,000,000 or over	7.9	6.3	6.5	5.9	1.5	4.1	9.0	4.1	6.7	3.8	1.2	2.8
	500,000 to 999,999	6.9	4.8	5.6	4.7	0.4	2.9	6.4	4.1	3.5	3.2	-1.2	2.6
	250,000 to 499,999	14.1	6.4	10.8	6.3	1.7	3.8	12.6	1.7	9.1	1.7	3.2	0.7
	100,000 to 249,999	14.6	4.8	12.7	4.6	2.8	3.1	17.0	4.5	12.8	4.3	3.5	2.8
	30,000 to 99,999	16.6	8	14	7.8	2.3	4.8	15.4	6.1	11.9	5.3	2.5	3.6
	1,000 to 29,999	15.3	6.7	11.7	6.7	2.9	4.3	16.8	6.8	13.7	6.3	1.9	3.6
	Rural areas	29.6	7.2	24.4	6.4	7.4	5.3	28.5	5.4	22.5	5.3	7.5	4
	Total	12.5	6.2	10.2	5.9	2.3	4	13	4.5	9.9	4.1	2.2	2.9

National EB and EP Characteristics : EERit

		2019						2021					
Characteristic	**Description**	**2M_EB**	**2M_EP**	**6_EB**	**6_EP**	**10_EB**	**10_EP**	**2M_EB**	**2M_EP**	**6_EB**	**6_EP**	**10_EB**	**10_EP**
Household Type	**One person**	19.40	13.5	16.60	12.9	5.00	9.3	19.5	10.5	16.0	9.9	4.6	6.7
	Couple without children	14.50	3.1	11.70	2.9	1.60	2	15.3	2.1	11.0	1.8	2.6	1.2
	Couple with children	6.50	3.6	4.60	3.4	0.50	2	5.9	2.1	4.0	1.9	0.8	0.7
	Lone Parent	13.00	10.3	11.10	10.2	3.90	5.8	16.6	5	12.0	4.3	1.7	3.8
	Other	7.70	3.1	6.52	2.8	1.89	2	7.6	2.5	5.7	2.4	0.9	1.2
Marital Status	**Married**	10.4	3	8.1	2.9	1.2	2	10.9	2.1	7.7	1.9	1.7	0.9
	Common-Law	7.3	3.1	5.6	3	0.4	1.4	6.5	1.8	4.3	1.7	1.0	1.1
	Never Married	34	8.9	29.4	8.7	9.9	7.2	11.4	8.9	9.2	8.2	3.1	5.6
	Seperated	15.5	15.2	13.4	14	4.4	9.9	19.0	8.5	13.8	7.6	2.1	5.9
	Divorced	16.7	10.6	13.2	9.7	3.2	5.5	15.8	7.8	12.3	7.7	2.2	3.5
	Widowed	10.3	12.4	9.3	11.9	2.7	8.3	30.9	7.9	25.8	7.7	7.0	6.2
Employment	**Worked full-time**	7.8	2.6	6	2.6	1.3	2.1	7.0	0.5	4.9	0.5	0.9	0.4
	Worked part-time	11	6.2	9	5.9	1.5	4.2	11.8	4.7	8.8	4.2	2.1	1.9
	Did not work	20.2	11.3	16.9	10.6	4.3	6.6	21.9	9.5	17.1	9	4.7	6.4
Number of Bedrooms	**One**	0	0	0	0	0	0	4.8	5.2	3.8	4.3	0.8	2.3
	Two	0	0	0	0	0	0	12.3	6.8	8.5	6.4	1.9	3.6
	Three	0	0	0	0	0	0	16.8	4.3	13.6	3.9	3.4	2.8
	Four	0	0	0	0	0	0	12.0	3.1	8.6	2.9	2.1	2
	Five or more	0	0	0	0	0	0	11.1	3.1	8.3	3.1	2.1	2.1
City	**City**	8.5	6.5	7.1	6.1	1.4	4.3	9.6	4	6.7	4	1.3	2.9
	Other	16.9	6.1	13.7	5.9	3.2	3.9	17.2	5.1	13.5	4.6	3.4	3
Urban Size	**1,000,000 or over**	7.9	6.3	6.5	5.9	1.5	4.1	9.0	4.1	6.7	3.8	1.2	2.8
	500,000 to 999,999	6.9	4.8	5.6	4.7	0.4	2.9	6.4	4.1	3.5	3.2	-1.2	2.6
	250,000 to 499,999	14.1	6.4	10.8	6.3	1.7	3.8	12.6	1.7	9.1	1.7	3.2	0.7
	100,000 to 249,999	14.6	4.8	12.7	4.6	2.8	3.1	17.0	4.5	12.8	4.3	3.5	2.8
	30,000 to 99,999	16.6	8	14	7.8	2.3	4.8	15.4	6.1	11.9	5.3	2.5	3.6
	1,000 to 29,999	15.3	6.7	11.7	6.7	2.9	4.3	16.8	6.8	13.7	6.3	1.9	3.6
	Rural areas	29.6	7.2	24.4	6.4	7.4	5.3	28.5	5.4	22.5	5.3	7.5	4
	Total	12.5	6.2	10.2	5.9	2.3	4	13	4.5	9.9	4.1	2.2	2.9

National EB and EP Characteristics : EERhctax													
		2019						2021					
Characteristic	Description	2M_EB	2M_EP	6_EB	6_EP	10_EB	10_EP	2M_EB	2M_EP	6_EB	6_EP	10_EB	10_EP
Dwelling age	1960 or before	18.4	7.3	19.5	7.5	6.8	5.6	17.2	7.9	16.9	7.9	5.6	5.3
	1961-1980	13.5	6.2	14.9	6.2	4.9	4.6	15.4	3.6	15.2	3.5	4.8	2.2
	1981-2000	11.1	5.5	12.1	5.5	2.2	3.8	11.3	3.2	11.1	3.2	3.5	2.4
	2001 and after	11.6	2.8	12.7	2.8	3.9	1.8	10.6	2.4	10.5	2.4	3.8	1.8
Dwelling Type	Single Detached	17	4.4	18.3	4.4	5.5	3.7	16.8	3.5	16.6	3.5	5.2	2.5
	Semi-Detached	11.9	3.1	14	3.1	4.1	2.7	13.4	3.6	13.2	3.6	5.1	2.7
	Townhouse and Duplex	13.1	5.9	14.6	5.9	4.9	4.1	11.5	3.5	10.9	3.5	3.8	2.8
	Low-rise Apartment	5.1	9.3	5.4	9.7	1.2	6.2	6.1	7.8	6.1	7.5	1.4	4.8
	High-rise Apartment	3.8	8.7	4	8.7	0.5	2.4	6.2	4.0	6.1	4.0	3.8	2.1
Household Size (# of People/ Household)	One person	20.4	12.4	22	12.6	8	8.8	20.2	10.0	19.9	9.9	7.8	7.1
	Two person	14.6	3.3	15.8	3.3	4.3	2.4	14.5	2.1	14.3	2.1	4.4	1.6
	Three person	9.9	3.5	10.5	3.5	3.3	2.6	11.2	1.3	11.0	1.3	3.2	0.9
	Four person	9.5	2.8	10.4	2.8	1.4	2.2	7.1	2.1	7.0	2.1	1.0	0.8
	Five or more person	5.9	3.4	6.4	3.5	2.2	2.5	5.9	2.4	5.9	2.4	1.8	1.6
Rent or Mortgage	Owned with mortgage	14.4	2.6	15.4	2.6	5.2	2.1	12.9	1.2	12.7	1.2	5.1	0.9
	Owned without mortgage	15.1	5.8	16.6	5.8	3.8	4.5	16.4	5.3	16.3	5.2	4.2	4.0
	Rent	10.4	10.1	11.2	10.3	3.8	6.5	10.7	7.6	10.5	7.4	3.5	4.5
Maintenance	Only regular maintenance	12.2	4.8	13.3	4.8	3.5	3.5	12.5	3.5	12.3	3.5	3.9	2.5
	Minor repairs	14.9	6.4	16.2	6.5	5.2	4.2	15.4	5.1	15.3	5.0	4.9	2.9
	Major repairs	22.4	9.5	23.1	9.5	9.3	8.2	16.4	6.3	16.3	6.2	6.7	5.5
Education	Highshool Equivelant or less	17.6	8.7	18.8	8.8	5.6	6.4	20.6	6.9	20.6	6.8	6.8	4.6
	Trade Certificate, College etc..	14.2	5.2	15.3	5.3	4.7	3.8	13.4	3.2	13.0	3.2	4.4	2.4
	Bachelors Degree or higher	8.9	2.7	9.9	2.7	2.9	1.8	8.2	2.9	8.1	2.9	2.5	2.0
Income	0-29K	20	36.4	20.9	36.9	9	27.0	23.2	33.3	23.2	32.8	10.4	24.1
	30K-59K	28.2	2.3	30.1	2.3	9.8	1.4	29.5	2.0	29.1	2.0	10.5	0.8
	60K-89K	0	0	0	0	0	0	0	0	0	0	0	0
	90K-119K	0	0	0	0	0	0	0	0	0	0	0	0
	120K+	0	0	0	0	0	0	0	0	0	0	0	0

