Energy poverty: understanding its impact on hospitalization among Canadian adults aged 40 and older

by

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Abstract

Objective. About 17% to 18% of Canadian households experience energy poverty meaning that they are unable to afford or access domestic energy services needed to meet their needs and maintain healthy temperatures inside their homes. Despite these statistics, little is known about the effects of energy poverty on the health of Canadians. Using a weighted sample representing 3.9 million Canadians aged 40 and over, this thesis examines the effects of energy poverty on cardiovascular, respiratory, and cardiorespiratory-related hospitalizations occurring within 10 years. More precisely, this research project examines the associations between exposure to energy poverty and having at least one hospital admission, a single admission relative to zero, and two or more admissions relative to zero.

Methods. This study uses population-based linked health data from the Canadian Census Health & Environment Cohort and the Discharge Abstract Database. Energy poverty is measured through expenditure-based indicators. The associations between energy poverty and cardiovascular and respiratory-related hospitalizations are modelled through logistic and multinomial logistic regressions and are adjusted for various socioeconomic, housing, and geographical variables.

Results. Being energy-poor is associated with a higher likelihood of being hospitalized at least once for cardiovascular (OR: 1.07; 95%CI: 1.05, 1.09), respiratory (OR:1.15; 95%CI: 1.12, 1.18), and cardiovascular or respiratory (OR: 1.10; 95%CI: 1.08, 1.12) diseases. Being energy-poor increases the relative risk of being admitted for cardiovascular (RRR: 1.05; 95%CI: 1.03, 1.08), respiratory (RRR:1.13; 95%CI: 1.10, 1.16) and cardiorespiratory (RRR= 1.13; 95%CI: 1.09, 1.17) diseases. Similarly, energy poverty increases the relative risk of having two or more cardiovascular (RRR: 1.13; 95%CI: 1.09, 1.16), respiratory (RRR:1.22; 95%CI: 1.16, 1.28), and cardiorespiratory-related (RRR:1.16; 95%CI: 1.12, 1.19) admissions.

Conclusion. Energy poverty is an independent housing-related social determinant of cardiovascular and respiratory health among Canadian adults aged 40 and older. Future research should explore the effect of energy poverty on the respiratory health of Canadian children as well as the impact on mortality.

Résumé

Objectif. Environ 17% à 18% des ménages canadiens sont en situation de pauvreté énergétique, c'est-à-dire qu'ils ne peuvent accéder à des services énergétiques domestiques nécessaires pour répondre à leurs besoins et protéger leur santé. Malgré ces données, on connaît peu sur les effets de la pauvreté énergétique sur la santé des Canadiens. Par conséquent, en utilisant un échantillon pondéré représentant 3.9 millions de Canadiens âgés de 40 ans et plus, cette thèse examine les effets de la pauvreté énergétique sur les hospitalisations liées aux maladies cardiovasculaires, respiratoires et cardiorespiratoires survenues au cours d'une période de 10 ans. Plus précisément, ce projet de recherche examine les associations entre l'exposition à la pauvreté énergétique et le fait d'avoir au moins une admission à l'hôpital, une seule admission par rapport à zéro, et deux admissions ou plus par rapport à zéro.

Méthodes. Cette étude utilise des données de santé liées à la population provenant de la Cohortes santé et environnement du recensement du Canada et de la Base de données sur les congés des patients. La pauvreté énergétique est mesurée par des indicateurs basés sur les dépenses. Les associations entre la pauvreté énergétique et les hospitalisations liées aux maladies cardiovasculaires et respiratoires sont modélisées par des régressions logistiques et logistiques multinomiales, et sont ajustées pour diverses variables socio-économiques, de logement et géographiques.

Résultats. La pauvreté énergétique est associée à une probabilité plus élevée d'être hospitalisé au moins une fois pour des maladies cardiovasculaires (OR= 1.07 ; 95%CI : 1.05, 1.09), respiratoires (OR=1.15 ; 95%CI : 1.12, 1.18), et cardiorespiratoires (OR= 1.10 ; 95%CI : 1.08, 1.12). Être en situation de pauvreté énergétique augmente le risque relatif d'être admis pour des maladies cardiovasculaires (RRR =1.05 ; 95%CI : 1.03, 1.08), respiratoires (RRR=1.13 ; 95%CI : 1.10, 1.16) et cardiorespiratoires (RRR= 1.13 ; 95%CI : 1.09, 1.17). De même, la pauvreté énergétique augmente le risque relatif d'avoir au moins deux admissions pour des maladies cardiovasculaires (RRR=1.13 ; 95%CI : 1.09, 1.16), respiratoires (RRR=1.22 ; 95%CI : 1.16, 1.28) et cardiorespiratoires (RRR=1.16 ; 95%CI : 1.12, 1.19).

Conclusion. La pauvreté énergétique est un déterminant social de la santé cardiovasculaire et respiratoire chez les adultes canadiens âgés de 40 ans et plus. Les recherches futures devraient

explorer l’effet de la pauvreté énergétique sur la santé respiratoire des enfants canadiens ainsi que l’impact sur la mortalité.

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Contribution of authors

The research question and objectives of this thesis were formulated by myself, Sophie Kingunza Makasi, and by Prof. Mylène Riva. I conducted the literature review, data analysis, writing and editing of the thesis. Prof. Riva and Prof. Sébastien Breau provided guidance on the research methods and data analyses, offered feedback and advice on the chapters, and assisted with editing.

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List of Abbreviations and acronyms

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census metropolitan influenced zone, 35

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Chapter 1: Introduction and objectives

Canada has one of the world's largest and most diverse energy supplies (Natural Resources Canada, 2017). Ironically, many citizens face difficulties in affording or accessing energy within their homes for purposes such as heating, cooling, cooking and lighting. Such a situation is commonly referred to as energy poverty (EP), and, depending on the indicator used to measure it, about 6% to 19% of Canadians were estimated to experience EP in 2017 (Riva et al., 2021).

Several studies conducted in European countries, New Zealand, Australia and the United States have shown that EP can adversely impact health and wellbeing. For instance, living in a poorly heated home can worsen or lead to respiratory problems such as asthma, pulmonary embolism, and bronchitis (Liddell & Morris, 2010; Marmot Review Team, 2011; O'Sullivan, 2019). Exposure to cold indoor temperatures as a result of EP can also heighten the risk of suffering cerebrovascular and cardiovascular complications, such as strokes, ischaemic heart diseases, and myocardial infarctions (Liddell & Morris, 2010; Marmot Review Team, 2011; O'Sullivan, 2019; World Health Organization (WHO), 2018). In contrast, being unable to cool one's dwelling during warm weather can cause heat stress, which may affect cardiovascular (Jessel et al., 2019; Marmot Review Team, 2011) and renal health (Jessel et al., 2019). Ultimately, these problems can lead to increased hospitalizations (Jessel et al., 2019; Marmot Review Team, 2011; O'Sullivan, 2019) and even death (Jessel et al., 2019; Liddell & Morris, 2010; Marmot Review Team, 2011; Thomson et al., 2017; WHO, 2018).

Given these health impacts, some European countries have taken action to address EP. For instance, the United Kingdom, where between 12% and 25% of households are estimated to be in EP (Bolton et al., 2022), adopted its first fuel poverty strategy in 2001 with the main priority of protecting human health (Liddell & Morris, 2010). Since then, the strategy has been updated multiple times while maintaining particular attention to protecting vulnerable households that are more highly impacted by the adverse health effects of EP (Department for Business, Energy & Industrial Strategy, 2021). Meanwhile, in Canada, where a similar prevalence of EP is observed, the discourse on energy poverty is still in its infancy. Only recently has new evidence demonstrated that living in a situation of energy poverty has an adverse effect and Canadian's self-rated mental and general health (Riva et al., in press). Still, it remains unknown how such association translates in terms of more objective health measures and healthcare service utilization.

Through a secondary analysis of the Canadian Census Health & Environment Cohort linked to the Discharge Abstract Database, my thesis research aims to address this knowledge gap by answering the following research question: **Does energy poverty influence cardiovascular and respiratory health outcomes of Canadian adults?** More specifically, I will examine whether Canadians aged 40 and older and living in EP have increased risks of being hospitalized at least once for cardiovascular diseases and respiratory diseases over a 10-year period; and, if so, compare how the risk varies for single and multiple hospitalizations.

To explore whether EP is a risk factor for cardiovascular and respiratory health for Canadian adults, my thesis uses a large representative sample of individuals over the age of 39 living in the provinces to which I apply logistic and multinomial logistic regression models to examine the associations between EP and hospitalizations occurring between 2006/2007 and 2016/2017.

Cardiovascular and respiratory diseases contribute to five of the top ten leading causes of death in Canada (Institute for Health Metrics and Evaluation, 2019). Therefore, identifying whether EP is a risk factor that contributes to poor cardiorespiratory health outcomes is an essential step to inform public health interventions and policies aimed at reducing the burden of these diseases. Findings generated by this research will provide greater knowledge on how EP acts as a determinant of health and particularly cardiovascular and respiratory health. Ultimately, these results have the potential to support advocacy for greater integration of energy poverty within Canadian energy policies and the public health agenda.

1.1 Outline of the dissertation

Following this introduction, the second chapter presents a review of relevant literature that aims to provide a greater understanding of energy poverty and its relationship to health, as well as a background of the Canadian energy context and discourse on EP in which the thesis is situated. The third chapter describes the conceptual framework guiding the research and is followed by a detailed description of the data and methods utilized in chapter 4. Chapter 5 presents the results of the descriptive and analytical analyses as well as the sensitivity analyses.

Following this, chapter 6 discusses the findings through comparison with existing literature, explores their policy implications, and acknowledges the methodological limitations of the study. Finally, chapter seven concludes the thesis by re-iterating the main objective and findings and proposes areas for future research.

Chapter 2: Literature review

2.1 The evolving definition of energy poverty

Historically, EP has been used to describe households in the global South who experience difficulties in accessing energy because of deficiencies in infrastructures and the country's level of development, whereas concerns about the affordability of energy for households in the global North were addressed as fuel poverty (Bouzarovski et al., 2017; Bouzarovski & Petrova, 2015). Nowadays, EP and fuel poverty are used interchangeably alongside other terms, such as energy precariousness, energy vulnerability, energy insecurity, and energy burden (Hernández, 2016; Jessel et al., 2019; O'Sullivan, 2019; Pellicer-Sifres, 2019; Sokołowski et al., 2020; Thomson et al., 2017), all referring to difficult situations that prevent hundreds of millions of households from reaching the seventh objective of the United Nations Sustainable Development Goals which aims to "ensure access to affordable, reliable, sustainable and modern energy for all" by 2030 (United Nations, 2022, p.14).

Within the global North context, EP was first defined by Brenda Boardman in 1991 in the United Kingdom as referring to households who needed to spend more than 10% of their income on energy services excluding transportation (Moore, 2012; Pellicer-Sifres, 2019; Rezaei, 2017). The definition of EP then evolved to include the concept of thermal comfort such that energy-poor households are those who spend over 10% of their income on energy services to maintain adequate housing temperature (Pellicer-Sifres, 2019). According to the WHO, adequate thermal comfort is achieved when the indoor temperature is kept at a minimum of 18°C or even higher for vulnerable populations (WHO, 2018). The meaning of EP was later modified to include a greater focus on energy services. Thus, EP now more broadly refers to households who are unable to secure an adequate level of domestic energy services, i.e. heating or cooling the dwelling, cooking and refrigerating food, lighting rooms, using appliances and devices, etc., needed to meet social norms and protect their health (Bouzarovski & Petrova, 2015; O'Sullivan, 2019; Thomson et al., 2019).

2.2 What causes energy poverty?

Although income is important in determining how much energy a household can afford to pay, there is a general agreement that EP is not only a poverty issue but rather the combination of low incomes, high energy prices, and the energy inefficiency of housing and appliances (Marmot Review Team, 2011; Sharpe et al., 2019; Thomson et al., 2017). Besides these three main factors, occupants' behaviours and needs, as well as other demographic, socioeconomic, and housing factors, also affect a household's likelihood of experiencing EP (Jessel et al., 2019; Marmot Review Team, 2011; O'Sullivan, 2019; Thomson et al., 2017). For instance, lone-parent families, especially female-headed households, are more likely to be in EP because they are the sole caregiver and have to bear all the financial responsibilities (Healy, 2017; Jessel et al., 2019). Tenancy relations can also affect households' vulnerability to EP given that tenants have limited capacity to physically modify the house in order to increase its energy efficiency (Healy, 2017; Jessel et al., 2019; Marmot Review Team, 2011; O'Sullivan, 2019). Additionally, they may avoid asking their landlords for improvements in fear of being evicted or because they do not wish to invest in a house that they will temporarily occupy (Howden-Chapman et al., 2012; Marmot Review Team, 2011). On the other hand, landlords may not have the motivation to bear the upfront cost and upgrade their properties, as they will not directly benefit from reduced energy bills (Marmot Review Team, 2011). People with increased energy needs also have a heightened vulnerability to EP (Thomson et al., 2017). For instance, older adults, young children and people with chronic health conditions may need to maintain a higher ambient temperature to be comfortable. They are also more likely to spend more time at home and may use energy-consuming medical devices, therefore increasing their energy use (e.g., people relying on home dialysis and oxygen machines) (Grey et al., 2017; Jessel et al., 2019; O'Sullivan, 2019; Petrova, 2018; Sharpe et al., 2019; Thomson et al., 2017).

2.3 Measuring energy poverty

As depicted in Table 1, various measurement approaches are employed to measure energy poverty, including expenditure-based, self-reported, direct and composite measures, with the first two being the most common (Bosch et al., 2019; Thomson et al., 2017).

Table 1. Summary of various energy poverty indicators

Approach	Indicators
Energy expenditure	**Absolute measures**
	10% threshold: More than 10% of income is spent on energy expenditures
	Relative measures
	Twice the national median threshold (2M): The share of income spent on energy costs is more than twice the national median
	Low Income High Costs (LIHC): (1) Household energy cost adjusted for household composition is above the national median and (2) household income adjusted for household size and composition, and calculated after energy cost, is below the 60% median poverty line
	Minimum income standard (MIS): Household net income after deducting housing costs and all other minimum living costs is lower than the required energy costs needed to achieve adequate indoor conditions
	After fuel cost poverty (AFCP): Household equalized income after deducting housing costs and energy costs is below 60% of the equalized national income
	Low Income Low Energy Efficiency (LILEE): (1) Household residual income after accounting for required energy costs is below the poverty line and (2) the energy efficiency rating of the dwelling is below Band C
Self-reported	Inability to heat / keep the home adequately warm
	Experiencing thermal discomfort during winter and/or summer
	Inability to pay utility bills/ having arrears on utility bills
	Dissatisfaction with heating equipment/ lack of adequate heating facility or equipment
	Presence of damp walls and/or floors or foundation, a leaking roof or rotten window frames and/or floor
Direct measurement	Indoor temperature measurements of housing
Composite	Multi-dimensional Energy Poverty Index: combines LIHC, inability to keep home adequately warm, difficulties paying bills, presence of dampness, leak and rot

	Compound Energy Poverty Indicator to measure EP: combines the 10% threshold, LIHC and AFCP

Expenditure-based measures use absolute or relative thresholds to compare a household's energy expenditure to its income (Thomson et al., 2017). A commonly used expenditure metric is Boardman's 10% cut-off that was previously mentioned. When this metric was developed in 1991, the selection of the absolute 10% threshold represented what the poorest 30% of households in the UK needed to spend to maintain adequate warmth, which was twice the national median share of energy expenditure relative to income (Atsalis et al., 2016; Rezaei, 2017; Thomson et al., 2017). Since then, however, many studies have blindly applied the 10% measure without considering its validity and suitability for the context in which it was being used (Rezaei, 2017; Thomson et al., 2017). As an alternative, the ratio of twice the national median (2M) has become another widely used measure (Thomson et al., 2017). Alongside it, the Low Income High Cost (LIHC) is a measure that considers households to be energy poor if they 1) have high energy costs that are above the national median, and 2) after paying for their energy costs, are left with an income below the poverty line (Atsalis et al., 2016; Belaid, 2019; Thomson et al., 2017). The minimum income standard (MIS) is another objective measure that defines households as being energy poor if the energy expenditure needed to attain adequate indoor conditions exceeds the minimum income required for that household to achieve a minimum acceptable standard of living (Atsalis et al., 2016; Rademaekers et al., 2016). Here, the minimum income is calculated by deducting housing and minimum living cost from a household's net income (Atsalis et al., 2016). Still, despite the diversity of expenditure-based indicators, they do not capture the severity, material deprivation, and social exclusion elements of energy poverty (Rezaei, 2017; Thomson et al., 2017).

Self-reported measures are based on self-assessment of housing conditions most often measured in population surveys (Atsalis et al., 2016; Herrero, 2017). For example, households are asked to report dampness or mould in their home, their ability to keep their house warm or to pay their utility bills on time (Herrero, 2017; Thomson et al., 2017). While these indicators can better depict the experience of energy poverty than expenditure-based measures, their subjectivity complicates comparison and can lead to the exclusion of households that may have different standards based on which they do not perceive themselves as being energy-poor (Rezaei, 2017; Thomson et al., 2017). Also, some of these subjective indicators could be more related to other housing conditions than to energy poverty (Bosch et al., 2019).

Expenditure and self-reported indicators capture different aspects of energy poverty; indeed, there is little overlap between both types of measures (Atsalis et al., 2016; Kahouli, 2020; Waddams Price et al., 2012). To illustrate this point, a French study compared one objective and two self-reported indicators of EP, namely the 10% threshold, difficulties heating the dwelling to a suitable level of warmth, and the financial ability to maintain adequate temperature. Results demonstrated that 26.3% of people were energy poor on a least one criterion, 8.3% experienced two, whereas only 2.5% were categorized as energy poor according to all three indicators (Kahouli, 2020). Hence, to account for the multiple facets of energy poverty, some authors have argued for the need to develop composite measures that include both consensual and expenditure-based data (Bosch et al., 2019; Kahouli, 2020; K. C. O'Sullivan, 2019; Rezaei, 2017; Sokołowski et al., 2020). However, assigning weights to the different components in a multidimensional index is complex (Rezaei, 2017).

Finally, *direct measurements* can also be utilized to measure EP (e.g., by taking temperature and humidity measurements in dwellings). However, this is rarely done because of technical limitations and ethical concerns about monitoring people's dwellings (Bosch et al., 2019; Healy, 2017; Thomson et al., 2017).

Other measures, often used in countries in the global South (not shown in Table 1), such as the Total Energy inconvenience Threshold, the Energy Development Index and the Multi-Tier Framework, can also be used to measure household EP, to monitor countries' transition towards more modern energy sources, and to assess the realization of the seventh sustainable development goal (Energy Sector Management Assistance Program, 2022; International Atomic Energy Agency, 2005; Mirza & Szirmai, 2010).

2.4 Canadian energy and energy poverty landscape

Canada is the second largest country, in terms of land area, with a dispersed population and an abundance of energy supplies (Natural Resources Canada, 2017b). Notably, the country holds large reserves of hydrocarbons and uranium, vast bodies of water that generate an important source of hydropower (Natural Resources Canada, 2017b), and great potential for wind and solar energy (Canada Energy Regulator, 2021; Natural Resources Canada, 2017b). This vast pool of resources makes Canada the sixth most important energy producer in the world, as well as the eighth top consumer (Natural Resources Canada, 2017a). Historically, the country's harsh winter climate has made access to energy for heating a necessity, explaining why 81% of residential energy consumption is spent on space and water heating (National Energy Board, 2019; Natural Resources Canada, 2017b). Nowadays, climate change and the expected increase in the urban heat island effect and heat waves are likely to make access to cooling another essential need (Berry & Schnitter, 2022). While there are variations in the type of energy used across provinces and territories, most households' primary sources of energy for heating are electricity and natural gas (Rezaei, 2017).

