Assessing whole life carbon impacts of retrofitting Canada's 19th and early 20th century homes towards net-zero.

MANCINI, A., SEDIKKI, M. and SCOTT, J.

2025

BUILDINGS FIT FOR CLIMATE CHANGE

ICAT 2025 ALICANTE

TAHAR KOUIDER
ANTONIO GALIANO GARRIGÓS

CONFERENCE PROCEEDINGS
11th International Congress on Architectural Technology
15-17 May 2025 University of Alicante - SPAIN

UNIVERSIDAD DE ALICANTE

BUILIDINGS FIT FOR CLIMATE CHANGE

ICAT 2025

TAHAR KOUIDER
ANTONIO GALIANO GARRIGÓS

CONFERENCE PROCEEDINGS OF THE
11TH INTERNATIONAL CONGRESS ON
ARCHITECTURAL TECHNOLOGY
15-17 MAY 2025
UNIVERSITY OF ALICANTE - SPAIN

UNIVERSIDAD DE ALICANTE

Publisher: UNIVERSIDAD DE ALICANTE
Carretera San Vicente del Raspeig s/n
03690 San Vicente del Raspeig - Alicante
Tel.: +34 965.90.34.00
https://dca.ua.es/en/icat2025alicante/home.html

Edited by: Tahar Kouider & Antonio Galiano Garrigós

ISBN: 978-84-1302-318-2
D.L.: A 201-2025
May 2025

Cover Images: Antonio Galiano Garrigós & Francisco Marco Peñas
Proof-reader: Tahar Kouider

Board Members

International Scientific Committee

Organization

University of Alicante, Spain.
Dept.Construcciones Arquitectónicas:
Technician Beatriz Piedecausa-García and Administration staff of the Department

ACKNOWLEDGEMENTS

The International Congress on Architectural Technology (ICAT) would like to express their thanks and gratitude to all those who helped and contributed to the organisation of the eleventh conference and the production of these proceedings:

The authors who contributed papers and presentations

The University of Alicante and its staff for hosting the conference. Especially to the administration staff of the Department of Architectural Constructions and to the technician Beatriz Piedecausa-García for her coordination work.

Members of the ICAT Board

Members of the conference Scientific Committee

Dr Antonio Galiano-Garrigós for chairing the conference and coordinating associated events

Dr. Ángel Benigno González-Ávilés for his support in the organization of the Congress

Tahar Kouider for editing the proceedings.

Dr Malachy Mathews ICAT Chair for his valuable contributions

The Casa Mediterráneo and the Orihuela City Council for their institutional support and for hosting the associated events

The Colegio Territorial de Arquitectos de Alicante for its institutional support and support in the organization of the Students' Event and key lectures

AEDAS Homes for its support in the organization of the key lectures

Newker for sponsoring the Students' Event

C3Systems for sponsoring catering

ASSESSING WHOLE LIFE CARBON IMPACTS OF RETROFITTING CANADA'S 19TH AND EARLY 20TH CENTURY HOMES TOWARDS NET-ZERO

A. MANCINI, M. SEDDIKI
Scott Sutherland School of Architecture and Built Environment, Robert Gordon University,
Email address: a.mancini@rgu.ac.uk
m.seddiki1@rgu.ac.uk

AND

J. SCOTT
Email address: j.r.scott@rgu.ac.uk

Abstract. The ongoing climate crisis provides a unique challenge within the residential sector to reduce greenhouse gas emissions by 2050 in response to Canada's net-zero goal. Although legislation has been put in place to address the decarbonisation of the existing housing stock, the challenging goal set by the Canadian government requires action beyond current energy guidelines. This poses a difficult challenge regarding the retrofit of housing built in the 19th and early 20th century. The extensive retrofit needed to bring these houses to the highest level of residential sustainability may counteract the idea of national zero-carbon when considering embodied carbon. This paper seeks to evaluate the whole-life carbon impacts of implementing deep retrofits in 19th and early 20th-century Canadian homes using the EnerPHit standard. To achieve this objective, the study compares whole-life carbon emissions under a non-retrofit baseline and a retrofit scenario that adheres to the EnerPHit standard, focusing on homes in Southern Ontario. HOT2000 Energy simulation software was used to assess the operational energy consumption, while One Click LCA was used to evaluate the whole life carbon of the two scenarios. This study found that the deep retrofit resulted in a 60% reduction in annual operational emissions compared to the baseline scenario. The whole-life carbon assessment further demonstrated a 48% reduction in total emissions over a 60-year period, with a carbon payback period of 6.8 years. These results imply that adapting this retrofit strategy would be beneficial to meeting Canada's 2050 net-zero goals, as the operational energy savings are superior to the total embodied carbon associated with the retrofit strategy.