National EB and EP Characteristics : EERhctax													
		2019						2021					
Characteristic	Description	2M_EB	2M_EP	6_EB	6_EP	10_EB	10_EP	2M_EB	2M_EP	6_EB	6_EP	10_EB	10_EP
Household Type	One person household	20.40	12.4	22.00	12.6	8.00	8.8	20.2	10.0	19.9	9.9	7.8	7.1
	Couple without children	14.20	2.9	15.20	2.9	3.90	2.3	13.7	1.8	13.5	1.8	4.3	1.2
	Couple with children	8.50	3.1	9.40	3.1	2.00	2.3	7.7	2.0	7.6	2.0	1.8	1.1
	Lone Parent	15.60	7.9	16.30	8.1	6.10	5.6	20.4	3.9	20.3	3.9	6.4	3.0
	Other	10.27	2.2	11.20	2.2	3.31	1.5	8.9	1.5	8.8	1.5	2.2	1.2
Marital Status	Married	11	2.6	11.9	2.6	2.9	2.0	10.9	1.9	10.7	1.9	2.9	1.1
	Common-Law	9.5	3.6	10.2	3.6	2.6	2.7	7.1	2.0	7.1	2.0	2.5	1.2
	Never Married	30.8	8.9	33.4	8.9	11.7	7.8	14.2	8.0	13.8	7.8	6.6	5.7
	Seperated	20.5	12.0	21.7	12.4	6.6	9.1	21.1	8.0	21.0	7.9	6.1	5.5
	Divorced	18.8	9.9	19.9	10.1	6	5.4	16.7	7.2	16.6	7.2	6.0	4.9
	Widowed	13	10.4	14.3	10.6	5.8	7.3	28.9	7.2	28.7	7.2	8.5	5.7
Employment	Worked full-time	10	1.8	10.8	1.9	3.3	1.6	7.8	0.5	7.7	0.5	2.2	0.3
	Worked part-time	13.1	6.3	14.3	6.3	3.6	4.4	13.3	4.1	13.1	3.9	4.9	2.6
	Did not work	19	10.3	20.7	10.4	6.4	7.2	21.1	9.0	21.0	8.9	6.6	6.4
Number of Bedrooms	One Bedroom	0	5.2	0	5.1	0	3.6	7.6	7.8	7.4	7.4	2.5	4.4
	Two Bedrooms	0	6.6	0	6.3	0	4.5	13.5	5.3	13.3	5.3	3.6	3.2
	Three Bedrooms	0	5.8	0	5.6	0	4.0	16.6	3.8	16.4	3.8	5.6	2.9
	Four Bedrooms	0	5.1	0	5.0	0	3.4	12.1	2.5	12.1	2.5	4.2	1.9
	Five or more Bedrooms	0	4.6	0	4.3	0	2.7	12.0	2.9	11.8	2.9	4.2	2.3
City	City	10.93	5.0	12.1	6.2	3.8	4.3	10.87	4.0	10.7	4.0	3.7	2.9
	Other	16.84	6.2	17.9	5.5	5.1	4.0	16.59	4.7	16.4	4.6	5.1	3.0
Urban Size	1,000,000 or over	10.50	4.9	11.5	8.8	3.9	6.0	10.5	3.8	10.4	4.1	3.8	2.9
	500,000 to 999,999	6.09	4.2	7.4	6.2	1.1	5.2	7.6	3.2	7.5	3.8	1.6	2.8
	250,000 to 499,999	14.38	6.2	15.6	6.4	4.2	5.2	13.6	1.7	13.6	3.2	5.2	2.6
	100,000 to 249,999	16.66	5.3	17.5	6.2	4.4	4.3	15.9	4.3	15.5	1.7	4.7	0.7
	30,000 to 99,999	17.15	8.6	18.2	5.5	4.5	4.0	16.1	5.8	15.8	4.3	4.8	2.8
	1,000 to 29,999	14.56	6.2	16	8.8	4.4	6.0	18.4	6.3	18.4	5.3	4.9	3.6
	Rural areas	28.31	6.4	29.7	6.2	10.2	5.2	23.8	5.3	23.5	6.3	7.9	3.6
	Total	13.64	5.5	14.7	6.4	4.4	5.2	13.6	4.2	13.4	5.3	4.4	4.0

Appendix B – Ontario Statistical Results

Ontario EB and EP Results for 2019 and 2021													
Descriptic	Province	2M_EB_2019	2M_EP_201	6_EB_2019	6_EP_2019	10_EB_2019	10_EP_2019	2M_EB_2021	2M_EP_2021	6_EB_2021	6_EP_2021	10_EB_2021	10_EP_2021
eer_it	ON	14.27	3.69	11.45	4.18	2.59	3.32	13.72	3.28	9.95	3.55	2.36	2.62
eer_hctax	ON	14.27	3.69	16.06	4.18	4.78	3.32	12.75	3.28	12.42	3.55	4.63	2.62
eer_hcfh	ON	15.73	4.65	22.03	4.77	8.66	3.67	16.34	3.03	18.80	3.03	7.39	2.14
eer_hchac	ON	14.85	5.48	21.80	5.12	8.48	3.90	14.13	4.49	18.22	4.12	6.99	2.61

Ontario EB and EP Characteristics : EERit											
Characteristic	Description	2M_EB_2019	2M_EP_2019	6_EB_2019	6_EP_2019	10_EP_2019	10_EB_2019	2M_EB_2021	2M_EP_2021	6_EB_2021	6_EP_2021
Dwelling age	1960 or before	15.97	6.25	13.10	5.81	5.28	3.76	14.05	5.91	11.64	5.52
	1961-1990	12.56	5.75	10.55	5.31	3.49	1.60	14.99	2.38	9.34	2.21
	1991 or after	9.29	4.45	8.15	4.26	3.18	0.92	9.10	4.67	7.18	4.14
Dwelling Type	Houses	14.33	5.00	12.02	5.00	0.00	0.00	14.41	3.93	10.79	3.47
	Apartment	1.20	8.40	1.18	5.85	0.00	0.00	3.71	7.11	2.88	7.11
Household Size (# of People/ Household)	One Person	22.35	12.52	18.96	11.42	9.34	4.16	22.80	10.47	17.94	10.47
	Two Person	15.10	3.67	12.80	3.30	2.31	2.00	14.67	3.74	10.42	3.04
	Three Person	7.84	4.76	7.22	4.76	3.97	0.77	9.22	1.77	6.98	1.43
	Four or more Persons	5.28	3.10	3.96	3.10	2.48	1.39	4.59	0	3.47	0
Rent or Mortgage	Owned with mortgage	9.86	2.84	7.95	2.84	1.96	1.75	9.96	2.20	8.16	1.88
	Owned without mortgage	19.17	4.91	16.36	4.74	4.18	2.76	19.23	5.04	14.11	4.63
	Rent	7.06	12.03	6.28	10.62	7.61	1.27	6.51	8.46	3.95	8.02
Maintenance	Regular maintenance	11.07	4.85	9.16	4.43	3.72	1.05	15.21	0	11.97	0
	Minor repairs	13.96	5.27	11.77	4.97	3.00	3.60	21.06	0	16.89	0
	Major repairs	22.19	12.25	20.08	12.25	8.35	6.69	17.35	0	14.01	0
Education	Highschool equivalent or less	18.56	8.86	14.64	8.46	6.15	2.96	21.32	6.67	16.55	5.79
	Trade certificate, college etc...	14.94	4.80	12.52	4.31	2.90	2.15	12.81	2.73	9.96	2.59
	Bachelors degree or higher	5.15	3.55	5.14	3.38	3.23	1.10	6.60	4.37	4.34	4.15
Income	0-29K	19.55	43.61	19.57	40.42	0.00	38.44	22.35	42.00	21.21	39.60
	30-59K	32.93	2.63	26.64	2.63	0.00	5.28	35.50	1.84	27.42	0.00
	60-89K	10.35	0.00	4.66	0.00	0.00	1.05	10.43	0.00	6.37	0.00
	90K+	1.98	0.00	0.00	0.00	0.00	0.00	2.00	0.00	1.35	0.00
Household Type	One person	22.35	12.52	18.96	11.42	9.34	4.16	22.80	10.47	28.41	0.00
	Couple without children	14.73	2.90	12.70	2.90	2.39	0.76	14.49	2.68	12.07	0.00
	Couple with children	6.68	3.19	5.36	2.92	2.20	1.23	5.10	2.00	5.63	0.00
	Lone Parent	14.55	10.41	12.41	10.41	5.17	6.06	15.56	6.01	16.06	0.00
Marital Status	Married/Common-Law	9.21	2.85	7.66	2.85	2.13	0.82	8.92	2.27	6.26	1.81
	Never Married	36.28	7.32	29.93	7.32	7.32	8.57	11.47	10.49	8.44	10.49
	Separated,Divorced,Widowed	12.99	11.86	11.39	10.43	7.45	2.89	22.90	6.63	18.45	6.24
Employment	Full-time	7.55	2.62	6.16	2.62	2.62	1.24	6.72	0.00	4.37	0.00
	Part-time	10.59	5.55	9.57	4.92	3.44	1.46	16.00	0.00	13.18	0.00
	Did not work	21.35	9.83	17.83	9.09	6.18	3.54	32.77	0.00	26.81	0.00
Number of Bedrooms	One	0.00	0.00	0.00	0.00	0.00	0.00	2.18	6.99	1.34	6.99
	Two	0.00	0.00	0.00	0.00	0.00	0.00	18.42	4.17	14.31	3.49
	Three	0.00	0.00	0.00	0.00	0.00	0.00	17.16	2.66	13.57	2.26
	Four or more	0.00	0.00	0.00	0.00	0.00	0.00	8.66	3.63	5.85	3.63
City	City	9.32	6.06	8.55	5.27	4.54	1.75	15.20	0.00	12.18	0.00
	Other	15.11	5.07	12.11	5.07	3.43	2.14	18.73	0.00	14.78	0.00
Urban Size	30,000 or less including rural	21.07	6.83	16.44	6.83	5.35	4.48	18.76	6.45	14.16	6.45
	100,000 to 499,999	15.64	4.71	13.10	4.71	2.85	1.56	14.27	3.66	10.94	3.07
	500,000 or over	8.33	5.35	7.46	4.72	3.87	1.36	6.98	6.99	4.00	6.99
	Total	12.49	5.48	10.51	5.12	3.90	2.00	17.00	0.00	13.50	0.00