Regulation of the electricity and parts of the natural gas sectors varies geographically as provinces have jurisdiction over their energy matters (Canada Energy Regulator, 2021; Riva et al., 2021). Several provinces have a vertically integrated structure where the state owns the main electricity providers such as in British Columbia, Manitoba, New Brunswick, Newfoundland and Labrador, Quebec and Saskatchewan (Pineau, 2021). Other provinces either have a deregulated market where electricity pricing is based on market supply and demand competition or a combination of a competitive market and vertically integrated private companies (Pineau, 2021). As for natural gas, although pipeline transmission and distribution are overseen by the Canada Energy Regulator and provincial authorities, commodity prices are deregulated (Natural Resources Canada, 2020). Consequently, the residential energy systems and energy prices differ by location, with the lowest electricity prices in Quebec at 7.3 cents per kilowatt hour (kWh) and the highest in the Northwest Territories at 38.2 cents per kWh (Alves, 2021), and variations in monthly natural gas bills ranging from $68 per month in Saskatchewan to $156 in New Brunswick (based on an average consumption of 7.37 gigajoules in 2018) (Canada Energy Regulator, 2018).

Canada's natural endowment in energy resources and its top rank in terms of energy security (World Energy Council, 2020) may partially explain why the issue of EP has been overlooked. In fact, the country does not have an official definition nor a measure of EP (Canadian Urban Sustainability Practitioners (CUSP), 2019b; Rezaei, 2017), and EP is not addressed in the energy policies. When I began this thesis in 2020, only a handful of studies had explored this issue using expenditure-based indicators to measure EP. Until the recent introduction of the 2018 Canadian Housing Survey, which asked questions about people's perception of the thermal comfort and energy efficiency of their dwelling, the ability to examine EP in Canada using people's own assessments was limited. Using data from Statistics Canada's Survey of Household Spending (a national survey that collects information on Canadian spending habits every two years) or from the Canadian census, studies that reported on EP relied on either the 10% cut-off or the 2M indicator to measure EP. Based on the 2017 Survey of Household Spending, 6% to 10% of households experienced EP when computed before and after housing costs as per the 10% threshold, whereas estimates for the 2M indicator vary between 18% and 19% (Riva et al., 2021). Studies have also demonstrated the geographical and social patterning of EP in Canada. For instance, a higher prevalence of EP is observed in Atlantic provinces and rural regions; for households with members living with a disability or illness, in single-detached and mobile dwellings, in houses constructed before 1960; and for Indigenous and some visible minority households (CUSP, 2019a, 2019b; Das, Martiskainen & Li, 2022; Green et al., 2016; Rezaei, 2017; Riva et al., 2021).

Other than the measurement of EP and its distribution, Canadian studies have also discussed EP in terms of energy and housing policy. Indeed, a publication from the Canadian Center for Policy Alternatives discussed the implication of British Columbia's transition towards zero-emission housing on EP. Namely, efforts to shift away from fossil fuels can inadvertently increase energy prices and limit the ability of low-income households to afford energy services if appropriate resources, such as income transfers and targeted energy efficiency programs, are not put into place to support them (Lee et al., 2011). Research has also explored potential strategies that could help alleviate EP, such as the aforementioned retrofitting programs, disconnection moratoriums, higher appliance and building energy efficiency standards, and non-profit housing programs (Das et al., 2022; Lee et al., 2011; Rezaei, 2017; Tardy & Lee, 2019). Das et al. (2022) further classify initiatives and policies that helped Ontarian households address EP or vulnerability to EP between 2003 and 2018 into three categories. These are financial support programs that are primarily aimed at making electricity more affordable or providing emergency assistance; consumer protection initiatives that protect households within the retail markets from being financially overloaded and disconnected from energy services, such as programs that assist with arrear payments, budgeted or equalized billing; and lastly the most promising strategies were energy efficiency and energy saving programs often aimed at addressing climate change concerns (Das et al., 2022).

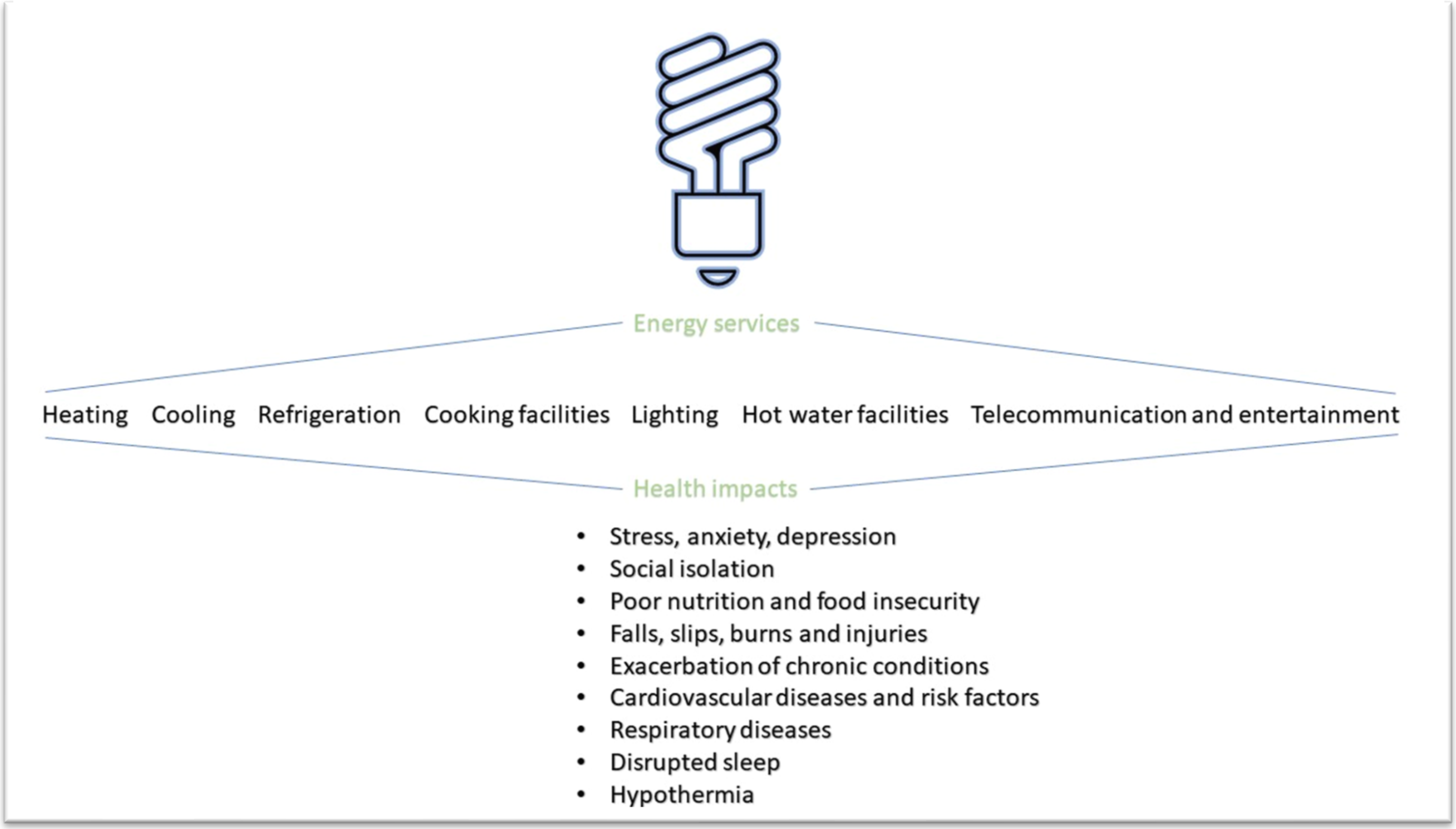
More recently, a study has shown that, independently of poor housing conditions and financial hardship, both expenditure-based and self-reported measures of EP are significantly associated with higher odds of reporting poor general and mental health among Canadian adults (Riva et al., in press). While this is a great first step in understanding the effects of EP on the health of Canadians, more studies with a longitudinal framework are needed to uncover how exposure to EP can influence more specific health outcomes, such as cardiovascular and respiratory functions and their related hospitalization and deaths.

2.5 Energy poverty and health

Figure 1 offers an overview of the various links between EP, energy services and their health effects. Many of these are related to inadequate heating and cold indoor conditions, which have been shown to exacerbate existing health conditions such as arthritis, rheumatism and sickle cell anemia (Jessel et al., 2019; Marmot Review Team, 2011; O'Sullivan, 2019); and promote falls and injuries, especially among older adults, by reducing dexterity (Marmot Review Team, 2011; O'Sullivan, 2019). Meanwhile, difficulties in accessing cooling contribute to excess indoor heat, which can disturb sleep patterns and provoke heat stress (Jessel et al., 2019; Kovats & Hajat, 2008). Additionally, thermal discomfort resulting from cold has been shown to discourage people from having guests and even lead to social isolation (Carrere et al., 2020; Longhurst & Hargreaves, 2019; Marmot Review Team, 2011; O'Sullivan et al., 2017). Other impacts include poor nutrition and food poisoning resulting from inadequate access to refrigeration (Jessel et al., 2019; O'Sullivan, 2019); poor hygiene and related infections and illnesses associated with limited access to hot water; falls and accidents caused by inadequate lighting. Worries and anxiety about being able to afford the various energy services or being deprived of them can cause depression and negatively affect mental and physical health (Carrere et al., 2020; Marmot Review Team, 2011; O'Sullivan et al., 2017).

Unfortunately, some of the coping strategies used by energy-poor households are maladaptive and further contribute to poor health.

Figure 1. Links between energy poverty and health, adapted from O'Sullivan et al. (2019)



For instance, one common strategy is to reduce energy consumption by self-limiting the use of heating, lighting, hot water, refrigeration, and telecommunication (Longhurst & Hargreaves, 2019; O'Sullivan, 2019; Poortinga et al., 2018). This may, however, lead to stress and tension between household members who may disagree on the various restrictions, such as those surrounding the utilization of electronic, telecommunication and entertainment devices (O'Sullivan, 2019).

Households may also resort to using cheaper alternative energy sources that generate toxic gases or cause fires, such as leaving the oven door open for heat and using generators, space heaters and gas stoves (Boateng et al., 2021; Cook et al., 2008; Jessel et al., 2019; O'Sullivan, 2019). Alternatively, they could continue to spend on energy and accumulate debts, which contributes to stress (O'Sullivan et al., 2016; Poortinga et al., 2018). Another strategy is the prioritization of energy services at the expense of other essential needs. In fact, due to scarcity of financial resources, some households face hard decisions and have to forego paying rent, seeking medical care and buying medication and nutritious food in order to afford energy, which may lead to other health concerns (Hernández & Phillips, 2015; Jessel et al., 2019; O'Sullivan et al., 2016; Poortinga et al., 2018).

Overall, although consideration of cooling needs within the literature on EP is increasingly recognized, discussion around EP continues to be mostly focused on heating service and its effects on cardiovascular and respiratory health. With this in mind, the next sections will describe the main pathways through which cold housing affects health, namely thermal discomfort and the presence of dampness and mould (Kahouli, 2020), and further discuss the association between EP and heat stress within the context of climate change. Following this, the relationship between EP and hospital admissions will be explored as an example of how EP can also influence the utilization of healthcare services, and finally, I will identify factors that have been adjusted for in previous studies on EP and health to support the selection of confounding variables for my methods.

2.5.1 Cold housing

A large body of evidence examining the impacts of energy poverty on health has focused on cold homes. Indeed, to cope with high energy costs, households in energy poverty may restrict their heating usage, thus resulting in cold indoor conditions (Marmot Review Team, 2011;

O'Sullivan, 2019). According to the WHO, temperatures below 16°C can lead to respiratory stress (Marmot Review Team, 2011; O'Sullivan, 2019; WHO, 2018), as cold air reduces the protective function of the respiratory tract by disrupting ciliary action and causing bronchoconstriction (Howden-Chapman et al., 2012; Marmot Review Team, 2011; O'Sullivan, 2019). Meanwhile, temperatures below 12°C cause cardiovascular stress by modifying the viscosity and pressure of the blood, which increases the likelihood of experiencing a cardio or cerebrovascular episode. (Howden-Chapman et al., 2012; Liddell & Morris, 2010; Marmot Review Team, 2011; O'Sullivan, 2019; WHO, 2018). Hypothermia becomes a major risk once the temperature falls under 6°C (Marmot Review Team, 2011; O'Sullivan, 2019; WHO, 2018). As a result, cold housing has been shown to contribute to excess winter morbidity and mortality (WHO, 2018).

In adults, the impact of living in a cold house mostly falls on both cardiovascular and respiratory health while in children it is focused on respiratory health (WHO, 2018). In a cross-sectional study, Oliveras et al. (2020) observed that people over 15 years of age in Barcelona, who reported being unable to maintain their house at an adequate temperature during both cold and warm months, experienced chronic bronchitis, asthma and myocardial infarction and or stroke 1.6 to 2.2 times more frequently than those who were not in EP. The associations for chronic bronchitis and myocardial infarction or stroke were heightened for women compared to men, which Oliveras et al. (2020) suggest is due to gender roles and the greater amount of time that women spend carrying housework indoors where they are exposed to cold conditions. Among younger age groups, it has been shown that children living in cold homes are approximately twice more likely to experience respiratory diseases than those who are not (Atsalis et al., 2016; Marmot Review Team, 2011). In a longitudinal Irish study, parents reporting being unable to keep the home adequately warm or having had to go without heat in the past 12 months were 1.41 and 1.47 times more likely to report that their child, aged between 9 months and 5 years old, experienced respiratory illness and wheezing (Mohan, 2021). The associations, however, were not significant for older children aged 9 to 17 (Mohan, 2021).

Cold housing can also have an indirect effect on health through exposure to dampness and mould. A decrease in heating contributes to a reduction in ventilation, which may lead to the accumulation of pollutants and humidity inside the house (Ginestet et al., 2020; K. C. O'Sullivan, 2019). Hence, homes that are inadequately heated are more likely to have dampness and promote the growth of mould, dust mites and fungi, which can trigger or worsen allergic reactions and respiratory infections (i.e. bronchitis, pneumonia, common cold, etc.) (Grey et al., 2017; Howden-Chapman et al., 2007b, 2012; Marmot Review Team, 2011; Mohan, 2021; K. C. O'Sullivan, 2019), and create a hospitable environment for airborne viruses and bacteria (Howden-Chapman et al., 2012; K. C. O'Sullivan, 2019). In turn, houses with dampness and mould require more heating, thus creating a vicious circle.

Among young people, Shorter et al. (2018) noted a dose-response relationship between exposure to dampness and mould and respiratory symptoms. Indeed, for every unit increase in presence of visible mould inside the bedroom reported separately by parents and researchers, children aged 12 to 84 months had 1.30 and 1.46 greater odds of wheezing (Shorter et al., 2018). Similarly, this case-control study demonstrated that each unit increase in the severity of mould odour assessed by researchers inside the bedroom was related to 2.35 higher odds of wheezing (Shorter et al., 2018). Moreover, a systematic review of longitudinal studies that examined the association between indoor exposure to mould and asthma and rhinitis reports a causal relationship between exposure to mould and asthma among children of various ages (Caillaud et al., 2018). Meanwhile, among British adults living in social housing, cross-sectional findings indicated that exposure to mouldy or musty odours was associated with 2.2 and 2.1 greater risks of seeing a doctor for asthma problems during the previous year and taking medication for asthma, respectively (Sharpe et al., 2015).

2.5.2 EP and heat stress

Canada's climate is warming at almost twice the global average rate and the frequency, duration and intensity of heat waves are expected to increase (Berry & Schnitter, 2022; Clark et al., 2021). It is therefore important to consider the adverse health effects experienced by households who are unable to adequately cool their dwelling as thermal discomfort associated with EP can also affect health through high temperatures. Exposure to high temperatures causes the widening of the blood vessels and sweating, which triggers a drop in blood pressure (Gronlund et al., 2018). As a result, individuals exposed to excess heat may experience various heat stress symptoms such as cramps, dizziness, headaches, dehydration, nausea and vomiting, exhaustion, and even heat stroke when the internal body temperature goes beyond 39°C to 40°C (Gronlund et al., 2018; Jessel et al., 2019; Kovats & Hajat, 2008). Exposure to high temperatures can also worsen existing cardiovascular and respiratory conditions (Clark et al., 2021; Tham et al., 2020).

Few studies have examined the association between EP, in terms of cooling needs, and health. One of these is a Canadian cross-sectional study by Riva et al. (in press) where we observed a statistically significant 70% increase in odds of self-reporting poor general health among respondents who were dissatisfied with their ability to maintain a comfortable temperature inside their dwelling during the summer compared to those who were satisfied. Furthermore, a panel study demonstrated that the adverse effect of EP on self-perceived general health is greater during the summer months and slightly stronger for Australians living in warmer states (Awaworyi Churchill & Smyth, 2021). These findings suggest that EP may be a contributing factor to the negative impacts observed during past heat waves in Canada, such as those from 2018 and 2009 where 66 Montrealers and 72 Vancouverites died, respectively (Clark et al., 2021).

2.5.3 Hospitalization

The effects of EP on health described above can translate into an increased utilization of health services, such as hospitalization. Evidence of the association between EP and hospitalization comes from a small number of studies that have directly investigated the relationship between EP and health service utilization (Atsalis et al., 2016; Cook et al., 2008; Ingham et al., 2019; Oliveras et al., 2020; Sharpe et al., 2019). For instance, in a longitudinal study, Atsalis et al. (2016) noted that about 2.7% to 7.4% of cardiovascular episodes and 3.1% to 8.5% of respiratory episodes treated annually by the two largest specialized hospitals in Greece are attributed to households being unable to keep their dwelling adequately warm. Likewise, Oliveras et al. (2020) reported that, in Barcelona, men who perceived themselves as being energy poor were 1.7 times more frequently hospitalized in the last 12 months than those who did not report being in EP. At a population level, this cross-sectional study showed that 1% and 7% of hospitalization in women and men were attributable to EP (Oliveras et al., 2020). Among younger age groups, Cook et al. (2008) showed that American children under the age of three and from low-income households that are in moderate energy insecurity have 22% greater odds of being admitted to a hospital since their birth than those from energy secure households. In this cross-sectional study, energy insecurity was measured through a four-question indicator that looks at whether a household has received, in the past month or past year, a shut-off notice, utilized a cooking stove to provide heating, gone without heating due to financial constraints and experienced a utility disconnection (Cook et al., 2008). A positive response to receiving a shut-off notice indicates moderate energy insecurity, while a positive response to more than one of the questions is categorized as severe energy insecurity (Cook et al., 2008). They also examined the association between hospital admission and severe energy insecurity, which was non-significant. In a prospective and unmatched case-control study using the Damp-Mould Index, an 8-item subscale of the Healthy Housing Index, Ingham et al. (2019) demonstrated a significant dose relationship between the presence of damp and mould and hospitalization rates for acute respiratory infection among children under the age of two. More precisely, every unit increase in the index was associated with a 15% increase in the odds of being hospitalized with an acute respiratory infection (Ingham et al., 2019). Contrary to these findings, Sharpe et al. (2019) did not observe a clear association between the probability of EP at the postal code level in England and 3-year admission rates for chronic obstructive pulmonary disease (COPD) and asthma.

Another body of evidence on the relationship between energy poverty and hospital admissions comes from research that has examined the impact of certain housing interventions on health outcomes (Fyfe et al., 2020; Howden-Chapman et al., 2007b; O'Sullivan et al., 2016; Poortinga et al., 2018; Rodgers et al., 2018; Sharpe et al., 2019). Although these interventions do not always target energy-poor populations, they connect changes in energy efficiency, one of the main drivers of EP, to health outcomes. In New Zealand, despite an increase in hospital admission rates in both intervention and control groups, recipients of insulation retrofits from the Warm-up New Zealand: Heat Smart programme had 9.26 fewer hospitalization per 1000 than those who did not receive the intervention; this statistically significant effect was especially stronger for cardiovascular and respiratory diseases (Fyfe et al., 2020). For the same program, O'Sullivan et al. (2016) reported that the hospitalization rate for children under 15 among intervention households was 6% less than the rate for those who did not receive the intervention. Although this overall effect on hospital admissions was not statistically significant, more pronounced and significant impacts were observed for children coming from rental and low-income households (O'Sullivan et al., 2016). The New Zealand Housing, Insulation and Health study, which provided insulation and draught proofing to selected low-income households where at least one member experienced respiratory problems, was shown to lead to improved health outcomes (Howden-Chapman et al., 2007b). Households who benefited from the intervention were less likely to experience respiratory symptoms such as wheezing, reported fewer colds and flu, better health and fewer visits to the doctor; and had 47% reduced, but non-significant, odds of being admitted for respiratory problems than those who did not receive the intervention (Howden-Chapman et al., 2007b).