Keywords: Net-Zero; Retrofit, whole life Carbon, Canada,

1. Introduction

Due to the climate crisis, Canada and other nations have increased their attention on energy consumption and demand reduction across all economic sectors to reduce greenhouse gas (GHG) emissions (Prabatha, Hewage et al. 2020). Legislation under the Canadian Net-Zero Accountability Act has been implemented to commit to reducing annual greenhouse gas emissions; this comes to support the government's net zero emissions target set for the year 2050 (NRCan 2020). To achieve this goal, the government of Canada put in place a new 2030 emissions reduction plan that sets to reduce Canada's annual carbon emissions by 40 to 45 percent of 2005 emission levels. This increased from its original 2030 target to reduce emissions 30% below 2005 levels. The increase in its ambition to reduce emissions stems from increasing global pressure to limit the impacts of climate change, which aligns with commitments under the Paris Agreement (NRCan 2020). This is the first emissions reduction plan issued under the Canadian Net-Zero Accountability Act (NRCan 2020). Further progress reports and legislation are set to periodically be curated every five years until 2050 to ensure the targets are met. In December 2024, Canada released a new 2035 GHG target to reduce emissions 45 to 50 percent below 2005 levels, but no new plan has been released yet outlining actions to meet this new target. The Government of Canada has outlined a sector-by-sector overview of commitments to meet its 2030 targets. The government of Canada's most recent national inventory report stated that the national GHG emissions were equal to 670 Mt CO_2e in 2021. The breakdown by economic sector showed that buildings contributed 87 Mt CO_2e (13%). In turn, the residential sector was responsible for 37 Mt CO_2e (5.52%), the largest emitter within the buildings sector (Environment and Natural Resources Canada 2023). As a result, Canada's government has implemented a Green and Inclusive Community Buildings program to address 2030 emissions reductions in residential housing through retrofits, repairs, and upgrades to existing or new housing stock. They also launched the Public Buildings Retrofits Initiative for green infrastructure deep retrofits of large buildings through a retrofit accelerator initiative, as well as a green building strategy to support provinces decarbonising their building stock (NRCan 2020).

In January 2025, Ontario, the most populated province in Canada, released the Home Renovation Savings Program, the largest investment in energy efficiency in Canadian history, to improve the efficiency of the existing housing supply. Many urban neighbourhoods in southern Ontario contain 19th-century to early 20th-century homes in cities such as Toronto, Hamilton, and Waterloo. These historic houses symbolise early development, as areas around them developed urban sprawl and modern housing. Although new housing meets modern efficiency standards, historic homes remain in their original state, far below current energy efficiency and human comfort regulations. To reach net zero by 2050, retrofitting these homes is necessary to meet decarbonisation targets. However, the extensive retrofit needed to bring these houses to the highest level of residential sustainability may counteract the idea of national zero-carbon when considering the entire carbon trail and looking beyond annual carbon consumption.

Although legislation and action have been taken towards sustainable new housing in Canada, this is not evident in practice and can not be observed in current housing developments in 2023. Current legislation in part 9, housing and small buildings and part 11 renovations of the Ontario and national building code are insufficient to meet the 2050 net carbon goal (Bastian, Schnieders et al. 2022). Ontario offers an appropriate field of study, as Ontario is prioritising the energy efficiency of existing buildings and building code requirements have recently been harmonised with National building codes Furthermore, Little attention and research have been prioritised to retrofit the existing housing stock in Canada, which is the current source of all residential carbon emissions. Without steps towards or further incentives on retrofitting the current stock, annual carbon emissions in the building sector can only be expected to rise from the current average.

Other studies that focused on building retrofit in Canada largely fixated on the reduction of operational carbon emissions and primarily did not focus on whole life cycle analysis; furthermore, studies that did consider Life Cycle Assessment (LCA) in their retrofit strategy did not consider housing built before the 20th century such as

(Prabatha, Hewage et al. 2020). Therefore, this paper seeks to evaluate the whole-life carbon impacts of implementing deep retrofits in 19th and early 20th-century Canadian homes using the EnerPHit standard. To achieve this objective, the study compares whole-life carbon emissions under two scenarios: a non-retrofit baseline and a retrofit scenario that adheres to the EnerPHit standard, focusing on homes in Southern Ontario.