Ontario EB and EP Characteristics : EERhctax													
Characteristic	Description	2M_EB_2019	6_EB_2019	10_EB_2019	2M_EP_2019	6_EP_2019	10_EP_2019	2M_EB_2021	6_EB_2021	10_EB_2021	2M_EP_2021	6_EP_2021	10_EP_2021
Dwelling age	1960 or before	15.61	17.78	6.16	6.02	6.20	4.40	15.5	15.5	9.0	4.99	4.99	0.0
	1961 - 1990	12.05	13.10	3.89	4.39	4.39	3.24	11.7	11.7	5.8	1.61	1.61	0.0
	1991 and after	12.75	16.29	3.52	3.76	3.95	3.55	11.5	11.3	6.6	2.13	2.13	0.0
Dwelling Type	Houses	14.61	16.92	4.95	3.75	3.75	3.26	13.9	13.8	7.4	2.82	2.82	0.0
	Apartment	5.23	6.63	1.20	10.26	11.06	6.21	8.9	8.9	6.5	3.99	3.99	0.0
Household Size (# of People/ Household)	One person	21.02	25.87	7.48	10.90	11.44	8.47	22.7	22.7	16.2	7.84	7.84	0.0
	Two person	14.98	16.63	4.81	3.13	3.13	2.45	14.0	14.0	6.9	1.95	1.95	0.0
	Three person	9.87	10.69	3.75	3.23	3.23	2.73	9.4	9.0	3.5	1.20	1.20	0.0
	Four or more person	7.95	9.54	2.31	2.83	2.83	2.26	0.0	0.0	0.0	0.00	0.00	0.0
Rent or Mortgage	Owned with mortgage	14.01	15.58	5.75	1.99	1.99	1.80	12.1	12.0	7.2	0.93	0.93	0.0
	Owned without mortgage	12.99	16.36	2.76	4.74	4.74	4.18	14.1	14.1	6.8	4.63	4.63	0.0
	Rent	12.30	13.80	4.37	10.21	10.75	6.83	13.1	13.1	8.1	4.79	4.79	0.0
Maintenance	Only regular maintenance	12.11	14.48	3.33	4.03	4.19	3.65	14.5	14.4	6.7	0.00	0.00	0.0
	Minor repairs	13.80	16.11	5.88	5.90	5.90	2.54	19.0	19.0	8.1	0.00	0.00	0.0
	Major repairs	23.51	23.51	11.05	7.15	7.15	7.15	17.7	17.7	8.8	0.00	0.00	0.0
Education	Highshool Equivelant or less	17.43	20.27	5.78	9.71	9.71	8.24	21.1	21.1	12.8	5.71	5.71	0.0
	Trade Certificate, College etc..	15.44	18.12	4.38	3.86	4.16	2.99	12.6	12.6	6.3	1.47	1.47	0.0
	Bachelors Degree or higher	7.82	8.93	3.43	1.56	1.56	0.83	8.1	7.9	4.4	2.43	2.43	0.0
Income	0-29K	24.49	25.04	9.21	36.74	37.75	30.25	29.4	29.4	34.1	27.00	27.00	0.0
	30K-59K	31.56	35.65	13.26	2.40	2.40	0.00	33.3	33.3	15.3	1.84	1.84	0.0
	60K-89K	12.65	16.93	1.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	90K+	1.98	2.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Household Type	One person	21.02	25.87	7.48	10.90	11.44	8.47	30.5	30.5	16.2	0.0	0.0	0.0
	Couple without children	13.78	15.93	3.73	3.48	3.48	2.88	14.3	14.3	6.5	0.0	0.0	0.0
	Couple with children	9.43	10.73	2.91	2.36	2.36	1.97	7.9	7.8	2.0	0.0	0.0	0.0
	Lone Parent	15.18	15.18	8.94	6.31	6.31	3.95	7.9	7.7	2.0	0.0	0.0	0.0
Marital Status	Married/Common Law	10.32	12.09	2.91	3.04	3.04	2.53	9.1	9.0	4.1	1.43	1.43	0.0
	Never married	30.19	34.42	9.41	8.41	8.41	8.41	15.0	15.0	14.0	6.86	6.86	0.0
	Seperated, divorced,widowed	15.42	17.98	6.76	7.66	8.11	5.07	22.4	22.4	11.4	4.87	4.87	0.0
Employment	Worked full-time	10.46	12.02	4.08	1.18	1.18	1.18	0.0	0.0	0.0	0.0	0.0	0.0
	Worked part-time	10.56	12.61	3.78	5.97	5.97	3.57	0.0	0.0	0.0	0.0	0.0	0.0
	Did not work	19.47	22.68	5.39	9.15	9.51	7.58	0.0	0.0	0.0	0.0	0.0	0.0
Number of Bedrooms	One Bedroom	0.00	0.00	0.00	0.00	0.00	0.00	11.1	11.1	8.0	4.46	4.46	0.0
	Two Bedrooms	0.00	0.00	0.00	0.00	0.00	0.00	16.0	15.7	7.1	3.66	3.66	0.0
	Three Bedrooms	0.00	0.00	0.00	0.00	0.00	0.00	14.6	14.6	8.9	3.22	3.22	0.0
	Four or more Bedrooms	0.00	0.00	0.00	0.00	0.00	0.00	9.9	9.9	5.1	2.09	2.09	0.0
City	City	11.86	13.90	4.87	4.44	4.57	3.61	15.03	14.92	7.71	0.00	0.00	0.0
	Other	14.47	16.77	3.99	4.91	5.01	3.79	17.00	17.00	6.96	0.00	0.00	0.0
Urban Size	500,000 or over	10.20	11.89	3.87	4.25	4.35	3.13	11.15	11.06	7.06	2.59	2.59	0.0
	100,000 to 499,999	14.94	18.52	4.60	4.83	5.06	3.69	14.11	14.11	5.89	2.85	2.85	0.0
	30,000 or less including rural	20.60	22.46	5.89	5.64	5.64	5.28	17.34	17.34	9.56	4.60	4.60	0.0
	Total	13.30	15.48	4.43	4.65	4.77	3.67	16.0	16.0	7.3	10.04	10.04	0.0

Dollar values rounded to $5, weighted counts rounded to 100.

2019 Ontario dwellilng in Energy Burden - Energy Consumption Distribution before housing cost - twice the median					
Total_EC_Weighted Average	Total_EC_Weighted StdDev	Total_EC_Weighted MAD	Total_EC_W 25th Percentile	Total_EC_W 50th Percentile	Total_EC_W 75th Percentile
3435	1840	1240	2160	3180	4085
Elec_Weighted Average	Elec_Weighted StdDev	Elec_Weighted MAD	Elec_W 25th Percentile	Elec_W 50th Percentile	Elec_W 75th Percentile
1785	1240	775	1080	1440	2220
NG_other_Weighted Average	NG_other_Weighted StdDev	NG_other_Weighted MAD	NG_other_W 25th Percentile	NG_other_W 50th Percentile	NG_other_W 75th Percentile
1650	1175	875	955	1520	2400
total income_Weighted Average	total income_Weighted StdDev	total income_Weighted MAD	total income_W 25th Percentile	total income_W 50th Percentile	total income_W 75th Percentile
43480	28560	21500	22560	38305	60045
2019 Ontario dwellilng in Energy Poverty - Energy Consumption Distribution before housing cost - twice the median					
Total_EC_Weighted Average	Total_EC_Weighted StdDev	Total_EC_Weighted MAD	Total_EC_W 25th Percentile	Total_EC_W 50th Percentile	Total_EC_W 75th Percentile
2500	1200	945	1540	2470	3175
Elec_Weighted Average	Elec_Weighted StdDev	Elec_Weighted MAD	Elec_W 25th Percentile	Elec_W 50th Percentile	Elec_W 75th Percentile
1470	900	610	1020	1200	1605
NG_other_Weighted Average	NG_other_Weighted StdDev	NG_other_Weighted MAD	NG_other_W 25th Percentile	NG_other_W 50th Percentile	NG_other_W 75th Percentile
1030	880	770	0	1035	1695
total income_Weighted Average	total income_Weighted StdDev	total income_Weighted MAD	total income_W 25th Percentile	total income_W 50th Percentile	total income_W 75th Percentile
18515	11890	8700	10580	18045	21840

Dollar values rounded to $5, weighted counts rounded to 100.

2021 Ontario dwellilng in Energy Burden - Energy Consumption Distribution before housing cost - twice the median					
Total_EC_Weighted Average	Total_EC_Weighted StdDev	Total_EC_Weighted MAD	Total_EC_W 25th Percentile	Total_EC_W 50th Percentile	Total_EC_W 75th Percentile
3485	2135	1330	2330	2975	4230
Elec_Weighted Average	Elec_Weighted StdDev	Elec_Weighted MAD	Elec_W 25th Percentile	Elec_W 50th Percentile	Elec_W 75th Percentile
1890	1470	845	1060	1440	2160
NG_other_Weighted Average	NG_other_Weighted StdDev	NG_other_Weighted MAD	NG_other_W 25th Percentile	NG_other_W 50th Percentile	NG_other_W 75th Percentile
1600	1320	900	770	1330	2015
total income_Weighted Average	total income_Weighted StdDev	total income_Weighted MAD	total income_W 25th Percentile	total income_W 50th Percentile	total income_W 75th Percentile
45010	30870	21780	24715	40245	56130
2021 Ontario dwellilng in Energy Poverty - Energy Consumption Distribution before housing cost - twice the median					
Total_EC_Weighted Average	Total_EC_Weighted StdDev	Total_EC_Weighted MAD	Total_EC_W 25th Percentile	Total_EC_W 50th Percentile	Total_EC_W 75th Percentile
2170	845	710	1245	2300	2975
Elec_Weighted Average	Elec_Weighted StdDev	Elec_Weighted MAD	Elec_W 25th Percentile	Elec_W 50th Percentile	Elec_W 75th Percentile
1355	640	460	930	1200	1630
NG_other_Weighted Average	NG_other_Weighted StdDev	NG_other_Weighted MAD	NG_other_W 25th Percentile	NG_other_W 50th Percentile	NG_other_W 75th Percentile
815	655	540			
total income_Weighted Average	total income_Weighted StdDev	total income_Weighted MAD	total income_W 25th Percentile	total income_W 50th Percentile	total income_W 75th Percentile
17970	12400	10085	5355	53100	54900

Appendix C – Modelling Results

2021 - BASELINE		End Use	kWh
RESULTS		SPACE HEATING	32168
Electricity Cost ($)	1370	SPACE COOLING	1555
Natural Gas Cost ($)	1328	LIGHTING	1318
Total Cost ($)	2619	APPLIANCES	6261
EER	0.13	WATER HEATING	4241
Energy Poverty Status	Energy Poor	Total in kWh	45544
		EUI (kWh)	316

2021 - Lighting Improved		End Use	kWh
RESULTS		SPACE HEATING	32339
$ Elec	$ 1,306	SPACE COOLING	1523
$ NG	$ 1,334	LIGHTING	923
$ Total	$ 2,641	APPLIANCES	6261
EER	0.13	WATER HEATING	4241
Energy Poverty Status	Energy Poor	Total in kWh	45287
		EUI (kWh)	314

GWP 2.5		End Use	kWh
RESULTS		SPACE HEATING	26495
$ Elec	$ 1,641	SPACE COOLING	3366
$ NG	$ 1,121	LIGHTING	1318
$ Total	$ 2,762	APPLIANCES	6261
EER	0.14	WATER HEATING	4241
Energy Poverty Status	Energy Poor	Total in kWh	41681
		EUI (kWh)	289