Other studies report mixed evidence, where interventions are associated with increased hospital admissions. For instance, an ecological study in England showed that areas that received more boiler and glazing upgrades had slightly lower 3-year hospitalization rates for asthma and COPD. However, the same study also reported that a one percent increase in dwellings with loft insulation was significantly associated with heightened admission rates for cardiovascular diseases, COPD and asthma by 0.4%, 0.2% and 0.4%, respectively (Sharpe et al., 2019). In Wales, a longitudinal panel study reported that, across all age groups, the greatest reductions in admissions for respiratory and cardiovascular diseases were observed for households who received electrical system (40%) and wall insulation (26%) improvements (Rodgers et al., 2018). Yet, households who moved into a home that already met heating system standards had a 21% and 31% statistically significant increase in cardiovascular and respiratory disease-related admissions (Rodgers et al., 2018). These conflicting findings can partially be explained by occupants' behaviour and practices, such as whether they continue to ration their energy consumption after receiving the upgrades (Sharpe et al., 2019). Similarly, rising energy prices and poor economic situation can overshadow the potential benefits associated with housing interventions, especially among the lowest-income household (Sharpe et al., 2019). Differences in the quality of interventions can also impact the results while some housing retrofits can reduce ventilation and lead to poor indoor air quality and increased humidity, thus adversely affecting health (Jessel et al., 2019; Sharpe et al., 2019).

2.5.4 Review of control variables in studies on EP and health

Several studies have investigated the role of EP in explaining various cardiorespiratory outcomes (see Table 2). In doing so, the vast majority of these have utilized self-reported EP or indoor mould/dampness assessment measures as their exposure variable. Models are most often adjusted for other variables that may affect one's susceptibility to EP and/or to health outcomes.

Table 2. Studies examining the impacts of EP on cardiorespiratory health

Author	**Study design**	**Exposure**	**Cardiovascular or respiratory outcome**	**Control variables**
Hagmolen of ten Have et al., 2007	Cross-sectional	Caregiver-reported mould and dampness	Asthma symptoms, lung functions, and severity of airway hyperresponsiveness	Age, gender, family history of asthma, history of inhalant allergy, history of rhinitis, parental education, smoking status, pet ownership, season, controller medication, presence of an inhalant allergy, and healthcare center
Liddel & Morris, 2010	Review	Self-reported EP: ability to keep the home warm during the previous winter	Caregiver-reported respiratory symptoms	Age, gender, socioeconomic status, ethnicity and caregiver's education, health status and work status
Webb et al., 2013	Longitudinal	Expenditure-based: annual fuel bills are more than 10% of net annual household income	Respiratory functions used to detect COPD	Age, gender, smoking history, social class, height, childhood respiratory health and housing tenure
Sharpe et al., 2015	Cross-sectional	Presence of visible mould and presence of mouldy/musty odour	Self-reported current asthma (seeing a doctor or taking medication for asthma problems)	Age, sex, current smoking, income body mass index, presence of a pet, date of tenancy and date upgrades were completed
Atsalis et al.,2016	Longitudinal	Self-reported EP: percentage of	Number of cardiovascular and respiratory episodes occurring	Time, meteorological parameters (total

Author	**Study design**	**Exposure**	**Cardiovascular or respiratory outcome**	**Control variables**
		households that are unable to keep their home adequately warm	in a month in specialized hospitals	number of monthly heating and cooling degree days), and months with special event
Caillaud et al., 2018	Systematic review	Self-reported visible mould, mould odour or humidity Direct measurements of mould exposure	Doctor-diagnosed asthma, self-reported (caregiver) asthma, incidents of respiratory symptoms, respiratory admissions, etc.	Not reported
Shorter et al., 2018	Incident case-control	Indoor dampness and mould factors assessment reported by a researcher, inspector and caregiver	New-onset of wheezing	Age and gender
Ingham et al., 2019	Prospective, unmatched case-control	Inspector reported dampness and mould Damp-Mould Index	Acute respiratory infection-related hospitalization	Housing tenure, household crowding, season, age, gender, ethnicity, and social deprivation
Sharpe et al., 2019	Cross-sectional ecological study	Probability of fuel poverty Energy efficiency retrofits	Emergency hospital admission for cardiovascular disease, COPD, and asthma	Deprivation, urban-rural, air pollution, weather trends, income, employment, housing type, and housing tenure

Author	Study design	Exposure	Cardiovascular or respiratory outcome	Control variables
Carrere et al., 2020	Cross-sectional	Self-reported EP: 1) Ability to afford to keep the dwelling heated at an appropriate temperature during the winter months 2) Arrears on utility bills 3) Presence of leaks, dampness on the walls, floors, ceiling or in the foundation, or rotten floors, windows or doorframes	Self-reported chronic bronchitis and asthma	Age, sex, place of birth, household composition, education level, employment status, ability to face surprise expenses of 750 euros or more, and tenure status
Oliveras et al., 2020	Cross-sectional	Self-reported EP: A household that cannot afford to maintain the dwelling at an adequate temperature during cold and/or warm months	Self-reported myocardial infarction and/or stroke, asthma and chronic bronchitis	Sex, country of birth (high-income vs low and middle-income) and social class
Mohan, 2021	Longitudinal	Self-reported EP: Does the household keep the home adequately warm?	Caregiver-reported respiratory disease and wheezing	Gender, survey wave, maternal education, employment, home ownership, household income, urban location, material deprivation, smoking, and time
Oliveras et al., 2021	Cross-sectional	Self-reported: 1) Can the household afford to keep the home at an adequate	Asthma	Social class

Author	Study design	Exposure	Cardiovascular or respiratory outcome	Control variables
		temperature during the cold/warm months? 2) Dwelling with leak/damp (self-reported) 3) Dwelling without means/ability to heat 4) Dwelling without means/ability to cool		

Thus, to guide my analyses, and particularly the selection of variables that may confound the relationship between EP and hospitalization for cardiovascular and respiratory diseases, this section will review the control factors that were utilized in other studies.

Age and gender were the most commonly controlled variables. Indeed, as previously mentioned, young children and older adults tend to spend more time at home, have poor thermoregulation, and are more sensitive to cold and heat stress (Howden-Chapman et al., 2007a; Jessel et al., 2019; Marmot Review Team, 2011; O'Sullivan, 2019). Thus, they are concurrently more likely to experience EP because their energy demands are above average and their fragile health makes them physiologically more vulnerable to the adverse effects of EP (Awaworyi Churchill & Smyth, 2021; Jessel et al., 2019; Marmot Review Team, 2011; O'Sullivan, 2019). In regard to sex and gender, women tend to be responsible for domestic tasks and caregiving and are often disadvantaged by the labour market (Robinson, 2019). As a result, households led by single mothers are particularly vulnerable to EP (Jessel et al., 2019). Because of their greater longevity, females also represent a greater portion of the older population (Robinson, 2019), which is vulnerable to EP and its health effect. Furthermore, because of biological differences and sociocultural factors, clinical and epidemiological research has shown that there are gender and sex differences across various cardiovascular and respiratory diseases (Gao et al., 2019; LoMauro & Aliverti, 2021; Pinkerton et al., 2015).

While the incidence of cardiovascular diseases is higher in men, women have poorer prognoses following sudden cardiovascular complications and higher mortality (Gao et al., 2019). There is also evidence of differences in the development and progression of abdominal aortic aneurysms and COPD among men and women, as well as gender differences in the types and or etiology of stroke and heart failures (Gao et al., 2019; LoMauro & Aliverti, 2021; Pinkerton et al., 2015). For instance, men are more at risk of having lacunar strokes while women experience more cardioembolic strokes (Gao et al., 2019). Additionally, some respiratory conditions, such as pulmonary hypertension and pregnancy-associated asthma exacerbation, occur exclusively or at a higher prevalence in females (Pinkerton et al., 2015).

Socioeconomic conditions can influence the resources available to afford energy services (Jessel et al., 2019b) and protect one's health. Therefore, a good number of studies adjust their analyses for some indicators of socioeconomic status, such as employment status, income, education level, social class, deprivation level, demographic and the ability to face unexpected expenses. Housing conditions, such as tenure and dwelling type, are also considered in many studies. As mentioned earlier, research has shown renters to have a higher vulnerability to EP than homeowners (Jessel et al., 2019b; Marmot Review Team, 2011; K. C. O'Sullivan, 2019). Meanwhile, the inclusion of dwelling type as a control variable can be explained by differences in energy efficiency across various housing types. For instance, mobile homes and trailers often are not properly insulated or weatherized, thus making their occupants more likely to experience EP (Jessel et al., 2019b). Single-family homes also tend to be less energy efficient than multi-family housing, and they pose greater financial responsibility since energy costs are not shared among various households (Jessel et al., 2019b; Kwon & Jang, 2017). Some studies also account for health-related variables such as smoking, health status, childhood or family health history, and body mass index as they may represent risk factors for some cardiovascular and respiratory diseases and confound the association between EP and the health outcome examined. Also, as mentioned in a previous section, people with health conditions that are sensitive to thermal discomfort (i.e. very high or low temperatures) such as COPD, sickle cell disease, Parkinson's disease or those who require electrical equipment for their treatment, will have higher energy needs and be more strongly affected by the adverse effect of EP (Jessel et al., 2019b; K. C. O'Sullivan, 2019).

A few studies also adjusted for meteorological variables (e.g., season, air pollution, heating and cooling degree days, etc.) that can affect both energy needs and severity of health impact. Another less common adjustment variable is rurality. The addition of the former variables is supported by research from Canada and elsewhere that has shown rural households to be more likely to experience EP than those in urban centers (CUSP, 2019b; Marmot Review Team, 2011). This is likely due to the fact that rural homes tend to be larger, older and less energy-efficient, and thus require more energy (CUSP, 2019b; Marmot Review Team, 2011). Also, rural households may face higher utility prices (CUSP, 2019b).

To follow this literature review, the next chapter discusses the conceptualization of EP.

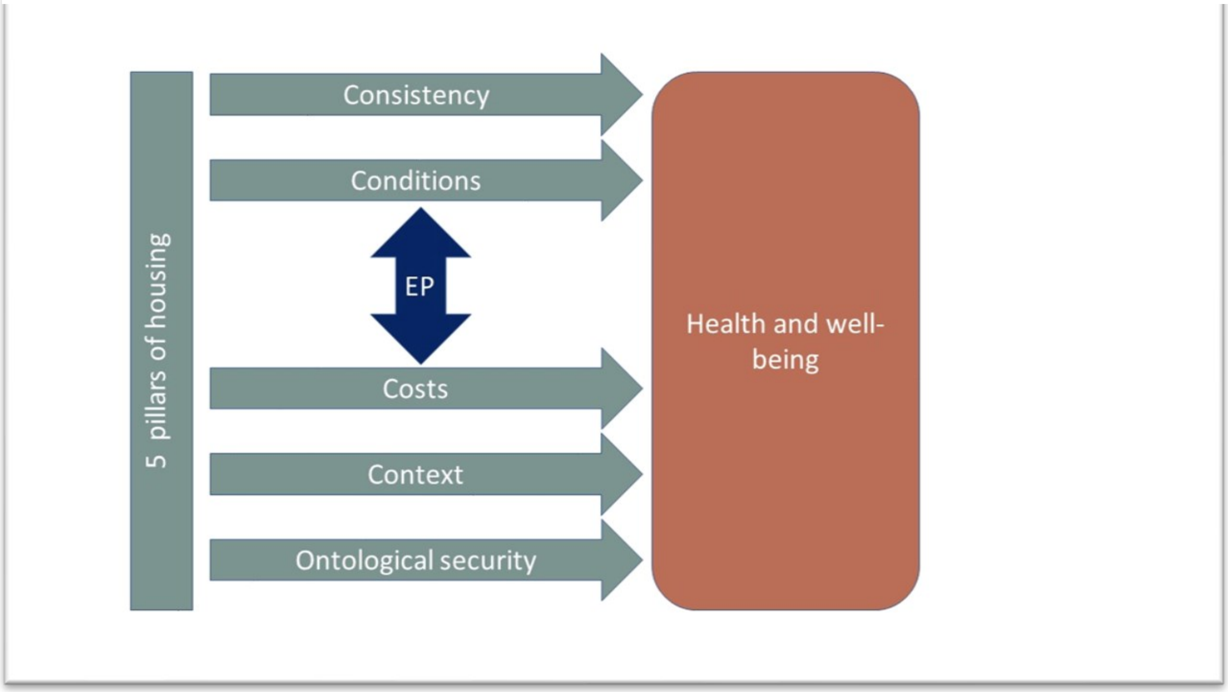
Chapter 3: Conceptual framework

This thesis is mainly situated within the social determinants of health (SDH) framework, specifically the housing and health pathway. The WHO defines the SDH as the "conditions in which people are born, grow, work, live, and age, and the wider set of forces and systems shaping the conditions of daily life" (WHO, 2021). Thus, the SDH are conditions beyond individual risk factors that can "get under the skin" (Mikkonen & Raphael, 2010, p.8) to positively or negatively influence health and thus contribute to the generation of health inequalities (Mikkonen & Raphael, 2010; WHO, 2021). In Canada, housing is identified as a SDH where poor quality, unaffordable and unsafe housing can lead to adverse physical and mental health outcomes (Mikkonen & Raphael, 2010). The relationship between housing and health can be summarized into the five pillars of healthy housing, namely cost, condition, consistency, context, and ontological security (Rosenberg et al., 2021; Swope & Hernández, 2019; WHO, 2018).

Housing costs refer to the affordability of shelter-related costs. Since shelter costs represent one of the largest household expenses, unaffordable housing reduces the disposable income that can be spent on other health-supportive resources such as access to healthy food, child development resources, and medical care and medications (D'Alessandro & Appolloni, 2020; Mikkonen & Raphael, 2010; Swope & Hernández, 2019). High housing costs can also encourage overcrowding as a coping strategy, which promotes poor mental health, hostility, the transmission of infectious diseases such as tuberculosis, and other adverse effects (D'Alessandro & Appolloni, 2020; Mikkonen & Raphael, 2010; Swope & Hernández, 2019). The structural integrity and indoor condition of a dwelling such as the presence of chemical pollutants, loose stairs, water leaks, and pest infestations can strongly influence the health of its inhabitants (D'Alessandro & Appolloni, 2020; Mikkonen & Raphael, 2010; Swope & Hernández, 2019). Thus, poor housing quality is associated with a wide range of adverse health outcomes such as injuries, lead poisoning, asthma and various other problems (D'Alessandro & Appolloni, 2020; Mikkonen & Raphael, 2010; Swope & Hernández, 2019). According to D'Alessandro & Appolloni (2020), housing consistency refers to a household's "capacity to willingly remain in their homes free from harassment or dispossession" (p.19). Hence, the lack of stable housing can lead to homelessness and is associated with poor access to healthcare services as well as poor physical and mental health outcomes (D'Alessandro & Appolloni, 2020; Mikkonen & Raphael, 2010). The household context refers to the characteristics of the surrounding area (D'Alessandro & Appolloni, 2020; Swope & Hernández, 2019). For instance, the presence of health-supportive resources in the neighbourhood such as greenspace, social connections and solidarity, groceries with affordable and healthy food options, and exercise facilities can improve health (D'Alessandro & Appolloni, 2020; Swope & Hernández, 2019). In turn, the absence of those positive factors or the presence of negative factors such as violence and crime, highways, and waste processing facilities in low-income areas can deteriorate health (D'Alessandro & Appolloni, 2020; Swope & Hernández, 2019). Lastly, ontological security denotes the sense of well-being associated with having a sense of 'home' (Dunn, 2000; Rosenberg et al., 2021). This is important because the home is a place where one forms their identity and can freely express themselves (Dunn, 2000; Mikkonen & Raphael, 2010; Rosenberg et al., 2021). When this sense of home and safety is lacking people are likely to experience mental health problems and difficulties with social relationships (Dunn, 2000; Rosenberg et al., 2021).

Within the housing and health pathway of the SDH framework, EP can negatively influence both housing costs and conditions as illustrated in Figure 2. In fact, the utilities and energy efficiency of a dwelling affect its operating costs while inadequate access to energy services, such as heating, cooling and lighting, affect indoor temperatures, the presence of dampness and mould, and injury risks (Swope & Hernández, 2019). Supporting this idea is an American qualitative study by Hernández (2016) that distinguished economic energy insecurity from physical energy insecurity and demonstrated how their lived experience can influence health and wellbeing. The former type of energy insecurity is caused by financial difficulties related to the cost of energy compared to income and other expenses such as rent, whereas the latter is associated with the physical conditions of the dwelling (Hernández, 2016). In the study, participants experiencing physical energy insecurity described their asthma or that of another household member to have worsened, especially during wintertime (Hernández, 2016). Additionally, people facing economic or physical energy insecurity experienced chronic stress with many also needing professional mental healthcare (Hernández, 2016). For instance, parents have reported feeling judged or worried about losing custody of their children because they were unable to "keep the lights on" (Hernández, 2016, p.7). Hence, my thesis aims to investigate whether EP is another housing-related determinant that influences the cardiorespiratory health of Canadians.

Figure 2. EP and the housing and health model, adapted from Swope & Hernández (2019)



Aside from the SDH approach, two other frameworks can be used to guide the conceptualization of EP. These are the capability and vulnerability approaches which have been used to understand the lived experience of energy-poor households. As indicated by its name, the capability approach focuses on what people can do and be, namely their capabilities (Robeyns, 2005). From this point of view, EP is understood as the inability to realize certain capabilities, e.g., having dignity, having meaningful relationships and participating in society, due to inadequate access to energy services (Day et al., 2016; Middlemiss et al., 2019). Although I will not be employing the capability approach to analyze how and through which mechanisms and pathways EP affects people's health, my research question can also be viewed through a capability lens as a way to understand whether EP negatively affects the capability of Canadian adults to be healthy.

The vulnerability framework suggests that the lived experience of the energy poor is much more complex and diverse than the triad of low-income, energy inefficiency, and high energy prices (Middlemiss & Gillard, 2015). Indeed, EP is a dynamic phenomenon that people can enter and exit depending on changes in their environment (e.g., political, social, economic), circumstances (e.g., housing, income), and energy needs (Bouzarovski et al., 2017). Depending on this set of conditions, households will have different degrees of vulnerability to EP that may fluctuate over time depending on their exposure, sensitivity, and capacity to adapt to EP (Middlemiss & Gillard, 2015). In particular, Middlemiss & Gillard (2015) have identified housing quality, energy costs and supply, the stability of household income, tenancy relations, social relations, and poor health as the six key challenges to energy vulnerability. Variation in any of these domains can either heighten a household's vulnerability to EP or empower them to exit this situation. Hence, in analyzing the relationship between EP and cardiovascular and respiratory outcomes, I will attempt to account as best as possible for these vulnerabilities in the selection of my control variables.

Now that the conceptualization of EP has been explored, the next chapter offers an in-depth presentation of the methods, data and analysis used to conduct my thesis.

Chapter 4: Methodology

My thesis is embedded within a more extensive study funded by the Canadian Institutes of Health Research that aims to investigate the spatial distribution of Energy Poverty in Canada (EPIC project) at small geographies and to provide epidemiological evidence on the health impacts of EP in Canada. For my thesis, I conducted a retrospective longitudinal study using linked data from the Canadian Census and Health and Environment Cohorts (CanCHECs) and the Discharge Abstract Database (DAD) to examine the association between EP and cardiorespiratory hospitalizations in Canadian adults aged 40 and older. The next sections present a detailed description of the data utilized, the development of the linked dataset and the statistical modelling.

