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# Achieving a low carbon housing stock: An analysis of low-rise residential carbon reduction measures for new construction in Ontario

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## ABSTRACT

Residential buildings contributed 14% of Canada's greenhouse gas emissions in 2014, making this sector pivotal to climate change mitigation. In 2016, the provincial government of Ontario, Canada mandated a net-zero carbon standard for new "small buildings" by 2030, meaning the low-rise residential sector must undergo major changes to meet this target. Through an energy modelling analysis of a typical single-family home in Ontario, this study demonstrates the potential carbon emissions savings of different reduction strategies, including changes to the building envelope and mechanical system. The most effective strategies include increasing building airtightness, installing additional exterior insulation, and switching to an air source heat pump for heating and cooling. These strategies were then analysed based on the incremental cost above a house built to the building code baseline. In terms of cost per kilogram of carbon mitigated, the most efficient strategies are further insulating the basement, adding additional exterior insulation, and increasing the efficiency of the heat recovery ventilator. Finally, a policy discussion demonstrates that carbon reductions implemented at the design stage must be verified and monitored post-occupancy using policy tools such as energy reporting and small-scale performance studies.

## 1. Introduction

Buildings are a significant source of greenhouse gas (GHG) emissions, which contribute to the acceleration of climate change. As such, countries internationally are targeting the building sector in their climate change mitigation plans. In June 2016, the provincial government of Ontario, Canada, released its Climate Change Action Plan (CCAP) outlining a five-year plan to transition to a low-carbon economy [1]. The Plan aims to reduce provincial GHG emissions by 80% below 1990 levels by 2050, which is consistent with the goals of other local jurisdictions, such as the City of Toronto [1,2]. As buildings account for nearly a quarter of all GHG emissions in Ontario, the CCAP specifically defines how reductions in this sector will be made [1]. One defined priority is facilitating updates the Building Code by 2030 with energy efficiency targets for achieving net-zero carbon emissions in "small buildings". In July 2017, the City of Toronto approved a similar plan which mandates that all new buildings will be designed and constructed to be near zero GHG emissions by 2030 [3].

Residential buildings alone accounted for 14% of national GHG emissions in 2014, making changes in this subsector critical for achieving reduction targets [4]. Furthermore, in Ontario, 64% of residential dwellings are single detached houses, making this building type key in the discussion of provincial GHG reduction as well [5]. Therefore, this study examines the effectiveness of several low-carbon technologies to assess their applicability for high performance single-family detached residential construction. The analysis uses a combination of energy modelling, carbon calculation, and cost estimation to determine the most effective strategies to achieve net-zero carbon homes. The central objective of this analysis is to determine the most efficient strategies for transforming the new low-rise residential building stock to net-zero carbon in terms of cost per kilogram of carbon mitigated. This methodology can easily be adopted by other jurisdictions seeking to allocate funding and direct policy to create net-zero or near-zero carbon housing.

The paper begins with an overview of existing literature. Next, the methodology and materials used for the analysis are described. The results of the energy modelling, carbon calculation, and cost estimation are then summarized and discussed, including a discussion on the policy strategy to supplement the work. Finally, a set of recommendations and conclusion is outlined.

## 2. Background

Building sector policies are currently trending toward high

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performance, climate conscious practices. However, there is variation in terminology among jurisdictions where some are targeting net-zero energy buildings, others *near*-zero energy, while others specifically target carbon emissions. To avoid misinterpretation and promote international collaboration, it is important to understand these terms within the context of their similar alternatives. Existing literature defines and discusses the differences among green building terminology and encourages international cooperation in resolving priorities in policy and research [6,7]. In Ontario, the CCAP has specified a *net-zero carbon* target for "small buildings" by 2030, with initial changes to the building code by 2020 [1].

This study was initially inspired by a previous study by Di Placido et al. [8] which demonstrated the investment potential of designing beyond the building code. However, a new building code, evolving legislation focused on carbon reductions, and recently introduced carbon pricing policy has renewed this discussion and necessitated a carbon-centric analysis approach. The Ontario Building Code (OBC) affecting housing experienced a significant shift in 2012, and more recently again with the introduction of the 2017 revision of Supplementary Standard SB-12 Energy Efficiency for Housing [9]. Each code iteration has increased the requirements for energy efficiency in housing, aiming to reduce carbon emissions [1]. Specifically, the prescriptive packages in the 2017 edition of SB-12 are anticipated to reduce energy use by at least 15% from the 2012 edition [10]. These new changes should therefore be tested and assessed for their progress toward an ultimate goal of net-zero carbon housing.