GWP 3.5		End Use	kWh
RESULTS		SPACE HEATING	22511
$ Elec	1720.335	SPACE COOLING	3890
$ NG	975.91	LIGHTING	1318
$ Total	2696.245	APPLIANCES	6261
EER	0.14	WATER HEATING	4241
Energy Poverty Status	Energy Poor	Total in kWh	38221
		EUI (kWh)	265

Natural Gas

2021 - Lighting + R-60 ROOF		End Use	kWh
RESULTS		SPACE HEATING	31221
$ Elec	$ 1,307	SPACE COOLING	1533
$ NG	$ 1,294	LIGHTING	923
$ Total	$ 2,601	APPLIANCES	6261
EER	0.1328896	WATER HEATING	4241
Energy Poverty Status	Energy Poor	Total in kWh	**44179**
		EUI (kWh)	307

2021 - Lighting + R-60 ROOF + R-20 Wall + inf0.0005		End Use	kWh
RESULTS		SPACE HEATING	25138
$ Elec	$ 1,319	SPACE COOLING	1611
$ NG	$ 1,071	LIGHTING	923
$ Total	$ 2,390	APPLIANCES	6261
EER	0.12	WATER HEATING	4241
Energy Poverty Status	Energy Poor	Total in kWh	38173
		EUI (kWh)	265

2021 - Lighting + R-60 ROOF + R-30 Wall + inf0.0005		End Use	kWh
RESULTS		SPACE HEATING	24146
$ Elec	$ 1,322	SPACE COOLING	1632
$ NG	$ 1,035	LIGHTING	923
$ Total	$ 2,357	APPLIANCES	6261
EER	0.12	WATER HEATING	4241
Energy Poverty Status	Energy Poor	Total in kWh	37203
		EUI (kWh)	258

2021 - Lighting + R-60 ROOF + R-40Wall + inf0.0005		End Use	kWh
RESULTS		SPACE HEATING	23623
$ Elec	$ 1,324	SPACE COOLING	1644
$ NG	$ 1,016	LIGHTING	923
$ Total	$ 2,341	APPLIANCES	6261
EER	0.12	WATER HEATING	4241
Energy Poverty Status	Energy Poor	Total in kWh	36691
		EUI (kWh)	255

Electric Heat Pump

2021 - Lighting + R-60 ROOF		End Use	kWh
RESULTS		SPACE HEATING	13860
$ Elec	$ 3,386	SPACE COOLING	1533
$ NG	$ 660	LIGHTING	923
$ Total	$ 4,047	APPLIANCES	6261
EER	0.21	WATER HEATING	4241
Energy Poverty Status	Energy Poor	Total in kWh	26817
		EUI (kWh)	186

2021 - Lighting + R-60 ROOF + R-20 Wall + inf 0.005		End Use	kWh
RESULTS		SPACE HEATING	11747
$ Elec	$ 2,993	SPACE COOLING	1696
$ NG	$ 562	LIGHTING	923
$ Total	$ 3,409	APPLIANCES	6261
EER	0.17	WATER HEATING	4241
Energy Poverty Status	Energy Poor	Total in kWh	24867
		EUI (kWh)	173

2021 - Lighting + R-60 ROOF + R-30 Wall + inf 0.005		End Use	kWh
RESULTS		SPACE HEATING	10719
$ Elec		SPACE COOLING	1632
$ NG	$ 2,930	LIGHTING	923
$ Total	$ 546	APPLIANCES	6261
EER	$ 3,476	WATER HEATING	4241
Energy Poverty Status	0.18	Total in kWh	23776
	Energy Poor	EUI (kWh)	165

2021 - Lighting + R-60 ROOF + R-40 Wall + inf 0.005		End Use	kWh
RESULTS		SPACE HEATING	10487
$ Elec	$ 2,897	SPACE COOLING	1644
$ NG	$ 537	LIGHTING	923
$ Total	$ 3,434	APPLIANCES	6261
EER	0.18	WATER HEATING	4241
Energy Poverty Status	Energy Poor	Total in kWh	23555
		EUI (kWh)	164

Natural Gas			
2021 - Lighting + R-60 ROOF + R-50 Wall + inf0.0005		**End Use**	**kWh**
RESULTS		**SPACE HEATING**	23301
$ Elec	$ 1,325	**SPACE COOLING**	1651
$ NG	$ 1,005	**LIGHTING**	923
$ Total	$ 2,330	**APPLIANCES**	6261
EER	0.12	**WATER HEATING**	4241
Energy Poverty Status	Energy Poor	**Total in kWh**	36377
		EUI (kWh)	253

2021 - Lighting + R-60 ROOF + R-20 Wall + inf(0.00025)		**End Use**	**kWh**
RESULTS		**SPACE HEATING**	14691
$ Elec	$ 1,565	**SPACE COOLING**	3247
$ NG	$ 691	**LIGHTING**	923
$ Total	$ 2,255	**APPLIANCES**	6261
EER	0.12	**WATER HEATING**	4241
Energy Poverty Status	Energy Poor	**Total in kWh**	29363
		EUI (kWh)	204

2021 - Lighting + R-60 ROOF + R-30 Wall + inf0.00025		**End Use**	**kWh**
RESULTS		**SPACE HEATING**	13839
$ Elec	$ 1,564	**SPACE COOLING**	3242
$ NG	$ 660	**LIGHTING**	923
$ Total	$ 2,223	**APPLIANCES**	6261
EER	0.11	**WATER HEATING**	4241
Energy Poverty Status	Energy Poor	**Total in kWh**	28506
		EUI (kWh)	198

2021 - Lighting + R-60 ROOF + R-40Wall + inf0.00025		**End Use**	**kWh**
RESULTS		**SPACE HEATING**	13388
$ Elec	$ 1,564	**SPACE COOLING**	3240
$ NG	$ 657	**LIGHTING**	923
$ Total	$ 2,220	**APPLIANCES**	6261
EER	0.11	**WATER HEATING**	4241
Energy Poverty Status	Energy Poor	**Total in kWh**	28054
		EUI (kWh)	195

2021 - Lighting + R-60 ROOF + R-50 Wall + inf 0.00025		**End Use**	**kWh**
.		**SPACE HEATING**	13112
$ Elec	$ 1,563	**SPACE COOLING**	3240
$ NG	$ 633	**LIGHTING**	923
$ Total	$ 2,196	**APPLIANCES**	6261
EER	0.11	**WATER HEATING**	4241
Energy Poverty Status	Energy Poor	**Total in kWh**	27776
		EUI (kWh)	193

Electric Heat Pump			
2021 - Lighting + R-60 ROOF + R-50 Wall + inf 0.005		**End Use**	**kWh**
RESULTS		**SPACE HEATING**	10344
$ Elec	$ 2,877	**SPACE COOLING**	1651
$ NG	$ 532	**LIGHTING**	923
$ Total	$ 3,409	**APPLIANCES**	6261
EER	0.17	**WATER HEATING**	4241
Energy Poverty Status	Energy Poor	**Total in kWh**	23420
		EUI (kWh)	163

2021 - Lighting + R-60 ROOF + R-20 Wall + inf + heatpump +inf 0.00025		**End Use**	**kWh**
RESULTS		**SPACE HEATING**	6522
$ Elec	$ 2,543	**SPACE COOLING**	3247
$ NG	$ 392	**LIGHTING**	923
$ Total	$ 2,935	**APPLIANCES**	6261
EER	0.15	**WATER HEATING**	4241
Energy Poverty Status	Energy Poor	**Total in kWh**	21193
		EUI (kWh)	147

2021 - Lighting + R-60 ROOF + R-30 Wall + inf 0.000025		**End Use**	**kWh**
RESULTS		**SPACE HEATING**	6143
$ Elec	$ 2,485	**SPACE COOLING**	3242
$ NG	$ 379	**LIGHTING**	923
$ Total	$ 2,864	**APPLIANCES**	6261
EER	0.15	**WATER HEATING**	4241
Energy Poverty Status	Energy Poor	**Total in kWh**	20810
		EUI (kWh)	145

2021 - Lighting + R-60 ROOF + R-40 Wall + inf 0.00025		**End Use**	**kWh**
RESULTS		**SPACE HEATING**	5943
$ Elec	$ 2,455	**SPACE COOLING**	3240
$ NG	$ 371	**LIGHTING**	923
$ Total	$ 2,827	**APPLIANCES**	6261
EER	0.14	**WATER HEATING**	4241
Energy Poverty Status	Energy Poor	**Total in kWh**	20609
		EUI (kWh)	143

2021 - Lighting + R-60 ROOF + R-50 Wall + inf 0.00025		**End Use**	**kWh**
RESULTS		**SPACE HEATING**	5821
$ Elec		**SPACE COOLING**	3240
$ NG	$ 2,437	**LIGHTING**	923
$ Total	$ 367	**APPLIANCES**	6261
EER	$ 2,804	**WATER HEATING**	4241
Energy Poverty Status	0.14	**Total in kWh**	20485
	Energy Poor	**EUI (kWh)**	142