4.1 Description of the data

The CanCHECs link socioeconomic and demographic data obtained from the long-form census or the 2011 National Household Survey with administrative health data (Tjepkema et al., 2019). CanCHECs are thus national cohorts that follow non-institutionalized respondents of the census or the National Household Survey for various health outcomes, including hospitalization (Statistics Canada, 2019; Tjepkema et al., 2019). Information on hospital admissions for all provinces and territories, except Quebec, is provided by the Canadian Institute for Health Information (CIHI) DAD, which holds approximately 75% of all hospital discharges in Canada (CIHI, 2012). The DAD collects demographic, administrative, intervention and diagnostic information associated with each acute hospital separation (i.e. when a patient is discharged, signed out or transferred to another institution and dies) that occurs within a fiscal year (CIHI, 2012). Over time, the DAD has also collected, in some provinces, information pertaining to day surgeries, chronic care, rehabilitation and other types of care (CIHI, 2012). Therefore, an individual can have multiple records representing different hospitalization and day surgery events. For all abstracts recorded since 2004-2005, diseases are coded according to an enhanced version of the 10th revision of the International Statistical Classification of Diseases and Related Health Conditions, namely the ICD-10-CA (CIHI, 2012).

There are currently five CanCHEC cohorts available (1991, 1996, 2001, 2006 and 2011), however, only the last two are linked to the DAD (CIHI, 2012; Statistics Canada, 2019). Unlike the 2006 census, which was compulsory, the completion of the 2011 NHS was voluntary; this introduced some limitations such as non-response bias, where some individuals are less likely to respond than others. For instance, people who earned more than $500,000 and youths aged 20 to 24 were underrepresented in the NHS compared to the 2006 census, whereas women and those who were married were overrepresented (Nield & Nordstrom, 2016). Furthermore, the response rate of the 2011 NHS (68.5% unweighted, 77.2% weighted) was significantly lower than the 2006 census long-form (93.8%) (Smith, 2015). For these reasons, I used the 2006 CanCHEC cohort.

CanCHECs are created in Statistics Canada's Social Data Linkage Environment (SDLE). The SDLE is a highly secure environment comprised of a Derived Record Depository (DRD) that utilizes immigration, tax, birth and death files to create a list of unique individuals that are assigned an anonymous SDLE identifier (Government of Canada, 2015; Tjepkema et al., 2019; Trudeau, 2017). Eligible respondents from the 2006 census are then probabilistically linked to the DRD, while those from the DAD are deterministically linked to the repository (Tjepkema et al., 2019). Probabilistic linkage employs non-unique identifiers such as name, sex, date of birth and postal code to compare records and estimate the probability that they belong to the same individual, whereas deterministic linkage matches records based on their shared common unique identifiers such as the health insurance number (Government of Canada, 2015; SDLE production section, 2018). As a result, the 2006 CanCHEC cohort comprised 5.9 million individuals (Statistics Canada, 2019; Tjepkema et al., 2019), which represents an overall linkage rate of 90.8% (Health Analysis Division, 2019). The linkage rate of the 2006 CanCHEC cohort to the DRD varies by geographic and sociodemographic characteristics such as age, marital status, place of residence and Indigenous status. For this reason, population weights based on previous censuses are applied to ensure that the cohort is representative of the population (Tjepkema et al., 2019). The final weighted 2006 CanCHEC cohort thus represents 32 million Canadians (Statistics Canada, 2019; Tjepkema et al., 2019).

For the DAD, 94.1% of the 2000 to 2017 records were linked to the DRD (Health Analysis Division, 2019). Similarly, other datasets such as the T1 personal Master File, an "annual file derived from tax returns [that] contains name, date of birth, sex and postal code" (Rotermann et al., 2015, p.11) are linked to the DRD in order to track the annual postal code history of census respondents aged 15 and older who accepted to have their information linked to their tax records (Tjepkema et al., 2019). Finally, given the SDLE identifier, linkage keys can be used to link the DAD to the 2006 CanCHEC cohort and its associated census data.

The 2006 CanCHEC-DAD linked dataset is suitable for my research question given that it has a large sample size and provides both the socioeconomic information required to calculate an expenditure-based measure of EP, as well as information on respondents' hospital admissions. Additionally, this dataset has been collected and validated by Statistics Canada. Still, despite these advantages, some limitations should be highlighted. First, this dataset represents a healthier population because institutionalized individuals (e.g., people in hospitals, nursing homes, prisons, etc.) are excluded (Tjepkema et al., 2019). Thus, associations between EP and cardiorespiratory outcomes could be underestimated. However, to compensate for this, I will be looking at the differences between non-institutionalized individuals living with pre-existing conditions and those without. Moreover, 22 First Nations reserves were incompletely enumerated (Statistics Canada, 2008) and 4.3% of eligible respondents are missing from the 2006 census (Health Analysis Division, 2019). These individuals were likely to have low-income and be mobile, young, homeless and Indigenous, which makes many of them particularly vulnerable to EP (Health Analysis Division, 2019).

4.2 Target population and follow-up time

As previously stated, studies examining the effect of EP on adults have explored both cardiovascular and respiratory outcomes, whereas those focused on children have largely focused on respiratory outcomes. This is because age is an important risk factor for CVD, such that, in Canada, the prevalence of heart disease for both sexes in 2015/2016 was 0.65 (0.52-0.77)[1] for those aged 20-39, 2.81 (CI 2.52 to 3.09) for those between 40 to 59, 11.49 (10.91- 12.05) for the 60 to 79 years of age and 23.49 (21.84 to 25.15) for the population that is in the 80 years and older (Dai et al., 2021). Cases of CVD in children and younger people are more likely due to genetic and lifestyle behaviours than EP. Thus, I restricted my analyses to the adult population aged 40 and older.

This population was followed for their hospital records over 10 years ranging from the fiscal years 2006/2007 to 2016/2017. This decision was motivated by multiple reasons. Firstly,

[1] The numbers in parentheses represent 95% confidence intervals (CI)

given the lack of information on smoking status, health history, pollution and meteorological variables, which are all important control factors, it is impossible to assess the short-term acute effect of EP on health. Thus, I examined the association between EP and cardiorespiratory hospitalization over a longer period. Secondly, although the DAD records linked to the 2006 CanCHEC are available from 2000/2001 to 2016/2017, the adoption of the ICD-10 classification system across all provinces and territories was only completed in 2004/2005. Hence, using earlier records would have required the use of different disease classification systems and complicated the analyses as well as predated the exposure to EP. Lastly, since the measurement of EP is based on data from the census that was conducted on May 16, 2006, I used the year 2006 as the baseline and follow records from that point onwards. There may, however, be a small gap where some of the 2006/2007 hospital discharges occurred before the census day given that the DAD fiscal years go from April 1 to March 31. The chosen timeframe is also similar to the other studies that have examined the association between EP and health outcomes within a span of nine to seventeen years (Atsalis et al., 2016; Awaworyi Churchil & Smyth, 2021; Kahouli, 2020).

4.3 Variables of interest and covariates

4.3.1 Primary predictor: energy poverty status

Given the content of the census and because housing costs affect the disposable income that can be spent on energy (Moore, 2012), an expenditure-based measure of EP was computed after considering other housing costs. Respondents of the long-form census are asked to report their annual payments for energy expenses (i.e. electricity, oil, coal, wood, gas, and other fuels) as well as their annual earnings or to authorize Statistics Canada to access their income tax files. They also report various annual or monthly housing costs such as rent, mortgage, condominium fees and property taxes. Thus, to construct my independent variable, I constructed an energy cost variable by combining the annual electricity and fuel variables. However, observations that had 1) electricity or fuel payment included in their rents or not applicable; 2) energy costs with a value of 0; and 3) energy costs greater than household after-tax income were marked as missing. I then generated a yearly housing cost variable. To do this, condominium fees were recoded as 0 if marked as non-applicable, and mortgage and property taxes that were marked as non-applicable were recoded as missing value or as 0 if the household did not own the house, which then eliminates these costs. Similarly, non-applicable rent was also recoded as missing or 0 if the household did not rent their dwelling. After this, monthly condominium fees, mortgage payments and rent variables were multiplied by 12 to obtain annual equivalence and added to the annual property taxes. This new housing cost variable was then subtracted from the household after-tax income to generate the household income after-tax and after-housing. Here, observations were marked as missing if the household after-tax income was at or below 0. Finally, the ratio of energy cost to household income after-tax and after-housing was calculated and found to have a median value of 0.0482954.

EP, the primary predictor, was computed as per the 2M measure and coded as a binary variable where 1 signifies that a household spends more than twice the national median share of energy cost to household income after-tax and after housing, and 0 when it is not. This indicator was selected to provide consistency with other Canadian studies (CUSP, 2019a, 2019b; Rezaei, 2017; Riva et al., 2021). The 10% cut-off was also computed and coded as a binary variable for robustness checks. The two EP indicators are:

1) EP2M = annual energy cost / (annual after-tax income – annual housing cost) > 2 x (0.0482954) = 0.0965908
2) EP10 = annual energy cost / (annual after-tax income – annual housing cost) > 0.10

4.3.2 Outcomes of interest: hospitalizations for cardiovascular, respiratory, and cardiovascular or respiratory diseases

According to Solon et al. (1967), an episode of care refers to “one or more medical services received by an individual during a period of relatively continuous contact with one or more providers of service, in relation to a particular medical problem or situation” (p.404). For this reason, the possibility of patients having multiple admissions for the same health issue was considered in defining a hospitalization event. For instance, following the initial admission to a hospital, a patient might be 1) temporarily moved from one health facility to another to get a procedure or testing that is not provided in the first facility, 2) permanently transferred from one facility to another, and 3) readmitted within 24 hours of discharge (Osman et al., 2015). Therefore, transfers and 24-hour readmissions were treated as a single hospitalization event.

Using this criterion, the three main outcomes of interest were defined as at least one hospitalization for cardiovascular diseases, respiratory diseases, and cardiovascular or respiratory diseases during a 10 year period. These outcomes were computed as binary variables where 1 indicates that an individual has had one or more hospital admission and 0 when they have not.

The three secondary outcomes explored were nominal variables representing the total number of cardiovascular, respiratory, and cardiovascular or respiratory hospital admissions experienced by an individual during the same period. For these three outcomes, the response categories were either 0, 1 or 2 and more. As per the ICD-10, hospitalizations related to cardiovascular problems were identified as those whose most responsible cause was coded as I00-I99, and admission related to respiratory conditions were between J00-J99 (Wang & Morrison, 2006).

4.3.3 Confounding variables

As demonstrated in earlier sections, the relationship between EP and cardiorespiratory health is complex since numerous factors can affect one's vulnerability to EP and the extent to which their health is impacted by it. For example, household characteristic such as members' age and health status can affect their energy needs and the extent to which their health is adversely impacted by EP. Some racialized communities and Indigenous groups, who are already known to experience poorer health outcomes than the general Canadian population (Public Health Agency of Canada, 2018), may simultaneously face higher vulnerability to EP. Various housing conditions can promote energy-inefficient dwellings, thus increasing energy consumption and costs (Jessel et al., 2019b), and directly influencing health. Socioeconomic conditions can influence the resources available to be spent on energy services and health. Furthermore, energy prices, types of housing, health outcomes, and access to health services are all elements that vary by location.

Given these elements and based on the data available in the 2006 census, I adjusted my analyses for the following variables: age, sex, chronic illness or disability status, visible minority and Indigenous status, marital status, household structure, repairs needed, year of construction of the dwelling, education level, province and statistical area classification (SAC). This later variable "groups census subdivisions (CSDs) according to whether they are a component of a census metropolitan area (CMA), a census agglomeration (CA), or census metropolitan influenced zone (MIZ)" (Statistics Canada, 2022). The MIZ is used to classify the influence (i.e. strong, moderate, weak, no influence) that a CMA or CA has on a CSD that is outside its perimeter (Statistics Canada, 2017a). For instance, strong MIZ are areas where 30% of the employed population goes to work in the CMA or CA, whereas for the weak MIZ the percentage is anywhere from 1 to 4% (Statistics Canada, 2017a). Household size and rurality were also considered as potential confounding variables. To avoid collinearity between household size and household structure and because the latter variable provides more information on the type of occupants, household size was omitted from the analyses. Urban vs rural location was excluded because associations with this variable were not significant in all models and the SAC provided similar information as regions further from the metropolitan area are more likely to be rural than urban and vice versa. Since household income is already accounted for in the measurement of EP, I did not include it as a separate confounder. Coding for the control variables, predictors, outcomes and other relevant variables that were used to create the main variables of interest is presented in Table 3.

4.4 CanCHEC-DAD: the case of Quebec and the territories

As previously mentioned, discharges from Quebec are not included in the DAD. Instead, this information is "appended to the DAD to create the Hospital Morbidity Database" (CIHI, n.d.), which is a similar national database that collects information on acute hospital separations. While it would still be possible to include data from Quebec, since residents from the province responded to the 2006 census that forms the CanCHEC cohort and they could have been hospitalized elsewhere, this was not done because the province comprised less than 1% of the sample. The territories were also excluded because the data available for these regions in national datasets are often unreliable (Rezaie, 2017) and they also represented only a small portion of the sample.

Table 3. Reference guide of predictors, outcomes, confounders, and other variables of interest utilized in the data development and analysis

Type of variable	**Variable name**	**Description**	**Categorization**
Confounder	age	Age at baseline	1: 40-54 2: 55-64 3: 65-74 4: 75+
	built	Period of construction of the house	1: 1960 or before 2: 1961–1980 3. 1981–2006
	disabfl	Indicates whether a person has difficulties with daily activities and/ or has to reduce the amount of activity done at home, work, school, or other places due to a physical or mental problem	0: No 1: Yes
	dtype	Indicates the type of dwelling	1: Single detached 2: Semi-detached, double, row, duplex, other single-attached 3: Apartment 4: Mobile home
	dvismin	Visible minority population to which the respondent belongs	0: Not a visible minority 1: Visible minority 2: Indigenous
	hcdd	Education: Highest certificate, diploma, or degree	1: Less than high school 2: High school or equivalent 3: Post-secondary
	hhstruct	Household structure	1: Person living alone 2: Couple with kids 3: Couple without kids 4: Lone-parent 5: Other

Type of variable	Variable name	Description	Categorization
	marsth	Historical marital status	1: Married or living in common-law 2: Single or never married 3: Separated, widowed, or divorced
	nunits	Number of individuals in the household	1:1 2:2 3:3 4:4 5: 5 or more
	pr	Province or territory of residence at baseline	1: Ontario 2: Quebec 3: Atlantic Provinces 4: Prairies 5: British Columbia
	rpair	Condition of the dwelling (i.e. whether it needs repairs)	1: No repairs are needed 2: Minor repairs needed 3: Major repairs needed
	ruindfg	Rural-urban classification	0: Urban 1: Rural
	sac_type	Indicates the type of SAC	1: CMA 2: CA 3: Strong or Moderate MIZ 4: Weak MIZ, No influence MIZ or Territories
	sex	gender of the respondent	0: Male 1: Female
	tenur	Tenure status of the dwelling	0: Rented 1: Owned by a household member

Type of variable	Variable name	Description	Categorization
Other	elect	Annual payment for electricity	$0 - $6000
	cdwel	Types of collective dwelling	0: Not a collective dwelling 1: A collective dwelling
	fcond	Monthly condominium fees	$1- $1000
	yl_fcond	Annual condominium fees	$0- $12000
	fuel	Annual payment for fuel(s)	$0 - $4000
	hhinc_at	Household income after-tax	2 – 1.85E+07
	hhinc_at_ah	Household income after-tax and after-housing cost	1 – 1.85E+07
	loinca	Indicates if, after-tax, an individual is as member of a low-income economic family[2] or a low-income person that is not in an economic family	0: No, not low-income 1: Yes, low-income
	mortg	Monthly mortgage payments	$0 - $6000
	yl_mortg	Annual mortgage	$0 - $72000
	nhs	Marginal dwelling indicator (i.e. housing that is not suitable for year-round occupancy)	0: Dwelling is suitable 1: Dwelling is marginal/ not suitable
	rent	Monthly rent	$0 - $4500
	yl_rent	Annual rent	$0 - $54000
	taxes	Annual property taxes	$0 - $15000
	days_readmission	Days between readmission of a patient	From 0 and up
	e_cost	Annual electricity cost	$1 - $10000
	h_cost	Annual housing cost	$0 -$ 99000

[2] An economic family comprises people who live in the same house and "who are related to each other by blood, marriage, common-law union, adoption or a foster relationship" (Statistics Canada, 2017b)

Type of variable	Variable name	Description	Categorization
Outcome	mhospc	Indicates whether an individual has a minimum of 1 hospitalization for a cardiovascular disease	0: No 1: Yes, 1 or more
	mhospr	Indicates whether an individual has a minimum of 1 hospitalization for a respiratory disease	0: No 1: Yes, 1 or more
	mhospcr	Indicates whether an individual has a minimum of 1 hospitalization for a cardiovascular or respiratory disease	0: No 1: Yes, 1 or more
	nhospc	Indicates the number of times an individual was hospitalized for a cardiovascular disease	0: 0 1: 1 2: 2 or more
	nhospr	Indicates the number of times an individual was hospitalized for a respiratory disease	0: 0 1: 1 2: 2 or more
	nhospcr	Indicates the number of times an individual was hospitalized for a cardiovascular or respiratory disease	0: 0 1: 1 2: 2 or more
Predictor	EP10	Indicates whether an individual is in EP as defined by the 10% threshold	0: Not in EP 1: in EP
	EP2M	Indicates whether an individual is in EP as defined by the 2M measure	0: Not in EP 1: in EP

4.5 Data development

4.5.1 Step 1: Building a combined health and census dataset

The CanCHEC dataset is not an integrated dataset. Rather, the DAD and census files that comprise the 2006 CanCHEC are provided to researchers as separated entities. Thus, the first step in conducting my analyses was to combine the health and census data into a single dataset. I began this task by familiarizing myself with the DAD and its variables. Since there was no available codebook describing the hundreds of variables present in the DAD, I had to refer to the DAD Abstracting Manual, which "provides information on how to complete the DAD abstract, including detailed data element descriptions, collection instructions and notes for data users" (CIHI, n.d.). From this, I chose 14 initial variables that were relevant to my project. I also, later on, found a reference guide made by the New Brunswick Institute for Research, Data and Training (Kalu & Zikuan, 2017) that I used to compare the codes I had gathered. Once my preliminary variable selection was made, I merged all the annual DAD data files ranging from 2006 to 2016 into a single health dataset. Likewise, for the census file, I selected relevant demographic, socioeconomic, and housing variables. After this, the health dataset was merged with a first linking key that connects the DAD to the 2006 CanCHEC; a second linking key that provides the correspondence between CanCHEC, the census, the Canadian Vital Statistics Death, and the Canadian Mortality Database; and finally with the census file to obtain a combined DAD-census dataset with 12.2 million observations. Since the DAD is event-based, the combined census-DAD dataset was presented in a long format where entries with different DAD identifiers may share the same unique SDLE identifier. It should also be noted that, although demographic information such as birthdate, gender code and age units could also be drawn from the DAD, they were only selected from the census because, once merged, the information would be missing for individuals who were not hospitalized but are present in the census. Moreover, using demographic information from the census ensures that information is collected at baseline for all entries.

4.5.2 Step 2: Data cleaning and creation of variables of interest

Prior to running the analyses, the DAD-census dataset was reorganized and cleaned. Restrictions and modifications were first applied to some selected DAD variables. In fact, to respect the chosen timeframe for the analyses (2006/2007- 2016/2017), I began by removing observations that were collected during fiscal years before 2006 and those with unspecified fiscal years. Then, observations were restricted according to their admission category. Records classified as newborns, cadavers and stillbirths were deleted since they are dead or have not yet lived in a home outside of the hospital environment where exposure to EP can be measured. Similarly, observations from individuals whose hospital entries were classified as stillborn, newborn or a day surgery patient were also eliminated. To separate day surgery, rehabilitation, nursing home and other types of patients that were not acute inpatients, all records from institutions that were not identified as acute care were removed. I also dropped observations whose first diagnosis type was not the most responsible cause of the hospitalization. I then created three new variables depicting the total number of cardiovascular, respiratory, and cardiovascular or respiratory hospitalization for each individual. In order to do this, I generated a new readmission variable by calculating the difference in days between the admission date and the previous entry's discharge date for entries with the same identifier. Although the DAD already contains a readmission variable, I did not use the one that was provided because it only mentioned whether readmission was planned, occurred between 8 to 28 days or less than seven days, which was not clear enough to determine whether the 24-hour criterion was respected or not.