Several studies have explored possible avenues for achieving low-energy, climate resilient residential buildings [11–14]. Existing literature has also begun to define the technical, economic, and legislative barriers involved in the transition to low carbon building practices [15,16]. These include a lack of clarity in legislative language concerning desired outcomes, perceived lack of consumer interest in zero carbon housing, shortage of financial incentives, and the steep capital costs of district scale solutions. There is some insight into the cost of building net-zero carbon or comparable housing [17,18], but little that describes the incremental increases during the ongoing transition from traditional building practices. Specifically, little research has been done to describe the most cost-effective means of achieving net-zero carbon performance in new single-family residential buildings.

Policy plays a pivotal role in the successful transition from conventional housing to net-zero carbon. Furthermore, policy tools may address the frequent discrepancy between modelled energy performance and actual performance. The literature suggests this discrepancy is due to a variety of factors, including assumptions made for unknown or absent information, poor availability of data for plug loads, and the impact of occupant behaviour [19–22]. The feasibility of energy reporting programs and alternative building codes, such as outcome based codes, has typically only been explored for large buildings [19,23–27]. This study builds on this previous work to adapt energy monitoring practices to the low-rise residential sector.

## 3. Material and methods

The study is comprised of three phases. The first phase involved creating an energy model of a baseline home to establish how homes designed to the new 2017 building code minimum are likely to perform. Energy efficiency improvements were also modelled to determine their effectiveness in reducing annual energy consumption. The second phase involved converting this energy consumption to a universal carbon-based metric for direct comparison to GHG emission reduction targets. Within the context of this study, GHG emissions are addressed in terms of their carbon equivalence, kilograms $CO_2$eq or more broadly "carbon emissions". Finally, a costing study was performed to estimate the incremental costs of implementing measures at the construction stage which were associated with carbon savings. The results of this study are further examined within the context of policy tools that may verify actual carbon reductions.

### *3.1. Energy modelling*

The first phase of the study involved assessing the impact of efficiency measures on the energy consumption of the building. A two-storey detached single-family house was modelled in the HOT2000 energy simulation software. HOT2000 was selected as it is widely used across Canada in industry regulation and development, particularly for single family housing [28]. It is an official simulation engine for the EnerGuide Rating System for homes, ENERGY STAR for New Homes, and R-2000 energy efficiency programs [28]. The software was developed by the Office of Energy Efficiency at Natural Resources Canada (NRCan).

The modelled house parameters, such as conditioned floor area and glazing area, were selected to represent the average dwelling in Ontario based on the Survey of Household Energy Use (SHEU) performed by Statistics Canada and NRCan [5]. The SHEU is a combination of two phases of computer-assisted telephone interviews and mail-back questionnaires sent to residential occupants through household energy suppliers [5]. Each of the data points are assigned a quality code based on the coefficient of variation for the estimate [5]. Only data labelled as "Acceptable", the highest level of confidence, were used in this study. The energy models in this study were compared to the SHEU data for detached single-family homes built in Ontario between 2000 and 2011.

The modelled mechanical system and envelope were designed to the Ontario Building Code (OBC) minimums. The OBC provides two main paths for compliance; prescriptive compliance and performance compliance [9]. The prescriptive path includes a series of building packages based on climate and space heating type. These define minimums for envelope and mechanical components such as wall insulation and space heater efficiency. The performance compliance path allows designers more freedom in selecting building parameters, given the simulated energy use of the building meets the designated performance level. Alternatively, compliance to the technical requirements of the NRCan Energy Star for New Homes Standard or R2000 Standard also satisfies compliance in the OBC [9].

In this study, the modelled mechanical and envelope parameters were defined by a prescriptive compliance package (Package A3 in Table 3.1.1.2.A) defined in the 2017 edition of Supplementary Standard SB-12 Energy Efficiency for Housing [9]. The Toronto climate, which falls under the climate category "Zone 1" in the OBC, was modelled in the simulation. For reference, Toronto is in ASHRAE Climate Zone 6. To achieve net-zero carbon performance, both envelope and mechanical parameters must be optimized. The considered envelope parameters are defined in Table 1, while the mechanical parameters are defined in Table 2.

The building envelope includes all parts of the building that separate the exterior and interior environments [29]. Several envelope parameters regulated by the building code were isolated in the simulation and examined for their impact on overall energy consumption. These parameters were gradually improved based on reasonable construction practices and product availability. The resulting improvements for each parameter were determined by calculating the difference in energy between each new model and the original 2017 OBC code minimum baseline model.

A similar analysis was performed on the mechanical system, as shown in Table 2. All modelled mechanical efficiencies were the rated values provided by the manufacturer, with the exception of the air source heat pump. The HOT2000 default calculation of air source heat pump efficiency was replaced with a more rigorous approach. Since air source heat pumps have lower efficiencies in cold climates such as that of Toronto, the default simulation would have overestimated the benefit [30]. The impact of the heat pump was calculated using a curve fit to the rated efficiencies at various operating temperatures. This allowed the use of different efficiencies corresponding to average monthly temperatures, creating a more accurate profile of the heat pump's energy consumption.