Appendix D – Syntax used in the RDC for Statistical Analysis

Sample Syntax - Energy Poverty Calculation 2019
***2021 used the same syntax, the difference was in the variable names. Those are identified in Appendix E in the data dictionary**

```
import sys
sys.path.append('//tor-main/Utilities/Python/packages')
import pandas as pd
import numpy as np

# from sklearn.cluster import KMeans
# from sklearn.metrics import silhouette_score
import matplotlib.pyplot as plt

####2019 data set
df = pd.read_stata(r'P:\SHS_EDM_2019\rdc-
cdr\SHS_EDM_2019_v1\data_donnees\stata\interview\capi_adj_hhld_shs2019_v1.dta')
#print(df.head())
#print(df.info())

df = df.apply(pd.to_numeric)

################## Data Cleanup and Aggregation
# REMOVE INCOME& ENERGY ROWS ROWS WITH VALUES <0
df = df[(df['INC3015'] > 0) & (df['SH030'] > 0)& (df['SH030'] > 0)]

#########SIZE OF HOUSEHOLD GROUPING
#Merging Size of Houshold so it only has a cetegory of 7+ ppl
df['SizeOfHhld'] = df['SizeOfHhld'].apply(lambda x: 7 if x in [8,9,10,11] else x)

#######Low Income Categorizing & Threshold 'LIHC' Low-income high income
df['LIHC']= False
#print(df.loc[(df.SizeOfHhld == 1)&((df.INC3015 - df.TX010)
<26503),['LIHC','SizeOfHhld','INC3015','TX010']])
df.loc[(df.SizeOfHhld == 1)&((df.INC3015 - df.TX010) <21899),'LIHC'] = True
df.loc[(df.SizeOfHhld == 2)&((df.INC3015 - df.TX010) <26653),'LIHC'] = True
df.loc[(df.SizeOfHhld == 3)&((df.INC3015 - df.TX010) <33189),'LIHC'] = True
df.loc[(df.SizeOfHhld == 4)&((df.INC3015 - df.TX010) <41406),'LIHC'] = True
df.loc[(df.SizeOfHhld == 5)&((df.INC3015 - df.TX010) <47148),'LIHC'] = True
df.loc[(df.SizeOfHhld == 6)&((df.INC3015 - df.TX010) <52289),'LIHC'] = True
df.loc[(df.SizeOfHhld == 7)&((df.INC3015 - df.TX010) <57429),'LIHC'] = True
#print(df.loc[(df.SizeOfHhld == 1)&((df.INC3015 - df.TX010) <26503),'LIHC'] )

#Merge Categories for vetting
#Deleting mobile home, hotel and other
```

```
df = df[~df['DC_Q010'].isin([7, 8, 9])]  ##REMOVE HOTEL, MOBILE AND OTHER
df = df[~df['RP_HLE'].isin([99])] ##REMOVE NOT STATED EDUCATION
df = df[~df['TE_Q010'].isin([4])] ## REMOVE OCCUPIED RENT FREE

#######EDUCATION GROUPINGS
#Merging Education level: 01 - Less than high school & 02 -Secondary (high) school diploma or equivalent repalce with code 01
df['RP_HLE'] = df['RP_HLE'].apply(lambda x: 1 if x in [1, 2] else x)

#Merging Education level: 03 -Trade certificate or diploma from a vocation school or apprenticeship training
                #04 - Non-university certificate or diploma from a community college, CEGEP, school of nursing
                #05 - University certificate or diploma below Bachelor's
                #replace with code 03
df['RP_HLE'] = df['RP_HLE'].apply(lambda x: 2 if x in [3,4,5] else x)

#Merging Education level: 06 - Bachelor's degree (B.A., B.Sc., B.Ed.)
                 #07 - University degree, certificate or diploma above a Bachelor's
                  #with code 06
df['RP_HLE'] = df['RP_HLE'].apply(lambda x: 3 if x in [6,7] else x)

########DWELLING TYPE GROUPING
#Merging dwelling type: duplex and town house by replacing their original values of 03, 04 with code 03 01
df['DC_Q010'] = df['DC_Q010'].apply(lambda x: 3 if x in [4] else x)

##### Household type - creating an other category by combining 4 & 6 couples with unrealted individuals and other
df['HouseholdType6'] = df['HouseholdType6'].apply(lambda x: 6 if x in [4] else x)

#########DWELLING AGE GROUPING
#Merging dwelling age: 1991 and after
df['DC_Q031'] = df['DC_Q031'].apply(lambda x: 1 if x in [1,2,3] else x)

#Merging dwelling age: 1961-1980
df['DC_Q031'] = df['DC_Q031'].apply(lambda x: 2 if x in [4,5] else x)

#Merging dwelling age: 1981-2000
df['DC_Q031'] = df['DC_Q031'].apply(lambda x: 3 if x in [6,7] else x)

#Merging dwelling age: 2001 and after
df['DC_Q031'] = df['DC_Q031'].apply(lambda x: 4 if x in [8,9] else x)
```

```
#Adjusting age to be within a range based on statistics canada age groups
# Define bins and labels
bins = [0, 15, 25, 35, 45, 55, 65, 100]
labels = [1, 2, 3, 4, 5, 6, 7]

# Replace values in 'age' column
df['RP_Age'] = pd.cut(df['RP_Age'], bins=bins, labels=labels, right=False)

# Replace codes in 'Prov' column with Prov names
code_word_mapping = {
   '10': "NL",
   '11': "PEI",
   '12': "NS",
   '13': "NB",
   '24': "QC",
   '35': "ON",
   '46': "MN",
   '47': "SK",
   '48': "AB",
   '59': "BC",
   '60': "YK",
   '61': "NT",
   '62': "NV"}

df['Province'] = df['Province'].astype(str).replace(code_word_mapping)

#### Adding a total energy row - without water
Total_EC = df.SH032 + df.SH033 + df.SH034
df['Total_EC']= Total_EC

###Total NG + Other
NG_other = df.SH033 + df.SH034
df['NG_other'] = NG_other

################## Income Clusters based on Stats Canada ###############
#Adjusting income to be within a range based on statistics canada income cluster groups
# Define new bins and labels
income_bins = [0, 30000, 60000, 90000, 120000, 150000, 180000, 200000, float('inf')]
income_labels = ['0-29K', '30K-59K', '60K-89K', '90K-119K', '120K-149K', '150K-179K', '180K-
199K','200K+']

# Create the 'income_bins' column based on the new bins and labels
df['income bins'] = pd.cut(df['INC3015']-df['TX010'], bins=income_bins, labels=income_labels,
right=False)
```

```
#Defining bins and labels for EC
ec_bins = [0,1000,2000,3000,4000,5000, 6000, float('inf')]
ec_labels = ['0-999', '1K-1999', '2K-2999','3K-3999', '4K-4999','5K-5999', '6K+']

##Elec
elec_bins = [0,2000,4000, float('inf')]
elec_labels= ['0-1999', '2K-3999', '4K+']

#Ng & Other
ng_bins = [0,2000,4000, float('inf')]
ng_labels = ['0-1999', '2K-3999', '4K']

other_bins = [0,2000,4000, float('inf')]
other_labels = ['0-1999', '2K-3999', '4K']

ng_other_bins = [0,2000,4000, float('inf')]
ng_other_labels = ['0-1999', '2K-3999', '4K']

df['ec bins']=pd.cut(df['Total_EC'], bins=ec_bins, labels=ec_labels, right=False)
df['ec bins - elec']=pd.cut(df['SH032'], bins=elec_bins, labels=elec_labels, right=False)
df['ec bins - ng']=pd.cut(df['SH033'], bins=ng_bins , labels=ng_labels, right=False)
df['ec bins - other']=pd.cut(df['SH034'], bins= other_bins, labels=other_labels, right=False)
df['ec bins - ng & other']=pd.cut(df['NG_other'], bins=ng_other_bins, labels=ng_other_labels,
right=False)

############## Energy Expedinture Ratio Calculations
# Calculate Energy Exedinture Ratio
eer_matrix = df[['WeightC','Province', 'City','UrbanSize','INC3015', 'income bins', 'SH004', 'SH011',
'Total_EC', 'ec bins','SH032','ec bins - elec', 'NG_other','ec bins - ng & other','SH033','ec bins - ng',
'SH034','ec bins - other', 'TX010', 'FDREF_C','HC001_C', 'HE008', 'HE021',

'HouseholdType6','TE_Q010','DC_Q010','DC_Q031','RP_HLE','DC_Q040','RP_GENDER','RP_MarSt','R
P_EmpStatus', 'SizeOfHhld', 'LIHC']]
eer_matrix.columns = ['WeightC','Prov','City','urban size','total income', 'income bins', 'Rent',
'Mortgage','Total_EC', 'ec bins' ,'Elec','ec bins - elec', 'NG_other','ec_bins - ng & other', 'NG', 'ec
bins - ng','Other', 'ec bins - other', 'Inc_Tax', 'food', 'health', 'ac', 'aheaters',
                'household type','rent or mortgage','dwelling type', 'dwelling age',
'education','maintenance','gender','ms','employment','num ppl','LIHC']

#income_aftertax
eer_it = eer_matrix['Total_EC'] / (eer_matrix['total income'] - eer_matrix['Inc_Tax'])
#income_aftertax_rent_mortgage (hctax)
```

```
eer_hctax = eer_matrix['Total_EC'] / (eer_matrix['total income']  - eer_matrix['Inc_Tax']-
eer_matrix['Rent']- eer_matrix['Mortgage'])
#income_aftertax_rent_mortgage_food_healthexpenses (hcfh)
eer_hcfh = eer_matrix['Total_EC'] / (eer_matrix['total income']  - eer_matrix['Inc_Tax'] -
eer_matrix['Rent']- eer_matrix['Mortgage'] - eer_matrix['food']- eer_matrix['health'])
#income_aftertax_rent_mortgage_food_healthexpenses_addcooling_addheating( hchac)
eer_hchac = eer_matrix['Total_EC'] / (eer_matrix['total income'] - eer_matrix['Inc_Tax']-
eer_matrix['Rent']- eer_matrix['Mortgage'] - eer_matrix['food']- eer_matrix['health']-
eer_matrix['ac']-eer_matrix['aheaters'])

#One table with all the expense levels,
eer = pd.concat([eer_matrix, eer_it.rename('eer_it'),eer_hctax.rename('eer_hctax'),
eer_hcfh.rename('eer_hcfh'), eer_hchac.rename('eer_hchac')], axis=1)

###### For a National Analysis comment out this section
###### ONTARIO/ TORONTO
### Filter rows where the value in the 'Province' column is 'ON'
##eer = eer[eer['Prov'] == 'ON'].copy()

### Filter rows where the value in the 'City' column is 'TO'
#eer = eer[eer['City'] == 8].copy()
eer.to_csv('EER_2019.csv', index=False)
####### More DATA CLEN UP - Count and maybe remove negative eer values
# Count negative values in 'eer_it' column
negative_eer_it = (eer['eer_it'] < 0).sum()

# Count negative values in 'eer_hctax' column
negative_eer_hctax = (eer['eer_hctax'] < 0).sum()

# Count negative values in 'eer_hchcfh' column
negative_eer_hcfh = (eer['eer_hcfh'] < 0).sum()

# Count negative values in 'eer_hchcfh' column
negative_eer_hchac = (eer['eer_hchac'] < 0).sum()

print("Number of negative values in eer_it column:", negative_eer_it)
print("Number of negative values in eer_hctax column:", negative_eer_hctax)