After arranging the health-related variables, I reshaped the format of the dataset from long (multiple entries for the same individual) to wide (one entry per individual). Using the total number of hospitalizations for cardiovascular, respiratory, and cardiorespiratory disease, I then created the six outcome variables (mhospc, mhospr, mhospcr, nhospc, nhospr, and nhospcr) as described in section 4.3.2. I also created my housing costs, energy costs and EP variables using the approach explained in section 4.3.1. Following this, I excluded individuals that were younger than 40 at baseline and proceeded to create or modify the confounding variables from the census. For instance, some variables were recoded with simpler categorization or combined to create a new control variable. Lastly, I excluded individuals that lived in collective dwellings, marginal dwellings, Quebec, and the territories.

Following all these changes, the unweighted dataset had a sample size of 1.1 million individuals. I then merged this unweighted dataset with the bootstraps weight key to obtain a final weighted DAD-census dataset representing 5.9 million individuals.

4.6 Data analysis

Before running my analyses, I verified if the selected confounding variables did effectively have an association with both the EP variables and the hospitalization outcome variables. To do this, I utilized the unweighted DAD-census dataset to cross-tabulate each potential cofounder with the two predicting variables EP2M and EP10, and the six outcome variables. These cross-tabulations were specified for the Pearson chi-square test in order to assess whether the variables were significantly associated or not. To determine if some variables needed to be recoded (due to the small frequency of certain response categories) and guide my model selection for the regression analyses, I also specified the cross-tabulation with the EP variables to be displayed by row and column to better visualize how the variables are distributed across each other. For instance, because the distribution of different minority groups across the whole sample and the population in EP was very small, these groups were combined into a single visible minority category. I also tabulated each confounding variable to obtain the total frequency and the percentage of missing values. After this, I assessed whether there was collinearity between the confounding variables by running a linear regression with the total number of hospitalizations for all diseases as the continuous outcome and EP2M and all the confounders, and then extracting the variance inflation factor. Variables with a variation inflation factor value of 5 or more, such as household size and structure, posed concerns for collinearity and could not be used in the same regression.

To examine the relationship between EP and hospitalization outcomes, I utilized the weighted DAD-census dataset. Since my primary outcomes are dichotomous variables that describe whether an individual has been hospitalized at least once or not, the most appropriate statistical analysis model is logistic regression. I conducted 6 different logistic regressions; the first three models examined the association between EP2M and mhospc, mhospr, and mhospcr while adjusting for all confounding variables. Models 4 to 6 evaluated the same relationship, however, this time using EP10. For my secondary outcomes, which examine whether an individual had 0, 1, or multiple hospitalizations (i.e. 2 and more), I utilized an extension of the binomial logistic regression that can account for more than two response categories. Although the response categories are numbers, I did not consider the ordering because it does not necessarily indicate the severity of the hospitalization and used a multinomial logistic regression. Once again, I used three different models that examined the association between the two EP variables nhosp, nhospr and nhospcr. After excluding observations with missing values, these regressions used a weighted sample of 3.9 million Canadians.

Finally, to describe the representative sample population, tabulation of each selected cofounder, primary and secondary outcome and EP variables, and cross-tabulation between the confounder and outcome variables with the two EP variables were once again conducted. However, this time, the weighted DAD-census dataset was employed and confidence intervals, proportions and coefficient of variation were specified. Altogether, the weighted sample used in these steps varied from 3.9 million to 5.7 million Canadians.

4.6.1 Statistical equations

The next two equations illustrate how the associations between EP and the primary and secondary outcomes were modelled through logistic and multinomial logistic regressions.

Equation 1: Logistic regressions

Model 1 (cardiovascular)[3]

$$ln\left(\frac{p\ (mhospc=1)}{1-p\ (mhospc=1)}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_{sociodemographic} + \beta_4 x_{housing} + \beta_5 x_{geographic}$$

Equation 2: Multinomial logistic regressions

Model 7 (cardiovascular)[4]

$$ln\left(\frac{p(nhospc=k)}{p(nhospc=0)}\right) = \beta_{k0} + \beta_{k1} x_1 + \beta_{k2} x_2 + \beta_{k3} x_{sociodemographic} + \beta_{k4} x_{housing} + \beta_{k5} x_{geographic}$$

[3] Similar equations are used for other models with respiratory and cardiovascular or respiratory outcomes.

[4] Ibid.

This is the same as

$$ln\left(\frac{p(nhospc=1)}{p(nhospc=0)}\right) = \beta_{10} + \beta_{11}x_1 + \beta_{12}x_2 + \beta_{13}x_{sociodemographic} + \beta_{14}x_{housing} + \beta_{15}x_{geographic}$$

$$ln\left(\frac{p(nhospc=2)}{p(nhospc=0)}\right) = \beta_{20} + \beta_{21}x_1 + \beta_{22}x_2 + \beta_{23}x_{sociodemographic} + \beta_{24}x_{housing} + \beta_{25}x_{geographic}$$

Where p is the probability of being hospitalized; $mhospc$ is the minimum number of cardiovascular-related hospitalizations; $nhospc$ is the total number of cardiovascular-related hospitalizations, k is the outcome category (i.e. 0, 1, or 2); x_1 is the energy poverty status, x_2 is the chronic illness or disability status; $x_{sociodemographic}$ is a vector of sociodemographic variables such as sex, ethnicity, marital status, etc.; $x_{housing}$ is a vector of housing variables such as repairs need, tenure, dwelling type, etc.; $x_{geographic}$ is a vector of geographical variables such as province and SAC; β_0 is the intercept and $\beta_{1,2..5}$ are the coefficient terms of the explanatory variables.

4.7 Data access and confidentiality

The steps described in sections 4.5 and 4.6 were conducted in Stata/SE 17 at the McGill-Concordia Research Data Centre (RDC). The RDC is a secure facility where authorized researchers can access Statistics Canada microdata for research purposes. To gain access to the RDC, researchers must apply and have their projects approved, undergo security clearance by the Canadian Government and sign a contract with Statistics Canada that will consider them as a "deemed employee". Before releasing results from the RDC they must be vetted by a Statistics Canada Data Analyst. Observations with counts lower than 5 are not released from the RDC.

Now that the methodology has been explained, the next chapter brings attention to the results of the thesis.

Chapter 5: Findings

This fifth chapter presents the results of the thesis. Attention is first given to the descriptive results followed by those of the regression models.

5.1. Descriptive results

Table 4 and Table 5 present the descriptive statistics of the weighted sample of Canadians aged 40 years and older in 2006 and living in the provinces. As per the 2M metric, approximately 18% of the population experienced EP, while the prevalence based on the 10% threshold is slightly lower at around 17%. In terms of health variables, almost half the population (42%) had a pre-existing chronic illness or disability. Additionally, 17%, 8% and 23% of the population had been hospitalized at least once between 2006 and 2017 for cardiovascular, respiratory, and cardiovascular or respiratory disease, respectively. When looking at the specific number of hospitalizations during the follow-up period, 13%, 6% and 4% experienced only a single hospital admission for cardiovascular, respiratory and cardiorespiratory disease, respectively; 4%, 2% and 7% experienced 2 or more hospitalizations for each of those outcomes.

Females comprised slightly more than half of the sample (52%). In terms of age at baseline, 35% of individuals were aged between 40 to 54; 25% were between 55 to 64; 20% were between 65 to 74; and 20% were aged 75 years or older. About 36% of the sample had completed secondary school and 35% finished their postsecondary education. The majority of respondents were married or living in common law (69%); not a visible minority nor Indigenous (86%); and lived in a home that was owned by a household member (81%), single-detached (67%), in an urban area (77%), and specifically a CMA (62%). The most prevalent household structures were couples without children (42%), followed by those with children (27%) and single-person households (19%). In terms of household size, 45% were composed of two members; 15% were made of three occupants; 12% were made of four people; and 10% included five members or more. When looking at the after-tax income status, the majority of the sample was not considered to have a low after-tax income or to be from low-income economic families based on Statistics Canada's Low Income Cutoffs (92%). The percentages of individuals reporting that their dwelling required major repairs and was constructed in 1960 or earlier were 7% and 27%, respectively.

Table 4. Descriptive statistics of Canadian aged 40 years and above living in the provinces for the whole sample and those in EP (2M), 2006 CanCHEC

Variables and categories	Total sample % (95%CI)	Energy Poverty - 2M % (95%CI)
Energy poverty measures		
Energy poverty – 2M		
Yes	18.09 (18.00, 18.18)	--
Energy poverty – 10% threshold		
Yes	16.94 (16.85, 17.02)	93.64 (93.51, 93.77)
Health measures		
Chronic illness or disability status		
Yes	42.11 (42.01, 42.21)	52.32 (52.03, 52.60)
A single or more cardiovascular hospitalization		
Yes	16.94 (16.86, 17.01)	20.08 (19.85, 20.30)
A single or more respiratory hospitalization		
Yes	7.77 (7.72, 7.83)	10.13 (9.95, 10.31)
A single cardiovascular or respiratory hospitalization		
Yes	22.69 (22.60, 22.77)	27.36 (27.09, 27.62)
Total cardiovascular hospitalizations		
0	83.06 (82.99, 83.14)	79.92 (79.70, 80.15)
1	12.97 (12.90, 13.03)	14.92 (14.73, 15.13)
2 or more	3.97 (3.93, 4.01)	5.15 (5.03, 5.28)
Total respiratory hospitalizations		
0	92.23 (92.17, 92.28)	89.87 (89.69, 90.05)
1	5.91 (5.86, 5.96)	7.54 (7.40, 7.69)
2 or more	1.86 (1.83, 1.88)	2.59 (2.50, 2.68)
Total cardiovascular or respiratory hospitalizations		
0	88.98 (88.92, 89.04)	85.76 (85.55, 85.96)
1	4.47 (4.43, 4.51)	5.58 (5.45, 5.71)
2 or more	6.55 (6.50, 6.60)	8.66 (8.50, 8.83)
Socioeconomic characteristics		

Variables and categories	Total sample % (95%CI)	Energy Poverty - 2M % (95%CI)
Sex		
Male	47.54 (47.46, 47.62)	42.17 (41.89, 42.45)
Female	52.46 (52.38, 52.54)	57.83 (57.55, 58.11)
Age group		
40-54 years	34.69 (34.61, 34.77)	24.52 (24.27, 24.77)
55-64 years	24.89 (24.82, 24. 96)	23.53 (23.29, 23.77)
65-74 years	20.38 (20.32, 20.44)	23.93 (23.69, 24.16)
75 years and older	20.04 (19.98, 20.09)	28.03 (27.79, 28.27)
Education		
Less than secondary school	28.59 (28.50, 28.68)	41.73 (41.46, 42.01)
Secondary school completed (or equivalent)	36.03 (35.93, 36.12)	34.33 (34.07, 34.60)
Postsecondary education	35.38 (35.29, 35.48)	23.93 (23.68, 24.19)
Marital status		
Married or living in common law	69.22 (69.13, 69.31)	53.11 (52.83, 53.39)
Single or never married	6.54 (6.49, 6.59)	7.67 (7.52, 7.82)
Separated, divorced, or widowed	24.24 (24.16, 24.33)	39.22 (38.95, 39.49)
Visible minority and Indigenous Status		
Not a visible minority	86.46 (86.39, 86.53)	87.20 (87.01, 87.39)
Visible minority	10.45 (10.39, 10.52)	8.77 (8.61, 8.94)
Indigenous	3.09 (3.06, 3.12)	4.03 (3.93, 4.13)
Low-income after-tax status		
No	91.83 (91.77, 91.88)	82.62 (82.41, 82.84)
Yes	8.17 (8.12, 8.23)	17.38 (17.16, 17.59)
Housing conditions and setting		
Housing tenure		
Rented	18.75 (18.67, 18.83)	14.08 (13.88, 14.28)
Owned	81.25 (81.17, 81.33)	85.92 (85.72, 86.12)
Repairs needed to the dwelling		
Only regular maintenance	68.25 (68.15, 68.35)	59.52 (59.24, 59.79)
Minor repairs	24.90 (24.81, 24.99)	29.51 (29.25, 29.77)

Variables and categories	Total sample % (95%CI)	Energy Poverty - 2M % (95%CI)
Major repairs	6.85 (6.79, 6.90)	10.97 (10.80, 11.15)
Year of construction of the dwelling		
1960 or before	26.91 (26.82, 26.99)	38.70 (38.41, 39.00)
1961-1980	34.83 (34.74, 34.92)	33.00 (32.72, 33.28)
1981-2006	38.26 (38.17, 38.36)	28.29 (28.03, 28.55)
Dwelling type		
Single-detached	67.33 (67.24, 67.42)	77.80 (77.56, 78.03)
Semi-detached, double, row, duplex, other single-attached	13.44 (13.38, 13.51)	13.82 (13.63, 14.02)
Apartment	17.56 (17.48, 17.64)	6.03 (5.89, 6.17)
Mobile home	1.66 (1.64, 1.69)	2.35 (2.27, 2.43)
Household structure		
Person living alone	18.69 (18.61, 18.76)	34.34 (34.08, 34.60)
Couple with children	27.33 (27.24, 27.42)	14.51 (14.31, 14.72)
Couple without children	41.65 (41.56, 41.75)	37.89 (37.63, 38.15)
Lone-parent family	6.91 (6.85, 6.96)	8.98 (8.82, 9.15)
Other	5.42 (5.38, 5.47)	4.28 (4.16, 4.40)
Household size		
1	18.69 (18.61, 18.76)	34.34 (34.08, 34.60)
2	44.60 (44.51, 44.70)	44.20 (43.93, 44.48)
3	15.05 (14.98, 15.12)	9.91 (9.75, 10.07)
4	12.09 (12.03, 12.16)	6.35 (6.21, 6.50)
5 and more	9.56 (9.50, 9.62)	5.20 (5.07, 5.33)

Table 5. Geographic situation of Canadian aged 40 years and above living in the provinces for the whole sample and those in EP (2M), 2006 CanCHEC

Variables and categories	Total sample % (95%CI)	Energy Poverty – 2M % (95%CI)
Urban/rural setting		
Urban	77.43 (77.34, 77.51)	15.98 (15.88, 16.08)
Rural	22.57 (22.49, 22.66)	24.58 (24.38, 24.79)
SAC		
CMA	62.10 (62.00, 62.19)	15.22 (15.11, 15.33)
CA	15.74 (15.67, 15.81)	18.15 (17.92, 18.39)
Strong or moderate MIZ	12.08 (12.02, 12.15)	24.70 (24.42, 24.99)
Weak or no influence MIZ	10.08 (10.02, 10.14)	26.13 (25.81, 26.45)
Province		
Ontario	43.02 (42.93, 43.12)	19.16 (19.01, 19.3)
Atlantic Provinces	11.91 (11.85, 11.97)	27.54 (27.26, 27.82)
Prairies	22.74 (22.66, 22.81)	17.09 (16.9, 17.28)
British Columbia	22.33 (22.25, 22.41)	12.15 (11.98, 12.31)

Lastly, 43% of individuals resided in Ontario at the time of the census; 23% in the Prairies; 22% in British Columbia; and 12% in the Atlantic Provinces.

Another description of the sample by EP status is provided in Table 4 and Table 5. For Table 4, the numbers shown in the second column represent the column percentages obtained from cross-tabulation of the EP, health, socioeconomic and housing variables with EP status. Meanwhile, in Table 5 , those numbers represent the row percentages from cross-tabulations of the geographic variables with the EP variable. Based on the 2M measure, about 52% of the population considered to be in EP had a chronic illness or disability in 2006. The number of people that have experienced at least 1 hospitalization, and those that have experienced a total of 1 or 2 or more admissions for cardiovascular, respiratory and cardiorespiratory diseases within the 10 years is also slightly higher compared to the overall sample. Females (58%); non-visible minorities (87%); homeowners (86%); individuals residing in single-detached dwellings (78%); people that are married or living in common law (53%); and those who do not have a low after-tax income (83%) represent most of the population in EP. For the age distribution, 25% are between 40 and 54, 24% are between 55 and 64, 23% are between 65 and 74, and the remaining 28% are aged 75 and older. Concerning education, 34% and 24% of the people in EP have completed secondary and postsecondary school, respectively. Two-person households (44%), couples with (15%) and without children (38%), and single-person households (34%) remained the most common types of household size and structure. Additionally, 11% of individuals reported living in a home that required major repairs and 39% lived in a home that was built in 1960 or earlier. Geographically, 16% and 25% of people residing in urban and rural areas are in EP, respectively. Weak or no influence MIZs are shown to have the highest prevalence of EP (26%), closely followed by strong or moderate MIZs (25%) then CAs (18%) and CMAs (15%). With respect to the provinces, the Atlantic region has the highest number of people in EP at 28%. This is more than double the number observed in British Columbia which has the lowest prevalence at (12%). The distribution of the population that is in EP as per the 10% threshold is similar to what was described above and is also shown in Table 10 and Table 11 in the Appendix.

5.2 Analytical results

5.2.1 Results on the associations between energy poverty and the main outcomes

The results of the logistic regressions examining the association between EP measured as per the 2M metric and the main hospitalization outcomes are presented in Table 6. The results are reported as odds ratios (OR) along with their 95% CI. Given a specific exposure variable, the ORs represent the odds of being hospitalized at least once for cardiovascular, respiratory, and cardiovascular or respiratory disease during the 10-year follow-up, respectively. Starting with the first model, exposure to EP was significantly associated with increased odds of being admitted at least once for cardiovascular disease by 7% (95%CI: 1.05, 1.09). This association remains positive and significant for the other two disease models and is especially greater for respiratory disease ($OR_{respiratory}$ =1.15 (95%CI: 1.12, 1.18); $OR_{cardiorespiratory}$ = 1.10 (95%CI: 1.08, 1.12)).

Many of the control variables are also associated with the outcomes. People who have a chronic illness or disability; are older than 40 to 55; are Indigenous; are separated, divorced, or widowed; require major repairs on their house; live in mobile homes or apartments and outside a CMA all have significantly higher odds of being admitted for cardiovascular, respiratory and cardiorespiratory diseases. Being single or never married and being part of a household comprised of a couple with and without children, lone-parent families, and other types of household arrangements also heighten the risk of being admitted at least once for some of the outcomes.

In contrast, visible minorities, females, people who have completed a higher level of education, homeowners, and those living outside of Ontario and in a home built between 1981 and 2006 have significantly lower odds of being hospitalized at least once for all three outcomes. Living in a dwelling constructed between 1961 and 1980 reduces the odds of being hospitalized at least once for respiratory and cardiorespiratory diseases, whereas needing minor repairs on the house lowers the odds of being admitted for cardiovascular and cardiorespiratory diseases.