2. Literature Review

2.1. CANADIAN CONTEXT

2.1.1 19th-century to early 20th-century houses in canada

Houses built from the 19th to early 20th century in Canada (see figure1) evolved over time; therefore, there are different types of construction within this period; the most typical house would be Victorian architecture. Roof structures are made with milled lumber. This lumber rests on a sill plate supported by the exterior structural facade. Above the rafters sit wood planks which are topped with an asphalt membrane before being finished with asphalt shingles.

Figure 1: 19th-century to early 20th-century home

Structural walls for these buildings consist of interlocking bricks or stone (e.g., double brick facade), cement, lime, or cement lime mortar (Straube, Schumacher 2007). This study will focus on interlocking bricks in a double-skin facade, this structural wall is common in houses built in this century. These houses did not contain insulation, and later in the century, only minimal amounts were added between the 100-millimetre studs, using oil burning or fireplaces to heat the home. This method of human comfort may have been the most practical for the time; however, in 2023, the majority remain in this condition, falling far below the minimum requirements of thermal insulation in the Ontario building code, and instead continue to utilize high carbon emitting heating sources that work against Canada's climate targets.

2.1.2 Current Energy Guidelines and Standards in Canada

To address the retrofit of the existing housing stock, the government of Canada introduced EnerGuide, an assessment tool that assesses all aspects of a dwelling, such as airtightness, insulation levels of the walls and roof, windows, efficiency of heating and cooling equipment, as well as any other systems relating to the dwelling energy performance (NRCan 2018). This assessment then results in an EnerGuide label listing the overall performance rating of the dwelling and a renovation upgrade report. The performance upgrades in this report will outline the retrofit upgrades needed to meet a higher or even the best Energy Star rating (NRCan. 2018). Other studies have used this evaluation and design guide toward the deep retrofit of existing houses in Canada.

To achieve net-zero operation, other standards that target a higher level of sustainability than the current building code regulations (which have not been adjusted yet to align with government climate goals) must be utilised. Design standards for new construction, such as the ones developed by the Passivhaus Institute (PHI), are available. Energy standards toward deep retrofit of existing buildings are less prevalent, although standards such as EnerPHit have created retrofit guidelines for deep retrofits (Mohammadpourkarbasi, Riddle et al. 2023). The EnerPHit standard uses the same criteria as the Passivhaus standard; however, certain relaxations have been incorporated for retrofitting. These relaxations account for some common difficulties associated with converting existing buildings, such as air tightness and implementing passive strategies (Mohammadpourkarbasi, Riddle et al. 2023). The Enerphit standard can be achieved through two different methodologies: either heating demand, which is based on limits in terms of space heating demand, or the component methods, which are based on limits in terms of U-values.

2.2. PREVIOUS STUDY ON EMBODIED CARBON APPLIED TO RETROFIT

Although design standards such as EnerPHit outline reducing operational carbon through building standards and retrofit strategies, other factors contribute to annual global carbon emissions, such as embodied carbon of materials and building systems. Life cycle analysis (LCA) is a method of analysing the impact materials have on the environment over their life cycle, this includes the associated carbon from the material extraction, operational, and disposal phases. The embodied carbon of a material is comprised of the carbon emitted throughout the LCA phases over the product lifespan (Finnveden, Potting 2014). A holistic approach must be taken to determine what will best contribute to the reduction of annual carbon emissions in Canada; this includes an LCA of the proposed retrofit to determine the total embodied carbon of the retrofit components from material extraction to disposal.

Research by the University of British Columbia determined that the most common approach used for LCA is the cradle-to-grave system, which considers emissions of the manufacturing operational and disposal stages. This approach disregards emissions from the transportation and construction stages as previous literature has deemed it insignificant (Zhang, Hewage et al. 2021) (Feng, Liyanage et al. 2020); however, One Click LCA considers these phases within their calculations.

Previous studies that assessed the LCA of residential housing in Canada chose typologies that exhibited the highest potential for improving energy efficiency by adding a deep retrofit. These were houses erected between 1970-1979 and 1980-1999 and considered the age of construction, energy source and equipment, airtightness, and insulation to be the highest source of emissions associated with buildings (Prabatha, Hewage et al. 2020) (Wu, Mavromatidis et al. 2017) (Zhang, Hewage et al. 2021). This literature is one example of LCA studies on modern building typologies, indicating a need for additional research on older housing.