print("Number of negative values in eer_it column:", negative_eer_hcfh)
print("Number of negative values in eer_hctax column:", negative_eer_hchac)

#Count rows before removing negative values
total_rows_before = len(eer)

# Remove rows with negative values in 'eer_it' and 'eer_hctax' columns
```

```
cleaned_eer = eer[(eer['eer_it'] >= 0) & (eer['eer_hctax'] >= 0)]

# Count rows after removing negative values
total_rows_after = len(cleaned_eer)

# Calculate the number of rows removed
rows_removed = total_rows_before - total_rows_after

print("Total rows before removing negative values:", total_rows_before)
print("Total rows after removing negative values:", total_rows_after)
print("Number of rows removed:", rows_removed)

########### ENERGY POVERTY CALCULATIONS
##### Energy Poverty Unwegihted and Weighted Averages,Percentiles, counts and outliers
# Function to calculate weighted percentiles
def weighted_percentile(data, weights, perc):
    # Sort data and weights
    ix = np.argsort(data)
    data_sorted = np.array(data)[ix]
    weights_sorted = np.array(weights)[ix]

    # Compute cumulative distribution function (CDF)
    cdf = np.cumsum(weights_sorted) / np.sum(weights_sorted)

    # Interpolate the percentiles
    return np.interp(perc, cdf, data_sorted)

def calculate_stats_ep(df, weight_col, columns, group_col=None, threshold=None):
    results = []

    for col in columns:
        # Check if the column exists in the DataFrame
        if col not in df.columns:
            raise ValueError(f"Column {col} does not exist in the DataFrame.")

        data = df[col]
        weights = df[weight_col]

        if (group_col is not None) and (threshold is not None):
            # Filter data based on the group_col and threshold
            filtered_df = df[(df[group_col] > threshold)& (df['LIHC'])]
            if filtered_df.empty:
                # Skip if the filtered DataFrame is empty
                print(f"Filtered DataFrame is empty for column {col}.")
```

```
            continue
        data = filtered_df[col]
        weights = filtered_df[weight_col]

    # Calculate unweighted and weighted averages
    avg = data.mean()
    wavg = np.average(data, weights=weights)

    # Calculate percentiles
    percentiles = [0,25, 50, 75,100]
    q = np.percentile(data, percentiles)
    qw = weighted_percentile(data, weights, [0,0.25, 0.50, 0.75,1])

    # Calculate unweighted counts between percentiles
    counts = {
        '0-25': np.sum((data > q[0]) & (data <= q[1])),
        '25-50': np.sum((data > q[1]) & (data <= q[2])),
        '50-75': np.sum((data > q[2]) & (data <= q[3])),
        '75-100':np.sum((data > q[3]) & (data <= q[4])),}

    # Calculate weighted counts between percentiles
    weighted_counts = {
            '0-25': np.sum(weights[(data > qw[0]) & (data <= qw[1])]),
            '25-50': np.sum(weights[(data > qw[1]) & (data <= qw[2])]),
            '50-75': np.sum(weights[(data > qw[2]) & (data <= qw[3])]),
            '75-100': np.sum(weights[(data > qw[3]) & (data <= qw[4])]),}

    # Calculate IQR and outliers
    IQR = q[2] - q[0]
    lower_bound = q[0] - 1.5 * IQR
    upper_bound = q[2] + 1.5 * IQR
    outliers = ((data < lower_bound) | (data > upper_bound)).sum()

    IQR_w = qw[2] - qw[0]
    lower_bound_w = qw[0] - 1.5 * IQR_w
    upper_bound_w = qw[2] + 1.5 * IQR_w
    weighted_outliers = (((data < lower_bound_w) | (data > upper_bound_w)) * weights).sum()

    # Combine results into a dictionary
    result = {
        'Column': col,
        'Average': avg,
        'Weighted Average': wavg,
        'Count 0-25':counts['0-25'],
```

```
            '25th Percentile': q[1],
            'Count 25-50': counts['25-50'],
            '50th Percentile': q[2],
            'Count 50-75': counts['50-75'],
            '75th Percentile': q[3],
            'Count 75- 100': counts['75-100'],
            'Weighted Count 0-25':weighted_counts['0-25'],
            'Weighted 25th Percentile': qw[1],
            'Weighted Count 25-50': weighted_counts['25-50'],
            'Weighted 50th Percentile': qw[2],
            'Weighted Count 50-75':  weighted_counts['50-75'],
            'Weighted 75th Percentile': qw[3],
            'Weighted Count 75-100':weighted_counts['75-100'],
            'Outliers': outliers,
            'Weighted Outliers': weighted_outliers}
        results.append(result)

    results_apo = pd.DataFrame(results)
    return results_apo
### Calculate energy poverty ratio average, mean and percentiles without thresholds!
apo = calculate_stats_ep(eer, weight_col='WeightC',
columns=['eer_it','eer_hctax','eer_hcfh','eer_hchac'])

### Call the function with filtering (e.g., only include rows where 'group_col' > 0.5)
results_ec= calculate_stats_ep(eer, weight_col='WeightC', columns=['Total_EC', 'Elec', 'NG_other'],
group_col=None, threshold=None)

############## Average, percentiles for total energy consumption, electricity and natural gas
def calculate_stats_ec(df, group_col, eer_col=None, threshold=None):
    # filter for EP
    filtered_df = df[(df[eer_col] > threshold)& (df['LIHC'])]
    # List of energy columns to calculate statistics for
    energy_cols = ['Total_EC', 'Elec', 'NG_other']
    # Prepare a list to hold the results
    results = []

    # Loop through each group in the group column
    for group_name, group_df in df.groupby(group_col):
        # Optionally filter the group based on eer_col and threshold
        if eer_col is not None and threshold is not None:
            group_df = group_df[(group_df[eer_col] > threshold)& (df['LIHC'])]

        # Initialize a dictionary to store the results for the current group
        group_stats = {'Group': group_name}
```

```
    # Calculate statistics for each energy column
    for col in energy_cols:
        if group_df.empty:  # Check if the group is empty after filtering
            continue  # Skip this group if no data remains

        avg = group_df[col].mean()
        weights = group_df['WeightC']

        if weights.sum() > 0:
            wavg = np.average(group_df[col], weights=weights)
        else:
            wavg = np.nan  # or another appropriate value, like 0

        q = np.percentile(group_df[col], [0, 25, 50, 75, 100])
        qw = weighted_percentile(group_df[col].values, group_df['WeightC'].values, [0, 0.25, 0.50,
0.75, 1])

        # Calculate unweighted counts between percentiles
    counts = {
        '0-25': np.sum((group_df[col] > q[0]) & (group_df[col] <= q[1])),
        '25-50': np.sum((group_df[col] > q[1]) & (group_df[col] <= q[2])),
        '50-75': np.sum((group_df[col] > q[2]) & (group_df[col] <= q[3])),
        '75-100':np.sum((group_df[col] > q[3]) & (group_df[col] <= q[4])),}

    # Calculate weighted counts between percentiles
    weighted_counts = {
            '0-25': np.sum(weights[(group_df[col] > qw[0]) & (group_df[col] <= qw[1])]),
            '25-50': np.sum(weights[(group_df[col] > qw[1]) & (group_df[col] <= qw[2])]),
            '50-75': np.sum(weights[(group_df[col] > qw[2]) & (group_df[col] <= qw[3])]),
            '75-100': np.sum(weights[(group_df[col] > qw[3]) & (group_df[col] <= qw[4])]),}

        # Store the results in the dictionary
    group_stats[f'{col}_Average'] = avg
    group_stats[f'{col}_Weighted Average'] = wavg
    group_stats[f'{col}_Count'] = len(group_df)

    group_stats[f'{col}_25th Percentile'] = q[0]
    group_stats[f'{col}_Count_25-50'] = counts['25-50']
    group_stats[f'{col}_50th Percentile'] = q[1]
    group_stats[f'{col}_Count_50-75'] = counts['50-75']
    group_stats[f'{col}_75th Percentile'] = q[2]

    group_stats[f'{col}_W 25th Percentile'] = qw[0]
```

```
        group_stats[f'{col}_Weighted Count_25-50'] = weighted_counts['25-50']
        group_stats[f'{col}_W 50th Percentile'] = qw[1]
        group_stats[f'{col}_Weighted Count_50-75'] = weighted_counts['50-75']
        group_stats[f'{col}_W 75th Percentile'] = qw[2]

        # Append the dictionary to the results list
        results.append(group_stats
    # Convert the results list into a DataFrame
    results_ec = pd.DataFrame(results)
    return results_ec

#### Proportion of people under EP ########## Threshold Definition####
median_it = apo.loc[apo['Column']=='eer_it', 'Weighted 50th Percentile'].values[0]
tm_it =  2*median_it #Twice the median of teer_hcit

median_hctax = apo.loc[apo['Column']=='eer_hctax', 'Weighted 50th Percentile'].values[0]
tm_hctax =  2*median_hctax #Twice the median of teer_hctax

median_hcfh = apo.loc[apo['Column']=='eer_hcfh', 'Weighted 50th Percentile'].values[0]
tm_hcfh =  2*median_hcfh #Twice the median of eer_hchf

median_hchac = apo.loc[apo['Column']=='eer_hchac', 'Weighted 50th Percentile'].values[0]
tm_hchac =  2*median_hchac #Twice the median of teer_hctax

six_threshold =  0.06          #6%    the most common value used in Canadian Studies
ten_threshold =  0.1           #10%   the most common vlaue used in other studies including
Canadian studies

tm_thresholds = pd.DataFrame({
    'Column': ['eer_it', 'eer_hctax', 'eer_hcfh', 'eer_hchac'],
    'Thresholds':[tm_it,tm_hctax,tm_hcfh,tm_hchac]})

tm_thresholds.to_csv('tm_thresholds.csv', index = False)