Table 6. Results from adjusted logistic regression models reporting on the associations between energy poverty (2M) and a single or more hospitalization for cardiovascular, respiratory, and cardiovascular or respiratory diseases, 2006 CanCHEC

Variables and categories	Cardiovascular OR (95%CI)	Respiratory OR (95%CI)	Cardiovascular or Respiratory OR (95%CI)
Energy Poverty measures			
Energy Poverty – 2M			
No	1.00	1.00	1.00
Yes	1.07 (1.05, 1.09)	1.15 (1.12, 1.18)	1.10 (1.08, 1.12)
Health measures			
Chronic illness or disability status			
No	1.00	1.00	1.00
Yes	1.32 (1.31, 1.34)	1.89 (1.86, 1.93)	1.50 (1.48, 1.52)
Socioeconomic characteristics			
Sex			
Male	1.00	1.00	1.00
Female	0.55 (0.55, 0.56)	0.77 (0.76, 0.79)	0.58 (0.57, 0.59)
Age			
40-54 years	1.00	1.00	1.00
55-64 years	1.63 (1.60, 1.67)	1.46 (1.42, 1.51)	1.59 (1.56, 1.62)
65-74 years	2.40 (2.35, 2.46)	2.34 (2.26, 2.42)	2.43 (2.38, 2.48)
75 years and older	3.34 (3.27, 3.42)	3.46 (3.34, 3.58)	3.62 (3.55, 3.70)
Education			
Less than secondary school	1.00	1.00	1.00
Secondary school completed (or equivalent)	0.91 (0.90, 0.93)	0.84 (0.82, 0.86)	0.88 (0.87, 0.90)
Postsecondary education	0.82 (0.80, 0.83)	0.67 (0.65, 0.68)	0.76 (0.75, 0.77)
Marital status			
Married or living in common law	1.00	1.00	1.00
Single or never married	0.97 (0.90, 1.05) §	1.21 (1.07, 1.36)	1.05 (0.98, 1.12) §
Separated, divorced, or widowed	1.12 (1.04, 1.20)	1.25 (1.11, 1.39)	1.18 (1.10, 1.26)
Visible minority and Indigenous status			

Variables and categories	Cardiovascular OR (95%CI)	Respiratory OR (95%CI)	Cardiovascular or Respiratory OR (95%CI)
Not a visible minority	1.00	1.00	1.00
Visible minority	0.96 (0.94, 0.99)	0.86 (0.83, 0.89)	0.9 (0.91, 0.96)
Indigenous	1.14 (1.09, 1.18)	1.42 (1.34, 1.50)	1.23 (1.19, 1.28)
Housing conditions and setting			
Housing tenure			
Rented	1.00	1.00	1.00
Owned	0.87 (0.85, 0.89)	0.77 (0.75, 0.80)	0.82 (0.81, 0.84)
Repairs needed to the dwelling			
Only regular maintenance	1.00	1.00	1.00
Minor repairs	1.03 (1.01, 1.04)	1.00 (0.98, 1.03) §	1.01 (1.00, 1.03)
Major repairs	1.06 (1.03, 1.09)	1.07 (1.04, 1.11)	1.06 (1.04, 1.09)
Year of construction of the dwelling			
Before 1960	1.00	1.00	1.00
1961-1980	0.98 (0.97, 1.00) §	0.96 (0.94, 0.98)	0.98 (0.96, 0.99)
1981-2006	0.98 (0.96, 0.99)	0.92 (0.89, 0.94)	0.96 (0.94, 0.97)
Dwelling type			
Single-detached	1.00	1.00	1.00
Semi-detached, double, row, duplex, other single-attached	1.01 (0.99, 1.04) §	1.10 (1.07, 1.14)	1.04 (1.02, 1.06)
Apartment	1.03 (1.00, 1.06)	1.16 (1.11, 1.20)	1.06 (1.04, 1.09)
Mobile home	1.20 (1.14, 1.26)	1.30 (1.23, 1.38)	1.28 (1.23, 1.34)
Household structure			
Person living alone	1.00	1.00	1.00
Couple with children	1.00 (0.93, 1.08) §	1.18 (1.05, 1.32)	1.07 (1.00, 1.14) §
Couple without children	1.02 (0.95, 1.10) §	1.24 (1.10, 1.38)	1.10 (1.03, 1.17)
Lone-parent family	1.01 (0.98, 1.04) §	1.18 (1.13, 1.23)	1.06 (1.02, 1.09)
Other	1.06 (1.02, 1.09)	1.40 (1.34, 1.47)	1.18 (1.14, 1.21)
Geographic setting			
SAC			
CMA	1.00	1.00	1.00

Variables and categories	Cardiovascular OR (95%CI)	Respiratory OR (95%CI)	Cardiovascular or Respiratory OR (95%CI)
CA	1.17 (1.15, 1.19)	1.10 (1.07, 1.14)	1.16 (1.14, 1.18)
Strong or moderate MIZ	1.08 (1.06, 1.10)	1.16 (1.13, 1.20)	1.11 (1.09, 1.13)
Weak or no influence MIZ	1.17 (1.14, 1.19)	1.25 (1.21, 1.30)	1.19 (1.16, 1.22)
Province			
Ontario	1.00	1.00	1.00
Atlantic Provinces	0.84 (0.82, 0.86)	0.90 (0.87, 0.93)	0.84 (0.82, 0.85)
Prairies	0.80 (0.79, 0.82)	0.96 (0.94, 0.99)	0.82 (0.81, 0.84)
British Columbia	0.65 (0.64, 0.66)	0.78 (0.75, 0.80)	0.65 (0.64, 0.66)

Note. § denotes associations that are non-significant.

5.2.2 Results on the associations between energy poverty and the secondary outcomes

The results of the multinomial logistic regressions examining how exposure to EP, based on the 2M measure, is associated with the total number of hospitalizations experienced during the follow-up are shown in Table 7. Here, results are presented as relative risk ratios (RRR) with their confidence intervals. In the cardiovascular model, the RRR represents the risk of being hospitalized for a cardiovascular disease once during the 10-year follow-up when exposed to a specific variable compared to the risk of having no hospitalization, as well as the risk of being hospitalized for a cardiovascular disease twice or more compared to having no admission. The other two models present similar associations but are specified for respiratory and cardiovascular or respiratory-related hospital admissions. To ease the interpretation of results, I will first present the results for people who had one hospitalization compared to those who were not hospitalized and will follow with the results of those who were admitted multiple times compared to zero.

1 hospital admission relative to 0

Holding all other variables constant, the relative risk of being hospitalized once for cardiovascular disease is 1.05 (95%CI: 1.03, 1.08) times more likely for people who experienced EP than those who did not. The association was also statistically significant for single hospitalization for respiratory (RRR= 1.13; 95%CI: 1.10, 1.16) and for cardiovascular or respiratory diseases (RRR= 1.13; 95%CI: 1.09, 1.17). Additionally, people in EP are 1.13 (95%CI: 1.09, 1.16), 1.22 (95%CI: 1.16, 1.28) and 1.16 (95%CI: 1.12, 1.19) times more likely to be hospitalized twice or more for cardiovascular, respiratory and cardiorespiratory disease, respectively, than those who are not in EP. Thus, globally, there seem to be stronger associations for multiple hospitalizations.

As for the adjustment variables, people who have a chronic illness or a disability; are Indigenous; are aged 55 years or older; are separated, widowed or divorced; and are living in a mobile home and outside a CMA are consistently shown to have a higher relative risk of being hospitalized once for cardiovascular, respiratory, and cardiovascular or respiratory disease.

Table 7: Results from adjusted multinomial logistic regression models reporting on the associations between energy poverty (2M) and having 0, single, or multiple hospitalizations for cardiovascular, respiratory, and cardiovascular or respiratory diseases, 2006 CanCHEC

Number of hospitalizations	Variables and categories	Cardiovascular RRR (95%CI)	Respiratory RRR (95%CI)	Cardiovascular or Respiratory RRR (95%CI)
1	**Energy Poverty measures**			
	Energy Poverty – 2M			
	No	1.00	1.00	1.00
	Yes	1.05 (1.03, 1.08)	1.13 (1.10, 1.16)	1.13 (1.09, 1.17)
	Health measures			
	Chronic illness or disability status			
	No	1.00	1.00	1.00
	Yes	1.23 (1.21, 1.25)	1.72 (1.69, 1.76)	1.66 (1.62, 1.71)
	Socioeconomic characteristics			
	Sex			
	Male	1.00	1.00	1.00
	Female	0.56 (0.55, 0.57)	0.79 (0.77, 0.81)	0.82 (0.79, 0.84)
	Age			
	40-54 years	1.00	1.00	1.00
	55-64 years	1.58 (1.54, 1.62)	1.37 (1.32, 1.42)	1.26 (1.21, 1.31)
	65-74 years	2.21 (2.16, 2.27)	2.12 (2.04, 2.20)	1.83 (1.75, 1.91)
	75 years and older	2.96 (2.89, 3.04)	3.29 (3.16, 3.42)	2.81(2.69, 2.94)
	Education			
	Less than secondary school	1.00	1.00	1.00
	Secondary school completed (or equivalent)	0.93 (0.91, 0.95)	0.87 (0.84, 0.89)	0.88 (0.86, 0.91)
	Postsecondary education (below university)	0.84 (0.82, 0.86)	0.70 (0.68, 0.72)	0.72 (0.69, 0.74)
	Marital status			
	Married or living in common law	1.00	1.00	1.00
	Single or never married	0.96 (0.89, 1.06) §	1.17 (1.02, 1.33)	1.21 (1.05, 1.40)
	Separated, divorced, or widowed	1.12 (1.03, 1.21)	1.21 (1.06, 1.37)	1.21 (1.05, 1.39)

Number of hospitalizations	Variables and categories	Cardiovascular RRR (95%CI)	Respiratory RRR (95%CI)	Cardiovascular or Respiratory RRR (95%CI)
	Visible minority and Indigenous status			
	Not a visible minority	1.00	1.00	1.00
	Visible minority	0.98 (0.96, 1.01) §	0.89 (0.85, 0.93)	0.90 (0.85, 0.94)
	Indigenous	1.09 (1.04, 1.14)	1.34 (1.26, 1.43)	1.34 (1.25, 1.43)
	Housing conditions and setting			
	Housing tenure			
	Rented	1.00	1.00	1.00
	Owned	0.88 (0.86, 0.91)	0.80 (0.77, 0.84)	0.80 (0.77, 0.84)
	Repairs needed to the dwelling			
	Only regular maintenance	1.00	1.00	1.00
	Minor repairs	1.03 (1.01, 1.05)	1.00 (0.98, 1.03) §	0.99 (0.96, 1.02) §
	Major repairs	1.06 (1.03, 1.10)	1.06 (1.02, 1.11)	1.03 (0.98, 1.08) §
	Year of construction of the dwelling			
	Before 1960	1.00	1.00	1.00
	1961-1980	0.98 (0.96, 1.00) §	0.95 (0.93, 0.98)	0.96 (0.93, 0.99)
	1981-2006	0.98 (0.96, 1.00)	0.93 (0.90, 0.95)	0.93 (0.90, 0.96)
	Dwelling type			
	Single-detached	1.00	1.00	1.00
	Semi-detached, double, row, duplex, other single-attached	1.01 (0.98, 1.03) §	1.08 (1.05, 1.12)	1.08 (1.04, 1.12)
	Apartment	1.01 (0.98, 1.04) §	1.15 (1.10, 1.20)	1.13 (1.08, 1.19)
	Mobile home	1.16 (1.10, 1.23)	1.23(1.15, 1.32)	1.31 (1.21, 1.42)
	Household structure			
	Person living alone	1.00	1.00	1.00
	Couple with children	1.00 (0.92, 1.09) §	1.15 (1.01, 1.30)	1.15 (1.00, 1.32)
	Couple without children	1.01 (0.93, 1.10) §	1.19 (1.04, 1.35)	1.19 (1.04, 1.38)
	Lone-parent family	0.99 (0.96, 1.03) §	1.12 (1.07, 1.18)	1.12 (1.06, 1.18)

Number of hospitalizations	Variables and categories	Cardiovascular RRR (95%CI)	Respiratory RRR (95%CI)	Cardiovascular or Respiratory RRR (95%CI)
	Other	1.04 (1.00, 1.08)	1.36 (1.29, 1.43)	1.36 (1.29, 1.44)
	Geographic setting			
	SAC			
	CMA	1.00	1.00	1.00
	CA	1.14 (1.11, 1.16)	1.09 (1.06, 1.13)	1.07 (1.03, 1.10)
	Strong or moderate MIZ	1.05 (1.03, 1.08)	1.15 (1.11, 1.19)	1.15 (1.11, 1.19)
	Weak or no influence MIZ	1.12 (1.09, 1.15)	1.22 (1.17, 1.27)	1.17 (1.12, 1.23)
	Province			
	Ontario	1.00	1.00	1.00
	Atlantic Provinces	0.84 (0.82, 0.86)	0.89 (0.85, 0.92)	0.87 (0.84, 0.91)
	Prairies	0.81 (0.79, 0.82)	0.95 (0.92, 0.98)	0.94 (0.91, 0.97)
	British Columbia	0.65 (0.64, 0.67)	0.77 (0.75, 0.79)	0.76 (0.73, 0.78)
2+	**Energy Poverty measures**			
	Energy Poverty – 2M			
	No	1.00	1.00	1.00
	Yes	1.13 (1.09, 1.16)	1.22 (1.16, 1.28)	1.16 (1.12, 1.19)
	Health measures			
	Chronic illness or disability status			
	No	1.00	1.00	1.00
	Yes	1.71 (1.66, 1.76)	2.67 (2.55, 2.79)	1.98 (1.93, 2.02)
	Socioeconomic characteristics			
	Sex			
	Male	1.00	1.00	1.00
	Female	0.53 (0.51, 0.54)	0.73 (0.70, 0.76)	0.61 (0.60, 0.62)
	Age			
	40-54 years	1.00	1.00	1.00
	55-64 years	1.93 (1.84, 2.03)	1.96 (1.82, 2.12)	1.94 (1.86, 2.01)
	65-74 years	3.38 (3.23, 3.55)	3.46 (3.21, 3.73)	3.38 (3.25, 3.52)
	75 years and older	5.22 (4.97, 5.48)	4.38 (4.06, 4.72)	5.08 (4.89, 5.27)

Number of hospitalizations	Variables and categories	Cardiovascular RRR (95%CI)	Respiratory RRR (95%CI)	Cardiovascular or Respiratory RRR (95%CI)
	Education			
	Less than secondary school	1.00	1.00	1.00
	Secondary school completed (or equivalent)	0.86 (0.83, 0.88)	0.75 (0.72, 0.79)	0.82 (0.80, 0.84)
	Postsecondary education (below university)	0.75 (0.72, 0.77)	0.56 (0.54, 0.59)	0.69 (0.67, 0.70)
	Marital status			
	Married or living in common law	1.00	1.00	1.00
	Single or never married	0.98 (0.83, 1.16) §	1.39 (1.09, 1.77)	1.10 (0.96, 1.25) §
	Separated, divorced or widowed	1.12 (0.96, 1.31) §	1.40 (1.11, 1.76)	1.23 (1.08, 1.40)
	Visible minority and Indigenous status			
	Not a visible minority	1.00	1.00	1.00
	Visible minority	0.88 (0.83, 0.93)	0.76 (0.69, 0.83)	0.83 (0.79, 0.87)
	Indigenous	1.32 (1.22, 1.43)	1.66 (1.50, 1.82)	1.42 (1.33, 1.51)
	Housing conditions and setting			
	Housing tenure			
	Rented	1.00	1.00	1.00
	Owned	0.82 (0.78, 0.86)	0.69 (0.65, 0.73)	0.77 (0.74, 0.80)
	Repairs needed to the dwelling			
	Only regular maintenance	1.00	1.00	1.00
	Minor repairs	1.01 (0.98, 1.04) §	1.00 (0.96, 1.05) §	1.01 (0.99, 1.03) §
	Major repairs	1.06 (1.00, 1.11)	1.12 (1.04, 1.20)	1.10 (1.05, 1.14)
	Year of construction of the dwelling			
	Before 1960	1.00	1.00	1.00
	1961-1980	0.99 (0.96, 1.02) §	0.97 (0.93, 1.02) §	0.98 (0.95, 1.00) §
	1981-2006	0.98 (0.94, 1.01) §	0.87 (0.83, 0.92)	0.94 (0.92, 0.97)
	Dwelling type			
	Single-detached	1.00	1.00	1.00

Number of hospitalizations	Variables and categories	Cardiovascular RRR (95%CI)	Respiratory RRR (95%CI)	Cardiovascular or Respiratory RRR (95%CI)
	Semi-detached, double, row, duplex, other single-attached	1.04 (1.00, 1.08) §	1.17 (1.11, 1.25)	1.08 (1.05, 1.12)
	Apartment	1.10 (1.04, 1.16)	1.19 (1.10, 1.29)	1.13 (1.08, 1.18)
	Mobile home	1.32 (1.20, 1.44)	1.53 (1.38, 1.71)	1.34 (1.25, 1.44)
	Household structure			
	Person living alone	1.00	1.00	1.00
	Couple with children	1.02 (0.87, 1.20) §	1.29 (1.02, 1.63)	1.14 (1.01, 1.29)
	Couple without children	1.06 (0.91, 1.24) §	1.45 (1.15, 1.82)	1.20 (1.06, 1.36)
	Lone-parent family	1.07 (1.01, 1.14)	1.38 (1.27, 1.50)	1.16 (1.11, 1.22)
	Other	1.12 (1.05, 1.19)	1.56 (1.43, 1.69)	1.29 (1.23, 1.35)
	Geographic setting			
	SAC			
	CMA	1.00	1.00	1.00
	CA	1.30 (1.26, 1.35)	1.15 (1.09, 1.22)	1.23 (1.20, 1.27)
	Strong or moderate MIZ	1.16 (1.12, 1.21)	1.21 (1.14, 1.28)	1.17 (1.14, 1.21)
	Weak or no influence MIZ	1.32 (1.26, 1.38)	1.36 (1.27, 1.44)	1.33 (1.28, 1.37)
	Province			
	Ontario	1.00	1.00	1.00
	Atlantic Provinces	0.86 (0.83, 0.90)	0.96 (0.90, 1.02) §	0.89 (0.86, 0.92)
	Prairies	0.78 (0.75, 0.81)	1.01 (0.96, 1.06) §	0.87 (0.84, 0.89)
	British Columbia	0.65 (0.63, 0.68)	0.80 (0.76, 0.84)	0.72 (0.70, 0.74)

Additionally, individuals who are single or never married; those living in apartments or semi-detached, double, row, duplex, or other single-attached dwellings; and people in households comprised of couples with and without children, lone-parent families, and other household structures are also significantly more likely to be admitted once during the follow-up period for respiratory and cardiovascular or respiratory conditions. Individuals in houses that require minor repairs are also statistically more likely to be hospitalized a single time for cardiovascular disease while those who need major repairs are at risk for both cardiovascular and respiratory-related admissions.

Meanwhile, being a visible minority, female, and homeowner; having completed secondary or postsecondary education; living in a home built between 1981 and 2006 and in the Atlantic provinces, Prairies, and British Columbia are all protective socioeconomic and geographic factors that significantly reduce the risk of being admitted for a cardiovascular, respiratory, and cardiovascular or respiratory disease. Moreover, people living in houses that were built between 1961-1980 are more likely to have no admissions related to respiratory or cardiorespiratory disease than those living in dwellings constructed in 1960 or earlier.

2 hospital admission relative to 0

As mentioned before, exposure to EP significantly increases the relative risk of having multiple hospitalizations than none. Confounding variables that consistently increased the relative risk of having a single admission to zero, such as having a chronic illness or disability, being 55 years or older, being Indigenous, living in a mobile home and an area other than a CMA, also increase the relative risk of having multiple hospitalizations compared to none. Couples with and without children and people living in semi-detached, double, row, duplex, or other single-attached dwellings remain more likely to experience multiple hospital admissions for respiratory and cardiorespiratory diseases.

Unlike previous results for single admissions, people in apartments, lone-parent families and other household types acquire an increased risk of being admitted multiple times for cardiovascular disease while those in dwellings that require major repair now have a higher relative risk of being hospitalized twice or more for all outcomes. People who are separated, divorced, or widowed; single or never married; and living in a dwelling that requires minor repairs no longer have a statistically higher risk of being admitted twice or more for cardiovascular and respiratory problems.

Homeownership, being female, a visible minority, and having completed secondary or postsecondary school remain protective factors that reduce the relative risk of having multiple cardiovascular, respiratory and cardiovascular or respiratory-related hospitalizations to not having any admission. Living in a home that was built between 1961-1980 no longer reduces the relative risk of having multiple hospitalizations for any of the three outcomes, while dwellings constructed between 1981 and 2006 only protect against respiratory and cardiorespiratory-related admissions. Also, residence in the Atlantic provinces and the Prairies no longer reduces the relative risk of being admitted twice or more for respiratory diseases.