Studies on LCA conducted in the United Kingdom possessed a similar archetype and age to 19th to early 20th-century homes in southern Ontario. The LCA assessment of six retrofit scenarios of varying levels revealed that EnerPHit plus with naturally derived materials had the lowest impact on the environment compared to other strategies that utilised petrochemically derived materials. The utilisation of a deep retrofit strategy using EnerPHit was shown to contain higher levels of embodied carbon compared to shallow retrofits. However, the impact of EnerPHit standards over 60 years showed substantial energy savings compared to other strategies (Mohammadpourkarbasi, Riddle et al. 2023). This shows that although an invasive approach to retrofit contains higher embodied carbon values, the energy savings throughout the lifespan of the building make it an option to contribute to meeting Canada's 2050 net-zero target.

Using a shallow retrofit strategy over the 60-year period yielded results three times higher than those found using EnerPHit plus with naturally derived materials; the study notes that using heat pumps doubled the carbon impact. Results found that strategies without heat pumps and solar panels yielded lower operational carbon values; however, the addition of these systems increased the embodied carbon of the retrofit; nevertheless, when utilised, the operational carbon was anywhere from 2.6 to 6.4 times lower than the embodied carbon energy per year. The study also outlined that the use of more insulation and naturally derived materials was beneficial in reducing whole-life carbon, rather than the shallow retrofit with renewable or more efficient technologies; however, when considering future climate conditions and the need for cooling and ventilation, utilisation of these energy sources could future proof a retrofit (Mohammadpourkarbasi, Riddle et al. 2023).

Following the Enerphit guidelines, using petrochemical-derived materials may lead to initially higher embodied carbon; however, when considering the building lifespan, this approach yields more energy savings. This philosophy also applies to renewable energy sources, as the future increase in energy demand establishes the importance of incorporating these technologies in the retrofit strategy despite their additional embodied carbon. This can be justified as the literature suggests that on-site energy production is cleaner than renewable energy from the grid (Piccardo, Dodoo et al. 2020). The results found from these studies provide a crucial structure to approaching the LCA of 19th to early 20th-century homes, and the technologies utilised to create the most sustainable retrofit package can be incorporated in the analysis of this study.

2.3. GAP IN THE LITERATURE

Although research has been completed on the deep retrofit of historic Canadian homes dating back to the 19th century, and LCA studies on the deep retrofit of the existing housing stock in Canada, current research has yet to directly assess the LCA of a deep retrofit of this housing typology. This study aims to determine whether the deep retrofit of 19th to early 20th-century homes in southern Ontario to EnerPHit standards will positively contribute to meeting Canada's 2050 net-zero goal or if the embodied emissions associated with a retrofit of this magnitude will outweigh the payback period for this strategy to be beneficial.

3. Materials and Methods

A case study approach was employed to compare the whole-life carbon emissions of 19th to early 20th-century homes in Southern Ontario under two scenarios: a non-retrofit baseline and a retrofit scenario meeting the EnerPHit standard. This approach has been used for a similar purpose by many researchers to compare different approaches of refurbishment options and their effect on LCA (Mohammadpourkarbasi, Riddle et al. 2023).

3.1. CASE STUDY SELECTION

The Baseline model for this study is a 381 sq.m gothic revival home built in 1856, located in Branford, Ontario. It should be noted that the size of this house is larger than the average house of this typology in Ontario (see Figure 2). The case study was chosen due to its age, well-maintained condition, materiality, building fabric, structural system, and building components, all of which make it representative of typical 19th- to early 20th-century homes in Southern Ontario. The structural components of the house follow the principles commonly found with this housing typology. The model contains a triple-layer interlocking brick foundation, and a floor made of one course of brick. Above grade walls is a double brick façade with a thickness of 150mm and utilizes the fabric components of this construction type. The interior walls contain a 25mm air gap, 100mm lumber studs, and lath and plaster. The roof is made of rough-cut wood joists covered with wood planks and sealed with an asphalt membrane and shingles, and the floor structure is built up of rough-cut wood joists bearing on an intermittent rough-cut log.

Figure 2: Base model existing Floor plans. (King Homes Inc., Mancini 2022).