############################## UNWEIGHTED
def above_threshold_percent(df, column_name, threshold):
    # Count the number of people above the threshold in each province (numerator)
    above_threshold_counts = df[(df[column_name] > threshold) &
(df['LIHC'])].groupby('Prov')[column_name].count().reset_index(name='numerator')

    # Count the total number of people in each province (denominator)
    total_people_per_province =
df.groupby('Prov')[column_name].count().reset_index(name='denominator')
```

```
    # Merge the above_threshold_counts and total_people_per_province dataframes on 'Prov'
    result_df = pd.merge(above_threshold_counts, total_people_per_province, on='Prov', how =
'right')

    # Calculate the difference between the numerator and denominator
    result_df['difference'] = result_df['denominator'] - result_df['numerator']

    # Calculate the percentage of people above the threshold for each province
    result_df['percentage'] = (result_df['numerator'] / result_df['denominator']) * 100

    return result_df

####### WEIGHTED
def weighted_above_threshold_percent(df, column_name, weight_col, threshold):
    # Calculate the weighted count of people above the threshold in each province (numerator)
    df['weighted_numerator'] = df.apply(lambda row: row[weight_col] if (row[column_name] >
threshold) and(row['LIHC'])else 0, axis=1)
    above_threshold_counts =
df.groupby('Prov')['weighted_numerator'].sum().reset_index(name='numerator')

    # Calculate the total weighted count of people in each province (denominator)
    total_people_per_province =
df.groupby('Prov')[weight_col].sum().reset_index(name='denominator')

    # Merge the above_threshold_counts and total_people_per_province dataframes on 'Prov'
    result_df = pd.merge(above_threshold_counts, total_people_per_province, on='Prov',
how='right')

    # Calculate the difference between the numerator and denominator
    result_df['difference'] = result_df['denominator'] - result_df['numerator']

    # Calculate the weighted percentage of people above the threshold for each province
    result_df['percentage'] = (result_df['numerator'] / result_df['denominator']) * 100

    return result_df
#### UNWEIGHTED ####
## Proportions of people under energy poverty using calculated 2M
TM_ep_it = above_threshold_percent(eer, 'eer_it', tm_it)
TM_ep_hctax = above_threshold_percent(eer,'eer_hctax', tm_hctax)
TM_ep_hcfh = above_threshold_percent(eer,'eer_hcfh', tm_hcfh)
TM_ep_hchac = above_threshold_percent(eer,'eer_hchac', tm_hchac)

## Proportions of people under energy poverty using 6%
six_ep_it = above_threshold_percent(eer,'eer_it', six_threshold)
```

```
six_ep_hctax = above_threshold_percent(eer,'eer_hctax', six_threshold)
six_ep_hcfh = above_threshold_percent(eer,'eer_hcfh', six_threshold)
six_ep_hchac = above_threshold_percent(eer,'eer_hchac', six_threshold)

## Proportions of people under energy poverty using 10%
ten_ep_it = above_threshold_percent(eer,'eer_it', ten_threshold)
ten_ep_hctax = above_threshold_percent(eer,'eer_hctax', ten_threshold)
ten_ep_hcfh = above_threshold_percent(eer,'eer_hcfh', ten_threshold)
ten_ep_hchac = above_threshold_percent(eer,'eer_hchac', ten_threshold)

##### WEIGHTED #####
## Proportions of people under energy poverty using calculated 2M
WTM_ep_it = weighted_above_threshold_percent(eer, 'eer_it','WeightC', tm_it)
WTM_ep_hctax = weighted_above_threshold_percent(eer,'eer_hctax','WeightC', tm_hctax)
WTM_ep_hcfh = weighted_above_threshold_percent(eer,'eer_hcfh','WeightC', tm_hcfh)
WTM_ep_hchac = weighted_above_threshold_percent(eer,'eer_hchac','WeightC', tm_hchac)

## Proportions of people under energy poverty using 6%
wsix_ep_it = weighted_above_threshold_percent(eer,'eer_it','WeightC', six_threshold)
wsix_ep_hctax = weighted_above_threshold_percent(eer,'eer_hctax','WeightC', six_threshold)
wsix_ep_hcfh = weighted_above_threshold_percent(eer,'eer_hcfh','WeightC', six_threshold)
wsix_ep_hchac = weighted_above_threshold_percent(eer,'eer_hchac','WeightC', six_threshold)

## Proportions of people under energy poverty using 10%
wten_ep_it = weighted_above_threshold_percent(eer,'eer_it','WeightC', ten_threshold)
wten_ep_hctax = weighted_above_threshold_percent(eer,'eer_hctax','WeightC', ten_threshold)
wten_ep_hcfh = weighted_above_threshold_percent(eer,'eer_hcfh', 'WeightC',ten_threshold)
wten_ep_hchac = weighted_above_threshold_percent(eer,'eer_hchac','WeightC', ten_threshold)

# Create a DataFrame to store the results
TM_ep_it["Threshold"] = 'TM 2M (Unweighted)'
TM_ep_it["Income_type"] = 'eer_it'

TM_ep_hctax["Threshold"] = 'TM 2M (Unweighted)'
TM_ep_hctax["Income_type"] = 'eer_hctax'

TM_ep_hcfh["Threshold"] = 'TM 2M (Unweighted)'
TM_ep_hcfh["Income_type"] = 'eer_hcfh'

TM_ep_hchac["Threshold"] = 'TM 2M (Unweighted)'
TM_ep_hchac["Income_type"] = 'eer_hchac'

six_ep_it["Threshold"] = '6% (Unweighted)'
six_ep_it["Income_type"] = 'eer_it'
```

```
six_ep_hctax["Threshold"] = '6% (Unweighted)'
six_ep_hctax["Income_type"] = 'eer_hctax'

six_ep_hcfh["Threshold"] = '6% (Unweighted)'
six_ep_hcfh["Income_type"] = 'eer_hcfh'

six_ep_hchac["Threshold"] = '6% (Unweighted)'
six_ep_hchac["Income_type"] = 'eer_hchac'

ten_ep_it["Threshold"] = '10% (Unweighted)'
ten_ep_it["Income_type"] = 'eer_it'

ten_ep_hctax["Threshold"] = '10% (Unweighted)'
ten_ep_hctax["Income_type"] = 'eer_hctax'

ten_ep_hcfh["Threshold"] = '10% (Unweighted)'
ten_ep_hcfh["Income_type"] = 'eer_hcfh'

ten_ep_hchac["Threshold"] = '10% (Unweighted)'
ten_ep_hchac["Income_type"] = 'eer_hchac'

WTM_ep_it["Threshold"] = 'TM 2M (Weighted)'
WTM_ep_it["Income_type"] = 'eer_it'

WTM_ep_hctax["Threshold"] = 'TM 2M (Weighted)'
WTM_ep_hctax["Income_type"] = 'eer_hctax'

WTM_ep_hcfh["Threshold"] = 'TM 2M (Weighted)'
WTM_ep_hcfh["Income_type"] = 'eer_hcfh'

WTM_ep_hchac["Threshold"] = 'TM 2M (Weighted)'
WTM_ep_hchac["Income_type"] = 'eer_hchac'

wsix_ep_it["Threshold"] = '6% (Weighted)'
wsix_ep_it["Income_type"] = 'eer_it'

wsix_ep_hctax["Threshold"] = '6% (Weighted)'
wsix_ep_hctax["Income_type"] = 'eer_hctax'

wsix_ep_hcfh["Threshold"] = '6% (Weighted)'
wsix_ep_hcfh["Income_type"] = 'eer_hcfh'

wsix_ep_hchac["Threshold"] = '6% (Weighted)'
```

```
wsix_ep_hchac["Income_type"] = 'eer_hchac'


wten_ep_it["Threshold"] = '10% (Weighted)'
wten_ep_it["Income_type"] = 'eer_it'

wten_ep_hctax["Threshold"] = '10% (Weighted)'
wten_ep_hctax["Income_type"] = 'eer_hctax'

wten_ep_hcfh["Threshold"] = '10% (Weighted)'
wten_ep_hcfh["Income_type"] = 'eer_hcfh'

wten_ep_hchac["Threshold"] = '10% (Weighted)'
wten_ep_hchac["Income_type"] = 'eer_hchac'

ep_percent_thresholds = pd.concat([
    TM_ep_it, TM_ep_hctax, TM_ep_hcfh, TM_ep_hchac,
    six_ep_it,six_ep_hctax, six_ep_hcfh, six_ep_hchac,
    ten_ep_it, ten_ep_hctax, ten_ep_hcfh, ten_ep_hchac,
    WTM_ep_it, WTM_ep_hctax, WTM_ep_hcfh, WTM_ep_hchac,
    wsix_ep_it, wsix_ep_hctax, wsix_ep_hcfh, wsix_ep_hchac,
    wten_ep_it, wten_ep_hctax, wten_ep_hcfh, wten_ep_hchac])

ep_percent_thresholds = ep_percent_thresholds.pivot_table(index=["Income_type", "Prov"],
columns="Threshold").swaplevel(axis=1).sort_index(axis=1, level=0)

################## THIS SECTION FILTERS THE HOUSEHOLDS above THE DEFINED
THRESHOLD BASED ON CHARACTERISTICS & FINDS PERCENTAGE #################
########### ENERGY POVERTY & HOUSEHOLD CHARACTERISTICS #################
def calculate_unweighted_percentage(df, group_col, eer_col, threshold):
    # Filter rows above the threshold
    filtered_df = df[(df[eer_col] > threshold)& (df['LIHC'])]

    # Calculate the count of rows above the threshold for each group
    above_threshold_counts = filtered_df.groupby(group_col,
observed=True).size().reset_index(name='numerator')

    # Calculate the total count for each group
    total_counts = df.groupby(group_col, observed=True).size().reset_index(name='denominator')

    # Merge the counts dataframes
    merged_df = pd.merge(above_threshold_counts, total_counts, on=group_col)

    # Calculate the difference
```

```
    merged_df['difference'] = merged_df['denominator'] - merged_df['numerator']

    # Calculate the percentage
    merged_df['percentage'] = (merged_df['numerator'] / merged_df['denominator']) * 100

    # Calculate overall counts
    overall_numerator = filtered_df.shape[0]
    overall_denominator = df.shape[0]

    # Calculate the overall percentage
    overall_percentage = (overall_numerator / overall_denominator) * 100

    # Append overall results to the DataFrame
    overall_row = pd.DataFrame({
        group_col: ['Overall'],
        'numerator': [overall_numerator],
        'denominator': [overall_denominator],
        'difference': [overall_denominator - overall_numerator],
        'percentage': [overall_percentage] })

    # Concatenate the overall row to the merged DataFrame
    merged_df = pd.concat([merged_df, overall_row], ignore_index=True)
    return merged_df

def calculate_weighted_percentage(df, group_col, eer_col, weight_col, threshold):
    # Filter the DataFrame to include only rows where the eer_col value is above the threshold
    filtered_df = df[(df[eer_col] > threshold)& (df['LIHC'])]