5.2.3 Sensitivity analyses

The logistic and multinomial logistic regression models were re-run with the 10% threshold as the alternative measure of EP and their results are shown in Table 8 and Table 9. Exposure to EP significantly increases the odds of being hospitalized at least once, for cardiovascular, respiratory, and cardiovascular or respiratory conditions by 8% (95%CI: 1.06, 1.10), 16% (95%CI: 1.13, 1.19) and 11% (95%CI: 1.09, 1.13), respectively. For all three secondary outcomes, people in EP have statistically higher relative risk of having a single hospitalization compared to zero ($OR_{cardiovascular}$ =1.06 (95%CI: 1.04, 1.08); $OR_{respiratory}$ = 1.14 (95%CI: 1.10, 1.17); $OR_{cardiorespiratory}$= 1.14 (95%CI: 1.10, 1.17)), and higher relative risk of having 2 or more hospitalizations compared to zero ($OR_{cardiovascular}$ = 1.14 (95%CI: 1.10, 1.17); $OR_{respiratory}$ = 1.22 (95%CI: 1.16, 1.29); $OR_{cardiorespiratory}$=1.17 (95%CI: 1.13, 1.20)). The associations between the control variables[5] and outcomes also remained similar to what was presented in Table 6 and Table 7.

[5] The control variables include chronic illness or disability status, socioeconomic characteristics, housing conditions and household structure, and geographic location.

Table 8. Results from adjusted logistic regression models reporting on the associations between energy poverty (10% threshold) and a single or more hospitalization for cardiovascular, respiratory, and cardiovascular or respiratory diseases, 2006 CanCHEC

Variables and categories	Cardiovascular OR (95%CI)	Respiratory OR (95%CI)	Cardiovascular or Respiratory OR (95%CI)
Energy Poverty measures			
Energy Poverty – 10% threshold			
No	1.00	1.00	1.00
Yes	1.08 (1.06, 1.10)	1.16 (1.13, 1.19)	1.11 (1.09, 1.13)
Health measures			
Chronic illness or disability status			
No	1.00	1.00	1.00
Yes	1.32 (1.31,1.34)	1.89 (1.86, 1.93)	1.50 (1.48, 1.52)
Socioeconomic characteristics			
Sex			
Male	1.00	1.00	1.00
Female	0.55 (0.54, 0.56)	0.77 (0.76, 0.79)	0.58 (0.57, 0.59)
Age			
40-54 years	1.00	1.00	1.00
55-64 years	1.63 (1.60, 1.67)	1.46 (1.42, 1.51)	1.59 (1.56, 1.62)
65-74 years	2.40 (2.35, 2.46)	2.34 (2.26, 2.42)	2.43 (2.38, 2.48)
75 years and older	3.34 (3.27, 3.42)	3.46 (3.34, 3.58)	3.62 (3.55, 3.71)
Education			
Less than secondary school	1.00	1.00	1.00
Secondary school completed (or equivalent)	0.91 (0.90, 0.93)	0.84 (0.82, 0.86)	0.88 (0.87, 0.90)
Postsecondary education (below university)	0.82 (0.80, 0.83)	0.67 (0.65, 0.68)	0.76 (0.75, 0.77)
Marital status			
Married or living in common law	1.00	1.00	1.00
Single or never married	0.97 (0.90, 1.05) §	1.21 (1.07, 1.36)	1.05 (0.98, 1.12) §
Separated, divorced, or widowed	1.12 (1.04, 1.20)	1.25 (1.11, 1.39)	1.18 (1.10. 1.26)
Visible minority and Indigenous status			

Variables and categories	Cardiovascular OR (95%CI)	Respiratory OR (95%CI)	Cardiovascular or Respiratory OR (95%CI)
Not a visible minority	1.00	1.00	1.00
Visible minority	0.96 (0.93, 0.98)	0.86 (0.82, 0.89)	0.93 (0.91, 0.96)
Indigenous	1.14 (1.09, 1.18)	1.42 (1.34, 1.49)	1.23 (1.19, 1.28)
Housing conditions and setting			
Housing tenure			
Rented	1.00	1.00	1.00
Owned	0.87 (0.85, 0.89)	0.78 (0.75, 0.80)	0.82 (0.80, 0.84)
Repairs needed to the dwelling			
Only regular maintenance	1.00	1.00	1.00
Minor repairs	1.03 (1.01, 1.04)	1.00 (0.98, 1.02) §	1.02 (1.00, 1.03)
Major repairs	1.06 (1.03, 1.09)	1.07 (1.04, 1.11)	1.06 (1.04, 1.09)
Year of construction of the dwelling			
Before 1960	1.00	1.00	1.00
1961-1980	0.99 (0.97, 1.00) §	0.96 (0.94, 0.98)	0.98 (0.96, 0.99)
1981-2006	0.98 (0.96, 0.99)	0.92 (0.89, 0.94)	0.96 (0.94, 0.97)
Dwelling type			
Single-detached	1.00	1.00	1.00
Semi-detached, double, row, duplex, other single-attached	1.01 (0.99, 1.04) §	1.10 (1.07, 1.14)	1.04 (1.02, 1.06)
Apartment	1.03 (1.00, 1.06)	1.16 (1.11, 1.20)	1.06 (1.04, 1.09)
Mobile home	1.20 (1.14, 1.26)	1.30 (1.23, 1.39)	1.28 (1.23, 1.34)
Household structure			
Person living alone	1.00	1.00	1.00
Couple with children	1.01 (0.93, 1.09) §	1.18 (1.06, 1.32)	1.07 (1.00, 1.14) §
Couple without children	1.03 (0.95, 1.11) §	1.23 (1.11, 1.39)	1.10 (1.03, 1.17)
Lone-parent family	1.01 (0.98, 1.04) §	1.18 (1.13, 1.23)	1.06 (1.03, 1.09)
Other	1.06 (1.02, 1.09)	1.40 (1.34, 1.47)	1.18 (1.14, 1.21)
Geographic setting			
SAC			
CMA	1.00	1.00	1.00

Variables and categories	Cardiovascular OR (95%CI)	Respiratory OR (95%CI)	Cardiovascular or Respiratory OR (95%CI)
CA	1.17 (1.15, 1.19)	1.10 (1.07, 1.14)	1.16 (1.14, 1.18)
Strong or moderate MIZ	1.08 (1.06, 1.10)	1.16 (1.13, 1.20)	1.11 (1.09, 1.13)
Weak or no influence MIZ	1.16 (1.14, 1.19)	1.25 (1.21, 1.30)	1.19 (1.16, 1.22)
Province			
Ontario	1.00	1.00	1.00
Atlantic Provinces	0.84 (0.82, 0.86)	0.90 (0.87, 0.93)	0.84 (0.82, 0.85)
Prairies	0.80 (0.79, 0.82)	0.96 (0.94, 0.99)	0.82 (0.81, 0.84)
British Columbia	0.65 (0.64, 0.66)	0.78 (0.75, 0.80)	0.65 (0.64, 0.66)

Table 9. Results from adjusted multinomial logistic regression models reporting on the associations between energy poverty (10% threshold) and having 0, a single or multiple hospitalizations for cardiovascular, respiratory, and cardiovascular or respiratory diseases, 2006 CanCHEC

Number of hospitalizations	Variables and categories	Cardiovascular RRR (95%CI)	Respiratory RRR (95%CI)	Cardiovascular or Respiratory RRR (95%CI)
1	**Energy Poverty measures**			
	Energy Poverty – 10% threshold			
	No	1.00	1.00	1.00
	Yes	1.06 (1.04, 1.08)	1.14 (1.10, 1.17)	1.14 (1.10, 1.17)
	Health measures			
	Chronic illness or disability status			
	No	1.00	1.00	1.00
	Yes	1.23 (1.21, 1.25)	1.72 (1.69, 1.76)	1.66 (1.62, 1.71)
	Socioeconomic characteristics			

Number of hospitalizations	Variables and categories	Cardiovascular RRR (95%CI)	Respiratory RRR (95%CI)	Cardiovascular or Respiratory RRR (95%CI)
	Sex			
	Male	1.00	1.00	1.00
	Female	0.56 (0.55, 0.57)	0.79 (0.77, 0.81)	0.82 (0.79, 0.84)
	Age			
	40-54 years	1.00	1.00	1.00
	55-64 years	1.58 (1.54, 1.62)	1.37 (1.32, 1.42)	1.26 (1.21, 1.31)
	65-74 years	2.22 (2.16, 2.27)	2.12 (2.04, 2.20)	1.83 (1.75, 1.91)
	75 years and older	2.96 (2.89, 3.04)	3.29 (3.17, 3.43)	2.81 (2.69, 2.94)
	Education			
	Less than secondary school	1.00	1.00	1.00
	Secondary school completed (or equivalent)	0.93 (0.92, 0.95)	0.87 (0.85, 0.89)	0.88 (0.86, 0.91)
	Postsecondary education (below university)	0.84 (0.82, 0.86)	0.70 (0.68, 0.72)	0.72 (0.69, 0.74)
	Marital status			
	Married or living in common law	1.00	1.00	1.00
	Single or never married	0.96 (0.89, 1.06) §	1.17 (1.02, 1.33)	1.21 (1.05, 1.40)
	Separated, divorced, or widowed	1.12 (1.03, 1.21)	1.21 (1.07, 1.37)	1.21 (1.05, 1.39)
	Visible minority and Indigenous status			
	Not a visible minority	1.00	1.00	1.00
	Visible minority	0.98 (0.96, 1.01) §	0.89 (0.85, 0.92)	0.90 (0.86, 0.94)
	Indigenous	1.09 (1.04, 1.14)	1.34 (1.26, 1.43)	1.33 (1.25, 1.43)
	Housing conditions and setting			
	Housing tenure			
	Rented	1.00	1.00	1.00

Number of hospitalizations	Variables and categories	Cardiovascular RRR (95%CI)	Respiratory RRR (95%CI)	Cardiovascular or Respiratory RRR (95%CI)
	Owned	0.89 (0.86, 0.91)	0.80 (0.77, 0.84)	0.80 (0.76, 0.84)
	Repairs needed to the dwelling			
	Only regular maintenance	1.00	1.00	1.00
	Minor repairs	1.03 (1.01, 1.05)	1.00 (0.97, 1.03) §	0.99 (0.96, 1.02) §
	Major repairs	1.06 (1.03, 1.10)	1.06 (1.012 1.10)	1.03 (0.98, 1.08) §
	Year of construction of the dwelling			
	Before 1960	1.00	1.00	1.00
	1961-1980	0.98 (0.96, 1.00) §	0.95 (0.93,0.98)	0.96 (0.93, 0.99)
	1981-2006	0.98 (0.96, 1.00)	0.93 (0.90, 0.95)	0.93 (0.90, 0.96)
	Dwelling type			
	Single-detached	1.00	1.00	1.00
	Semi-detached, double, row, duplex, other single-attached	1.01 (0.98, 1.03) §	1.08 (1.05, 1.12)	1.08 (1.04, 1.12)
	Apartment	1.01 (0.98, 1.04) §	1.15 (1.10, 1.20)	1.13 (1.08, 1.19)
	Mobile home	1.16 (1.10, 1.23)	1.23 (1.15, 1.32)	1.31 (1.21, 1.43)
	Household structure			
	Person living alone	1.00	1.00	1.00
	Couple with children	1.00 (0.92, 1.09) §	1.15 (1.01, 1.30)	1.15 (1.00, 1.32)
	Couple without children	1.02 (0.93, 1.10) §	1.19 (1.05, 1.35)	1.20 (1.04, 1.38)
	Lone-parent family	0.99 (0.96, 1.03) §	1.12 (1.07, 1.18)	1.12 (1.06, 1.19)
	Other	1.04 (1.00, 1.08)	1.36 (1.30, 1.43)	1.37 (1.29, 1.44)
	Geographic setting			
	SAC			
	CMA	1.00	1.00	1.00
	CA	1.14 (1.11, 1.16)	1.09 (1.06, 1.13)	1.07 (1.03, 1.10)
	Strong or moderate MIZ	1.05 (1.03, 1.08)	1.15 (1.12, 1.19)	1.15 (1.11, 1.19)
	Weak or no influence MIZ	1.12 (1.09, 1.15)	1.22 (1.17, 1.27)	1.17 (1.12, 1.23)

Number of hospitalizations	Variables and categories	Cardiovascular RRR (95%CI)	Respiratory RRR (95%CI)	Cardiovascular or Respiratory RRR (95%CI)
	Province			
	Ontario	1.00	1.00	1.00
	Atlantic Provinces	0.84 (0.82, 0.86)	0.89 (0.85, 0.92)	0.88 (0.84, 0.91)
	Prairies	0.81 (0.79, 0.82)	0.95 (0.92, 0.98)	0.94 (0.91, 0.97)
	British Columbia	0.65 (0.64, 0.67)	0.77 (0.75, 0.79)	0.76 (0.73, 0.78)
2+	**Energy Poverty measures**			
	Energy Poverty – 2M			
	No	1.00	1.00	1.00
	Yes	1.14 (1.10, 1.17)	1.22 (1.16, 1.29)	1.17 (1.13, 1.20)
	Health measures			
	Chronic illness or disability status			
	No	1.00	1.00	1.00
	Yes	1.71 (1.66, 1.75)	2.67 (2.55, 2.79)	1.98 (1.93, 2.02)
	Socioeconomic characteristics			
	Sex			
	Male	1.00	1.00	1.00
	Female	0.53 (0.51, 0.54)	0.73 (0.70, 0.76)	0.61 (0.60, 0.62)
	Age			
	40-54 years	1.00	1.00	1.00
	55-64 years	1.94 (1.84, 2.03)	1.96 (1.82, 2.12)	1.94 (1.86, 2.02)
	65-74 years	3.39 (3.23, 3.55)	3.46 (3.21, 3.73)	3.38 (3.25, 3.52)
	75 years and older	5.23 (4.98, 5.48)	4.38 (4.06, 4.72)	5.08 (4.89, 5.28)
	Education			
	Less than secondary school	1.00	1.00	1.00
	Secondary school completed (or equivalent)	0.86 (0.83, 0.88)	0.75 (0.72, 0.79)	0.82 (0.80, 0.84)

Number of hospitalizations	Variables and categories	Cardiovascular RRR (95%CI)	Respiratory RRR (95%CI)	Cardiovascular or Respiratory RRR (95%CI)
	Postsecondary education (below university)	0.75 (0.72, 0.77)	0.56 (0.53, 0.59)	0.69 (0.67, 0.70)
	Marital status			
	Married or living in common law	1.00	1.00	1.00
	Single or never married	0.98 (0.83, 1.15) §	1.39 (1.09, 1.77)	1.10 (0.96, 1.25) §
	Separated, divorced, or widowed	1.12 (0.96, 1.31) §	1.40 (1.11, 1.76)	1.23 (1.08, 1.40)
	Visible minority and Indigenous status			
	Not a visible minority	1.00	1.00	1.00
	Visible minority	0.88 (0.83, 0.93)	0.76 (0.69, 0.82)	0.83 (0.79, 0.87)
	Indigenous	1.33 (1.22, 1.43)	1.65 (1.50, 1.82)	1.41 (1.33, 1.50)
	Housing conditions and setting			
	Housing tenure			
	Rented	1.00	1.00	1.00
	Owned	0.82 (0.78, 0.86)	0.69 (0.65, 0.73)	0.77 (0.74, 0.80)
	Repairs needed to the dwelling			
	Only regular maintenance	1.00	1.00	1.00
	Minor repairs	1.01 (0.98, 1.04) §	1.00 (0.96, 1.05) §	1.01 (0.99, 1.03) §
	Major repairs	1.06 (1.00, 1.11)	1.12 (1.04, 1.20)	1.10 (1.05, 1.14)
	Year of construction of the dwelling			
	Before 1960	1.00	1.00	1.00
	1961-1980	0.99 (0.96, 1.02) §	0.97 (0.93, 1.02) §	0.98(0.95, 1.00) §
	1981-2006	0.98 (0.94, 1.01) §	0.87 (0.83, 0.92)	0.94 (0.92, 0.97)
	Dwelling type			

Number of hospitalizations	Variables and categories	Cardiovascular RRR (95%CI)	Respiratory RRR (95%CI)	Cardiovascular or Respiratory RRR (95%CI)
	Single-detached	1.00	1.00	1.00
	Semi-detached, double, row, duplex, other single-attached	1.04 (1.00, 1.08) §	1.17 (1.11, 1.25)	1.08 (1.05, 1.12)
	Apartment	1.10 (1.04, 1.16)	1.19 (1.10, 1.29)	1.13 (1.08, 1.18)
	Mobile home	1.32 (1.21, 1.44)	1.54 (1.38, 1.71)	1.34 (1.25, 1.44)
	Household structure			
	Person living alone	1.00	1.00	1.00
	Couple with children	1.02 (0.87, 1.20) §	1.29 (1.02, 1.63)	1.14 (1.00, 1.29)
	Couple without children	1.06 (0.91, 1.24) §	1.45 (1.15, 1.82)	1.20 (1.06, 1.36)
	Lone-parent family	1.07 (1.01, 1.14)	1.38 (1.27, 1.50)	1.16 (1.11, 1.22)
	Other	1.12 (1.05, 1.19)	1.56 (1.43, 1.69)	1.29 (1.23, 1.36)
	Geographic setting			
	SAC			
	CMA	1.00	1.00	1.00
	CA	1.30 (1.26, 1.35)	1.15 (1.09, 1.22)	1.23 (1.20, 1.27)
	Strong or moderate MIZ	1.16 (1.12, 1.21)	1.21 (1.14, 1.28)	1.18 (1.14, 1.21)
	Weak or no influence MIZ	1.32 (1.26, 1.38)	1.36 (1.27, 1.44)	1.32 (1.28, 1.37)
	Province			
	Ontario	1.00	1.00	1.00
	Atlantic Provinces	0.86 (0.83, 0.90)	0.96 (0.90, 1.02) §	0.89 (0.86, 0.92)
	Prairies	0.78 (0.75, 0.81)	1.01 (0.96, 1.06) §	0.87 (0.84, 0.89)
	British Columbia	0.65 (0.63, 0.68)	0.80 (0.75, 0.84)	0.72 (0.70, 0.74)

Chapter 6: Discussion

This study used linked data from the 2006 CanCHEC and the DAD to examine the relationship between an expenditure-based measure of EP and hospitalizations related to cardiovascular, respiratory, and cardiovascular or respiratory diseases among the Canadian adult population over a 10 year period. Descriptive statistics show that 18% and 17% of the sample are considered to be energy-poor as per the 2M and 10% threshold. With regard to the cardiovascular, respiratory, and cardiorespiratory outcomes, between 8 and 23% had been hospitalized at least once, between 4% and 13% had been hospitalized once only, and 2% to 7% had been hospitalized twice or more. Although some of these numbers may seem small, the total weighted analytical sample consisted of 3.9 million Canadian aged 40 and older living in the provinces. With this sample, the thesis demonstrated that EP potentially has an adverse effect on the cardiovascular and respiratory health of Canadian adults that is independent of sociodemographic, housing, and geographic conditions. More specifically, the three main findings of this thesis are described below.

1. EP significantly increases the odds of Canadian adults aged 40 and above being hospitalized at least once for cardiovascular (OR: 1.07; 95%CI: 1.05, 1.09), for respiratory (OR:1.15; 95%CI: 1.12, 1.18), and for cardiovascular or respiratory (OR: 1.10; 95%CI: 1.08, 1.12) diseases.

A limited number of studies have explored the relationship between exposure to EP and hospitalization among adults or the general population. Findings from this thesis support evidence reported by Oliveras et al. (2020) and Atsalis et al. (2016) which has shown that people in EP are more likely to be hospitalized. More specifically, 1.0 and 7.0% of hospitalizations in women and men from Barcelona are attributed to EP (Oliveras et al., 2020) and 2.7% to 8.5% of cardiovascular and respiratory problems treated annually in Greek hospitals are associated with EP (Atsalis et al., 2016). While the study by Oliveras et al. (2020) uses a cross-sectional design and a sample of 3519 individuals aged 15 and over, my research has the advantage of having a larger sample size that was followed for specific hospitalization outcomes over a decade. Furthermore, in comparison to the latter study by Atsalis et al. (2016), which used records from the two largest specialized hospitals, this thesis uses data from the DAD that is collected from multiple healthcare facilities across the country excluding those from the province of Quebec.

The literature also reports mixed evidence on the association between EP and cardiovascular and respiratory-related hospitalization. More precisely, an English study by Sharpe et al. (2019) observed that postal code areas with a higher probability of EP had lower 3-year admission rates for cardiovascular diseases as well as non-significant associations between the area-level probability of EP and hospitalization rates for asthma and COPD. Although these results appear to be conflicting with findings from this thesis, the ecological study design employed does not allow to make conclusions on the association between EP and hospitalization at the individual level, and thus makes it hard to compare results.

2. The association between exposure to EP and having at least one hospitalization is strongest for admissions related to respiratory diseases than cardiovascular diseases.

This second finding is aligned with the observation from Atsalis et al. (2016) that the contribution of EP to annual cases treated in Greek hospitals is greater for respiratory disease. More specifically, EP was associated with 3.1% to 8.5% of respiratory cases compared to 2.7% to 7.4% of cardiovascular cases (Atsalis et al., 2016). However, this effect becomes less observable when looking at specific cardiovascular and respiratory conditions and stratifying by sex. In fact, Oliveras et al. (2020) demonstrated that, among women in EP, reports of having chronic bronchitis, asthma, and myocardial infarction or stroke were respectively 2.2 (95%CI 1.3-3.6), 1.6 (95%CI 1.0, 2.5) and 2.0 (95%CI 1.1, 3.5) times more frequent than in women who were not in EP. Meanwhile, men in EP reported chronic bronchitis, asthma, and myocardial infarction or stroke 1.7 (95%CI 0.9, 3.2), 1.6 (95%CI: 1.0, 2.7), and 1.6 times (95%CI 0.9, 2.9) more frequently (Oliveras et al., 2020). Studies that do not directly examine EP but look at the effect of energy efficiency interventions on health outcomes also find that the impacts of the interventions on cardiovascular and respiratory-related admissions are not significantly different (Fyfe et al., 2020; Poortinga et al., 2018). Therefore, further studies would be needed to explore whether the effect size of EP on respiratory outcomes varies from cardiovascular outcomes.

3. The relative risks of having two or more hospitalizations for cardiovascular and/or respiratory diseases compared to zero are greater than the relative risks of having a single admission compared to none.

Research on EP shows that there is a gradient in how EP affects health outcomes. Indeed, some international studies have observed that the association between EP and poor health outcomes varies according to the severity of EP (Bosch et al., 2019; Carrere et al., 2020; Cook et al., 2008). For instance, Bosch et al. (2019), demonstrated that the European low-income population over 16 years of age who self-reported being in extreme EP had a greater chance of perceiving their health as poor compared to those with less severe forms of EP. Additionally, Cook et al. (2008) reported that children younger than 3 from moderately and severely energy-insecure households had 2.37 and 3.06 times higher odds of experiencing food insecurity than those from energy-secure homes. This same study also showed that the association between EP and hospitalization was only significant for children from moderately energy-insecure households (Cook et al., 2008). While my thesis did not assess the severity of EP, the association between EP and hospitalization was stronger when multiple hospitalizations were considered as outcome variables (compared to one, or no hospitalization). Still, more research is needed to assess whether the severity of EP is associated with more severe health problems.

Outside of these main findings, another surprising result is that individuals from visible minority groups had a significantly lower risk of experiencing the different health outcomes. Perhaps this is due to the concentration of visible minorities in large urban areas where people generally have better health outcomes (CIHI, 2006; Mitura & Bollman, 2005). For instance, compared to rural areas, homes in urban regions tend to be smaller, more recently constructed, and the utility prices are lower (CUSP, 2019b; Marmot Review Team, 2011) which decreases the likelihood of experiencing EP and its adverse health effects. In this study, almost all individuals who are visible minorities lived in an urban area (98%), and precisely a CMA (95%) as shown in Table 12 in the Appendix. Another explanation could be that the aggregation of different ethnic groups within a broad category of “visible minorities” can mask some important differences across the various groups (Public Health Agency of Canada, 2018). For example, when looking at food insecurity in Canada, some ethnic groups such as Latin Americans, Blacks, Arabs, and West Asian are at higher risk than Caucasians whereas others like South and Southeast Asians are not (Public Health Agency of Canada, 2018). The healthy immigrant effect which stipulates that recent immigrants are healthier than the native population could also be a contributing factor. Still, a further assessment would be needed to verify whether a large portion of the visible minority groups was comprised of new migrants. In reverse, some visible minority groups may face difficulties in accessing healthcare, which could also explain the observed results.

Finally, although the prevalence of EP across the provinces is similar to what is reported elsewhere (Das et al., 2022; Riva et al., 2021), the lower risk observed for all health outcomes in provinces outside of Ontario was also unexpected. Perhaps this is due to the higher prevalence of health outcomes in Ontario compared to other provinces as shown in Table 13 in the Appendix.

Overall, this thesis adds to the limited body of evidence on the health effects of EP in Canada. It shows that EP has a significant and negative impact on objective measures of health such as cardiovascular, respiratory, and cardiovascular and respiratory-related hospitalizations in adults aged 40 and older.

6.1 Implications for policy

This thesis demonstrated that EP is an important determinant of cardiovascular and respiratory health in Canada. As the current Covid-19 pandemic forces people to isolate themselves at home when infected, exposure to EP and its adverse health effect is likely to have increased in the last few years. Hence, now more than ever, Canada should put in place a national EP strategy as other countries, such as the United Kingdom, have done. The first step in doing so would be to adopt an official definition and guidelines to measure EP and systematically monitor EP across the country. Secondly, the known root causes of EP should be targeted in public health, housing, energy, climate change, and social policies. Higher wages and programs that offer financial assistance can serve as a palliative and emergency solution to help low-income household pay their energy bills (Primc & Slabe-Erker, 2020). In this study, only 15 to 16% of the individuals in EP had a low after-tax income, thus reaffirming the idea that EP is a separate phenomenon from poverty. Therefore, policies that tackle the energy efficiency of dwellings would provide a longer-lasting solution.

Living in a home that requires major repairs was consistently associated with increased odds of being hospitalized at least once and greater relative risks of being hospitalized multiple times compared to none. This indicates that poor housing quality, which is likely to be energy inefficient, contributes to poor health outcomes. Housing energy efficiency interventions such as draught-proofing, boiler, heating system, and insulation upgrades, as well as glazing doors and windows, can simultaneously curb EP and contribute to the fight against climate change by reducing carbon emission (Sharpe et al., 2019; Thomson et al., 2009). If carefully designed with adequate ventilation, these energy retrofits also have the potential to improve health outcomes, especially among vulnerable groups such as young children, those with chronic illnesses, and older adults (Sharpe et al., 2019). In Canada, various energy efficiency programs are offered by federal and provincial governments and their agencies, natural gas and electricity providers as well as energy efficiency utilities (Gaede et al., 2021). These programs vary from providing LED light bulbs to more important weatherization upgrades (Das, Martiskainen, & Li, 2022; Das et al., 2022; Riva et al., 2021) but are not always aimed at reducing EP. Moreover, some of these programs are only targeted at homeowners (Riva et al., 2021), although renters are more vulnerable to EP and more likely to be hospitalized for cardiovascular, respiratory, and cardiorespiratory diseases. Also, in many cases, they do not reach low-income households and remote populations such as Indigenous communities who would benefit most from the interventions (Gaede et al., 2021; Riva et al., 2021). Indeed, targeted retrofit programs along with energy pricing policies are essential to help low-income households face rising energy prices as the country transition toward zero-emission housing (Lee et al., 2011). Therefore, federal action is needed to ensure funding, harmonize the different energy policies and programs that exist across the provinces and territories, and asses their effectiveness in tackling EP. For instance, although some provinces such as Quebec, Alberta and Ontario have banned the disconnection of utilities for residential customers, federal leadership could help regularize the policies around winter utility disconnection bans, and perhaps also enforce the implementation of disconnection bans during heatwaves (Riva et al., 2021).

The latest data from the 2015 Survey of Household Energy Use reveals that only 15% of households have received energy efficiency audits and at least 7% of them have followed through and received grants for retrofits (Hoicka & Das, 2021). To alleviate EP and achieve the goal of zero-net emissions by 2050, a substantial increase in the delivery of energy retrofits is needed (Government of Canada, 2022; Haley & Torrie, 2021). The new 2022 federal budget plan is promising as it proposes a $200 million investment over five years to support retrofit audits and accelerate the provision of deep retrofits through the creation of the Deep Retrofit Accelerator Initiative (Government of Canada, 2022). This program is also predicted to include a focus on low-income affordable housing (Government of Canada, 2022). Another interesting proposition is the investment of $33.2 million over five years to implement the Greener Neighbourhoods Pilot Program (Government of Canada, 2022). Rather than single retrofit projects, this program aims to retrofit entire neighbourhoods by adopting the "Energiesprong" model from the Netherlands, which "leverages economies of scale to make deep retrofits more cost-effective" (Fischer, 2021).

As improvements in energy efficiency make energy service more affordable, this could lead to a rebound effect where occupants increase their energy consumption (Monteiro et al., 2017). Although greater access to cooling can help households combat EP during the summer period, overreliance on air-conditioning further contributes to climate change. Thus, new housing constructions and retrofits should be designed to minimize the need of using air-conditioning. For instance, this can be done by favouring green facades and roofs as well as white roofs. The latter type of roof has been shown to remain 30°C cooler than a traditional gray roof during a sunny summer afternoon (UN Environment Programme, 2020). Such action would simultaneously contribute to protecting households against EP and heat stress as well as reduce CO_2 emissions.

6.2 Limitations

The methods utilized in this thesis have some limitations that should be considered. Since data on household energy cost and income came from the census, EP was only measured once at baseline. Therefore, although EP is a dynamic phenomenon, this thesis assumes that individuals' EP status remained constant throughout the 10 years. This could have biased the associations as some of the hospitalizations among people considered to be in EP could have occurred while they were out of EP. Moreover, the expenditure-based measures used to compute EP were based on actual energy spending rather than required energy needs. Although actual energy expenditure is easier to calculate, it does not represent the true energy expenses needed to maintain thermal comfort as it is affected by household energy decisions (Atsalis et al., 2016; Herrero, 2017; Moore, 2012; Thomson et al., 2017). Hence, using actual expenditure can mask situations of hidden EP where household significantly reduce their energy consumption to save on costs (Atsalis et al., 2016; Herrero, 2017; Moore, 2012; Thomson et al., 2017). Yet not many places other than the United Kingdom have large national surveys with detailed information on housing conditions that facilitate the calculation of households' specific energy requirements, which is why I relied on actual expenditures (Herrero, 2017; Moore, 2012).

When calculating EP, household incomes and energy costs were not equivalized for household size and composition. In fact, equivalizing energy is complex because energy requirements may vary a lot based on specific household needs (Herrero, 2017; Imbert et al., 2016; Riva et al., 2021), and commonly used income equivalence scales, such as the one from the Organisation for Economic Co-operation and Development, are old and do not account for regional variations in the cost of living (Herrero, 2017; Riva et al., 2021). Thus, as in other Canadian studies, equivalization was omitted. Instead, I adjusted my analyses for household structure. Moreover, the prevalence of EP reported in this study may be an underestimation since 21.42% of the sample (unweighted) had missing energy cost because it was either included in the rent, equal to zero or less, or greater than the household income after-tax.

The lack of information on smoking status and other risk factors for cardiovascular and respiratory disease within the CanCHEC and DAD is another major obstacle. Indeed, smoking is an important risk factor for both cardiovascular and respiratory disease, thus the associations observed between EP and the different outcomes may be biased. It should also be mentioned that, although the provinces presented in the regression represent the location of residence at baseline, throughout the follow-up time individuals could have had out-of-province hospitalizations.

Chapter 7: Conclusion

To my knowledge, this thesis is the first to use a large population-based linked dataset to explore the health impacts of EP within the Canadian context. Previously, a study showed that energy-poor Canadians have poorer self-rated general health and mental health (Riva et al., in press). My study provides added evidence that EP is associated with poor cardiovascular and respiratory health in adults. Indeed, using expenditure-based measures of EP, this research demonstrated that Canadians aged 40 and over and experiencing energy poverty are significantly more likely to be hospitalized at least once for cardiovascular, respiratory, and cardiovascular or respiratory diseases than those who are not between 2006/2007 and 2016/2017. The associations were also shown to be independent of housing conditions, socioeconomic and geographic factors. This thesis also showed that the relative risks of being hospitalized once or multiple times for cardiovascular, respiratory, and cardiorespiratory problems relative to zero are significant. Overall, these results indicate that EP is an imported housing-related determinant of health in middle-aged and older Canadians.

Nowadays, with the ongoing Covid-19 pandemic and the stay-at-home measures, the prevalence and impact of EP on cardiovascular and respiratory health are likely to have increased. Therefore, the integration of EP within Canadian policies is even more urgent. This will require multidisciplinary and coordinated action from governments, utility companies, and the housing sector to ensure that households are able to afford their energy bills and live in sustainable and energy-efficient dwellings that protect their health. As the country transitions towards zero-net emissions, energy retrofit programs will become an essential part of the strategy to reduce both carbon emissions and energy poverty.

7.1 Future research

While this study focused on examining the impact of EP on cardiovascular and respiratory-related hospitalization of Canadians aged 40 or more, further work should explore how these associations vary for specific vulnerable groups such as young children, older adults, renters, Indigenous populations, etc. It would be pertinent for further work on EP and health to include seasonality and distinguish between winter and summer energy poverty. This would provide a greater understanding of the role of EP on excess seasonal hospitalizations and add to the limited evidence available on the association between EP and heat stress. Such analysis could help further advocate the integration of cooling needs within EP discourse, especially within the context of climate change and the rising frequency and severity of hot weather events. Another avenue of research that would be worth investigating is the impact of EP on cardiovascular and respiratory-related mortality. Lastly, since international studies have shown that some residential energy interventions have the potential to improve health outcomes, there is also an important need for interventional studies that can help identify best practices to reduce EP and protect the health of Canadians.

In conclusion, this thesis generated new knowledge on some of the impacts of EP on the health of Canadians but more research in this domain is needed to explore the full scope of how EP influences the health of Canadians and ways to address it.

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Appendix

Table 10. Descriptive statistics of Canadian aged 40 years and above living in the provinces for the whole sample and those in EP (10%), 2006 CanCHEC

Variables and categories	Energy poverty – 10% threshold
Energy poverty measures	**Yes % (95%CI)**
Energy poverty – 2M	
Yes	100
Energy poverty – 10% threshold	
Yes	--
Health measures	
Chronic illness or disability status	
Yes	52.50 (52.20, 52.80)
A single or more cardiovascular hospitalization	
Yes	20.14 (19.91, 20.37)
A single or more respiratory hospitalization	
Yes	10.20 (10.02, 10.39)
A single cardiovascular or respiratory hospitalization	
Yes	27.45 (27.18, 27.72)
Total cardiovascular hospitalizations	
0	79.86 (79.63, 80.09)
1	14.95 (14.75, 15.16)
2 or more	5.18 (5.06, 5.31)
Total respiratory hospitalizations	
0	89.80 (89.61, 89.98)
1	7.60 (7.45, 7.75)
2 or more	2.61 (2.52, 2.70)
Total cardiovascular or respiratory hospitalizations	
0	85.66 (85.45, 85.88)
1	5.61 (5.48, 5.75)

2 or more	8.73 (8.56, 8.90)
Socioeconomic characteristics	
Sex	
Male	41.97 (41.68, 42.26)
Female	58.03 (57.74, 58.32)
Age group	
40-54 years	24.68 (24.42, 24.94)
55-64 years	23.58 (23.34, 23.83)
65-74 years	23.62 (23.38, 23.87)
75 years and older	28.11 (27.86, 28.37)
Education	
Less than secondary school	41.90 (41.61, 42.18)
Secondary school completed (or equivalent)	34.22 (33.95, 34.49)
Postsecondary education (below university)	23.88 (23.62, 24.15)
Marital status	
Married or living in common law	52.26 (51.97, 52.55)
Single or never married	7.79 (7.64, 7.95)
Separated, divorced, or widowed	39.95 (39.67, 40.23)
Visible minority and Indigenous status	
Not a visible minority	87.08 (86.88, 87.27)
Visible minority	8.83 (8.67, 9.00)
Indigenous	4.09 (3.99, 4.19)
Low-income after-tax status	
No	81.71 (81.48, 81.93)
Yes	18.29 (18.07, 18.52)
Housing conditions and setting	
Housing tenure	
Rented	14.30 (14.10, 14.51)
Owned	85.70 (85.49, 85.90)
Repairs needed to the dwelling	
Only regular maintenance	59.25 (58.97, 59.52)
Minor repairs	29.59 (29.32, 29.86)

Major repairs	11.17 (10.99, 11.35)
Year of construction of the dwelling	
1960 or before	38.89 (38.58, 39.20)
1961-1980	32.91 (32.62, 33.20)
1981-2006	28.20 (27.93, 28.48)
Dwelling type	
Single-detached	77.70 (77.46, 77.94)
Semi-detached, double, row, duplex, other single-attached	13.87 (13.67, 14.07)
Apartment	6.10 (5.95, 6.25)
Mobile home	2.33 (2.25, 2.42)
Household structure	
Person living alone	35.16 (34.89, 35.43)
Couple with children	14.40 (14.20, 14.61)
Couple without children	37.12 (36.85, 37.39)
Lone-parent family	9.03 (8.86, 9.20)
Other	4.29 (4.17, 4.41)
Household size	
1	35.16 (34.89, 35.43)
2	43.55 (43.27, 43.83)
3	9.82 (9.65, 9.99)
4	6.32 (6.17, 6.47)
5 and more	5.15 (5.02, 5.29)

Table 11. Geographic situation of Canadian aged 40 years and above living in the provinces for the whole sample and those in EP (2M), 2006 CanCHEC

Variables and categories	Energy Poverty – 10% threshold % (95%CI)
Urban/rural setting	
Urban	14.94 (14.84, 15.04)
Rural	23.08 (22.88, 23.29)
SAC	
CMA	14.22 (14.13, 14.35)
CA	16.96 (16.73, 17.19)
Strong or moderate MIZ	23.18 (22.90, 23.46)
Weak or no influence MIZ	24.54 (24.23, 24.85)
Province	
Ontario	17.92 (17.78, 18.06)
Atlantic Provinces	25.90 (25.62, 26.18)
Prairies	15.95 (15.76, 16.14)
British Columbia	11.40 (11.24, 11.56)

Table 12. Visible minority and Indigenous status variation across rurality and SAC, 2006 CanCHEC

	Rurality		**SAC**			
Visible minority and Indigenous status	**Urban**	**Rural**	**CMA**	**CA**	**Strong or moderate MIZ**	**Weak or no influence MIZ**
Not a visible minority	75.76 (75.66, 75.86)	24.24 (24.14, 24.34)	59.12 (59.03, 59.22)	17.13 (17.04,17.21)	13.36 (13.29, 13.43)	10.40 (10.33, 10.46)
Visible minority	97.71 (97.62, 97.81)	2.29 (2.19, 2.38)	95.01 (94.87, 95.14)	3.19 (3.08, 3.31)	0.89 (0.84, 0.95)	0.91 (0.85, 0.97)
Indigenous	55.45 (54.97, 55.93)	44.55 (44.07, 45.03)	33.01 (33.49, 34.54)	19.45 (19.03, 19.88)	14.25 (13.89, 14.61)	32.29 (31.87, 32.71)

Table 13. Distribution of the main health outcomes by province, 2006 CanCHEC

Variables and categories	**A single or more cardiovascular hospitalization % (95%CI)**	**A single or more respiratory hospitalization % (95%CI)**	**A single or more cardiovascular or respiratory hospitalization % (95%CI)**
Province			
Ontario	19.56 (19.45, 19.67)	8.54 (8.46, 8.62)	25.87 (25.74, 26)
Atlantic Provinces	16.95 (16.74, 17.16)	7.85 (7.69, 8.01)	22.64 (22.41, 22.87)
Prairies	15.80 (15.64,15.95)	7.96 (7.85, 8.08)	21.70 (21.52, 21.88)
British Columbia	13.03 (12.89, 13.18)	6.06 (5.95, 6.17)	17.58 (17.42, 17.75)