    # Group by the specified column and sum the WeightC for rows above the threshold
    weighted_numerator = filtered_df.groupby(group_col,
observed=True)[weight_col].sum().reset_index(name='numerator')

    # Group by the specified column to get the total weighted sum for each category
    weighted_denominator = df.groupby(group_col,
observed=True)[weight_col].sum().reset_index(name='denominator')

    # Merge the weighted counts dataframes
    result_df = pd.merge(weighted_numerator, weighted_denominator, on=group_col)

    # Calculate the difference between numerator and denominator
    result_df['difference'] = result_df['denominator'] - result_df['numerator']

    # Calculate the weighted percentage of rows above the threshold for each category
    result_df['percentage'] = (result_df['numerator'] / result_df['denominator']) * 100
```

```
    # Calculate the overall weighted numerator and denominator
    overall_numerator = filtered_df[weight_col].sum()
    overall_denominator = df[weight_col].sum()

    # Calculate the overall weighted percentage
    overall_percentage = (overall_numerator / overall_denominator) * 100

    # Create a row for the overall results
    overall_row = pd.DataFrame({
        group_col: ['Overall'],
        'numerator': [overall_numerator],
        'denominator': [overall_denominator],
        'difference': [overall_denominator - overall_numerator],
        'percentage': [overall_percentage]  })

    # Append the overall row to the results DataFrame
    result_df = pd.concat([result_df, overall_row], ignore_index=True)
    return result_df

###### Combined Results

def combined_epcharac_results(df, group_col, weight_col, eer_col, tm_threshold, six_threshold,
ten_threshold):
    # Initialize an empty list to store the DataFrames
    results = []

    # Define a list of threshold names and values
    threshold_names = ['tm_threshold', 'six_threshold', 'ten_threshold']
    threshold_values = [tm_threshold, six_threshold, ten_threshold]

    # Loop through the thresholds and collect data from both functions
    for threshold_name, threshold_value in zip(threshold_names, threshold_values):
        # Calculate unweighted percentages
        unweighted_result = calculate_unweighted_percentage(df, group_col, eer_col,
threshold_value)

        # Calculate weighted percentages
        weighted_result = calculate_weighted_percentage(df, group_col, eer_col, weight_col,
threshold_value)

        # Rename columns to indicate the threshold
        unweighted_result = unweighted_result.rename(columns={
            'numerator': f'{threshold_name}_numerator_unweighted',
```

```
            'denominator': f'{threshold_name}_denominator_unweighted',
            'difference': f'{threshold_name}_difference_unweighted',
            'percentage': f'{threshold_name}_unweighted'})

        weighted_result = weighted_result.rename(columns={
            'numerator': f'{threshold_name}_numerator_weighted',
            'denominator': f'{threshold_name}_denominator_weighted',
            'difference': f'{threshold_name}_difference_weighted',
            'percentage': f'{threshold_name}_weighted'})

        # Merge unweighted and weighted results on the group_col
        combined_result = pd.merge(unweighted_result, weighted_result, on=group_col)

        #Append the combined result to the list
        results.append(combined_result)
    # Concatenate all the results into a single DataFrame
    final_df = pd.concat(results, ignore_index=True)
    return final_df

############## USING income after tax
##dw_type_ep = combined_epcharac_results(eer, 'dwelling type', 'WeightC','eer_it',tm_it,
six_threshold, ten_threshold)
##dw_age_ep = combined_epcharac_results(eer, 'dwelling age', 'WeightC','eer_it',tm_it,
six_threshold, ten_threshold)
##edu_ep = combined_epcharac_results(eer, 'education', 'WeightC','eer_it',tm_it, six_threshold,
ten_threshold)
##rm_ep = combined_epcharac_results(eer, 'rent or mortgage', 'WeightC','eer_it', tm_it,
six_threshold, ten_threshold)
##maint_ep = combined_epcharac_results(eer, 'maintenance', 'WeightC','eer_it', tm_it,
six_threshold, ten_threshold)
##ms_ep = combined_epcharac_results(eer, 'ms', 'WeightC','eer_it',tm_it, six_threshold,
ten_threshold)
##gender_ep = combined_epcharac_results(eer, 'gender', 'WeightC','eer_it',tm_it, six_threshold,
ten_threshold)
##emp_ep = combined_epcharac_results(eer, 'employment', 'WeightC','eer_it',tm_it,
six_threshold, ten_threshold)
##inc_ep = combined_epcharac_results(eer, 'income bins', 'WeightC', 'eer_it',tm_it, six_threshold,
ten_threshold)
##hh_type_ep = combined_epcharac_results(eer, 'household type','WeightC', 'eer_it',tm_it,
six_threshold, ten_threshold)
##num_ppl_ep = combined_epcharac_results(eer, 'num ppl','WeightC', 'eer_it',tm_it,
six_threshold, ten_threshold)
##city_ep = combined_epcharac_results(eer, 'City','WeightC', 'eer_it',tm_it, six_threshold,
ten_threshold)
```

```
##urban_ep = combined_epcharac_results(eer, 'urban size','WeightC', 'eer_it',tm_it, six_threshold, ten_threshold)

############### USING income after tax & housing cost
##dw_type_ep = combined_epcharac_results(eer, 'dwelling type', 'WeightC','eer_hctax',tm_hctax, six_threshold, ten_threshold)
##dw_age_ep = combined_epcharac_results(eer, 'dwelling age', 'WeightC','eer_hctax',tm_hctax, six_threshold, ten_threshold)
##edu_ep = combined_epcharac_results(eer, 'education', 'WeightC','eer_hctax',tm_hctax, six_threshold, ten_threshold)
##rm_ep = combined_epcharac_results(eer, 'rent or mortgage', 'WeightC','eer_hctax',tm_hctax, six_threshold, ten_threshold)
##maint_ep = combined_epcharac_results(eer, 'maintenance', 'WeightC','eer_hctax',tm_hctax, six_threshold, ten_threshold)
##ms_ep = combined_epcharac_results(eer, 'ms', 'WeightC','eer_hctax',tm_hctax, six_threshold, ten_threshold)
##gender_ep = combined_epcharac_results(eer, 'gender', 'WeightC','eer_hctax',tm_hctax, six_threshold, ten_threshold)
##emp_ep = combined_epcharac_results(eer, 'employment', 'WeightC','eer_hctax',tm_hctax, six_threshold, ten_threshold)
##inc_ep = combined_epcharac_results(eer, 'income bins', 'WeightC', 'eer_hctax',tm_hctax, six_threshold, ten_threshold)
##hh_type_ep = combined_epcharac_results(eer, 'household type','WeightC', 'eer_hctax',tm_hctax, six_threshold, ten_threshold)
##num_ppl_ep = combined_epcharac_results(eer, 'num ppl','WeightC', 'eer_hctax',tm_hctax, six_threshold, ten_threshold)
city_ep = combined_epcharac_results(eer, 'City','WeightC', 'eer_hctax',tm_it, six_threshold, ten_threshold)
urban_ep = combined_epcharac_results(eer, 'urban size','WeightC', 'eer_hctax',tm_it, six_threshold, ten_threshold)

###### Print reults to Excel CSV - Energy Poverty Proportion of people under EP per Threshold
##ep_percent_thresholds.to_csv('ep_percent_thresholds_2019.csv')

######Print results to Excel CSV - Energy Consumption per Household Characteristic
######Using income after tax
##dw_type_ec = calculate_stats_ec(eer, 'dwelling type', eer_col= 'eer_it')
##dw_age_ec = calculate_stats_ec(eer, 'dwelling age', eer_col= 'eer_it')
##hh_type_ec = calculate_stats_ec(eer, 'household type', eer_col= 'eer_it')
##num_ppl_ec = calculate_stats_ec(eer, 'num ppl', eer_col= 'eer_it')
##rm_ec = calculate_stats_ec(eer, 'rent or mortgage', eer_col= 'eer_it')
##edu_ec = calculate_stats_ec(eer, 'education', eer_col='eer_it')
##inc_ec = calculate_stats_ec(eer, 'income bins', eer_col='eer_it')
```

```
##dw_type_ec = calculate_stats_ec(eer, 'dwelling type', eer_col= 'eer_hctax')
##dw_age_ec = calculate_stats_ec(eer, 'dwelling age', eer_col= 'eer_hctax')
##hh_type_ec = calculate_stats_ec(eer, 'household type', eer_col= 'eer_hctax')
##num_ppl_ec = calculate_stats_ec(eer, 'num ppl', eer_col= 'eer_hctax')
##rm_ec = calculate_stats_ec(eer, 'rent or mortgage', eer_col= 'eer_hctax')
##edu_ec = calculate_stats_ec(eer, 'education', eer_col='eer_hctax')
##inc_ec = calculate_stats_ec(eer, 'income bins', eer_col='eer_hctax')

#####Print Results to EXcel CSV - Energy Consumption per characteristic
##dw_type_ec.to_csv('dw_type_ec.csv', index=False)
##dw_age_ec.to_csv('dw_age_ec.csv', index=False)
##hh_type_ec.to_csv('hh_type_ec.csv', index=False)
##num_ppl_ec.to_csv('num_ppl_ec.csv',index = False)
##rm_ec.to_csv('rm_ec.csv',index = False)
##edu_ec.to_csv('edu_ec.csv',index = False)
##inc_ec.to_csv('inc_ec.csv',index = False)

### Print results to Excel CSV - Energy Poverty per Household Characteristic
##dw_type_ep.to_csv('dw_type_ep.csv', index=False)
##dw_age_ep.to_csv('dw_age_ep.csv', index=False)
##edu_ep.to_csv('edu_ep.csv', index=False)
##rm_ep.to_csv('rm_ep.csv', index=False)
##maint_ep.to_csv('maint_ep.csv', index=False)
##ms_ep.to_csv('ms_ep.csv', index=False)
##gender_ep.to_csv('gender_ep.csv', index=False)
##emp_ep.to_csv('emp_ep.csv', index=False)
##inc_ep.to_csv('inc_ep.csv', index=False)
##hh_type_ep.to_csv('hh_type_ep.csv', index = False)
##num_ppl_ep.to_csv('num_ppl_ep.csv', index = False)
city_ep.to_csv('city_ep.csv', index = False)
urban_ep.to_csv('urban_e.csv', index = False)

##### energy consumption results to excel
##apo.to_csv('apo.csv',index = False)
##results_ec.to_csv('results_ec.csv', index = False)
```