3.2. OPERATIONAL CARBON MODELING

Energy consumption and building performance have been analysed using HOT2000 software. The energy simulations were performed for both; a non-retrofit baseline and a retrofit scenario that adheres to the EnerPHit standard, HOT2000 software has been sourced from Natural Resources Canada (NRCan 2018), and as previously mentioned, has been used in other studies for the analysis of an energy model for deep retrofit in Canada. Other studies that have looked at LCA studies, such as those by the University of Liverpool by (Mohammadpourkarbasi, Riddle et al. 2023) utilised SAP 10.0 in conjunction with One Click LCA, however, as this is a UK-based software, the conclusion of using an energy simulation tool with a north American derived database was justifiable to achieve the most accurate results. As HOT2000 is an industry standard for energy simulation in Canada, selections within the software include the option for EnerGuid rated products, this will be a key component during the analysis of the deep retrofit.

3.3. RETROFIT SOLUTIONS

The retrofit strategy has been adopted from previous literature looking at deep retrofit and new construction (Mohammadpourkarbasi, Riddle et al. 2023) (Prabatha, Hewage et al. 2020). studies that completed deep retrofit strategies using EnerPHit and EnerGuide on housing typologies constructed within the 19th to early 20th century took a holistic approach to retrofit these houses, with upgrades to air tightness, insulation, HVAC systems, and windows and doors being the most beneficial changes to this typology (Mohammadpourkarbasi, Riddle et al. 2023). As mentioned in the literature review, the EnerPHit standard uses the same criteria as the Passivhaus standard, but with relaxations incorporated for retrofitting. Previous literature suggests the utilization of EnerPHit resulted in significant energy savings under similar climate conditions (Mohammadpourkarbasi, Riddle et al. 2023) Criteria to achieve Enerhphit Standard through the building component method are outlined in Table 1 below.

TABLE 1: EnerPHit Criteria for the Building Component Method

Climate zone according to PHPP	Opaque envelope[1] against... ...ground	...ambient air			Windows (including exterior doors) Overall[4]			Glazing[5]	Solar load[6]	Ventilation	
	Insu-lation	Exterior insulation	Interior in-sulation[2]	Exterior paint[3]							
	Max. heat transfer coefficient (U-value)			Cool colours	Max. heat transfer coefficient ($U_{D/W,installed}$)			Solar heat gain coefficient (g-value)	Max. specific solar load during cooling period	Min. heat reco-very rate[7]	Min. hu-midity re covery rate[8]
	[W/(m²K)]			-	[W/(m²K)]			-	[kWh/m²a]	%	
Arctic	Deter-mined in PHPP from project specific heating and cooling degree days against ground.	0.09	0.25	-	0.45	0.50	0.60	$U_g - g*0.7 \leq 0$	100	80%	-
Cold		0.12	0.30	-	0.65	0.70	0.80	$U_g - g*1.0 \leq 0$		80%	-
Cool-temperate		0.15	0.35	-	0.85	1.00	1.10	$U_g - g*1.6 \leq 0$		75%	-
Warm-temperate		0.30	0.50	-	1.05	1.10	1.20	$U_g - g*2.8 \leq -1$		75%	-
Warm		0.50	0.75	-	1.25	1.30	1.40	-		-	-
Hot		0.50	0.75	Yes	1.25	1.30	1.40	-		-	60 % (humid climate)
Very hot		0.25	0.45	Yes	1.05	1.10	1.20	-		-	60 % (humid climate)

Therefore, to achieve the highest energy improvements the retrofit strategy to meet EnerPHit rating will consist of the adaption of an interior stud wall and vapour barrier to increase airtightness and reduce condensation and leakage. Increasing insulation to the exterior walls, foundation, and roof cavity. Upgrading to passive certified windows. The introduction of An MVHR and air source heat pump. And the use of on-site renewable energy sources. As seen in table 2.

TABLE 2: Proposed retrofit specifications

Component	**EnerPHit** Standard	**Retrofit Solution**	**Provided U-Values**
Airtightness	1.0 ach@50 Pa	- Self-adhering air barrier (ACL) -Secondary weather control layer (WCL) - Internal continuous membrane connecting to ACL & WCL	1.5 ach @50 Pa*
Windows	≤0.85-1.10 W/m^2K	Cascadia Passive approved triple glazed windows R-7.7	0.80 W/m^2K
Walls	≤0.15 W/m^2K	38mm x 180mm Internal cavity wall one-layer 120mm of sheep wool batt insulation within the studs and additional 120mm of sheep wool batt insulation. With drywall brackets connecting the gypsum wall board to the stud.	R-49 = 0.12 W/m^2K
Floor	≤0.15 W/m^2K	150mm rigid Insulation under new 100mm concrete slab With thermal break at wall connection	R-40 = 0.14 W/m^2K
Roof	≤0.15 W/m^2K	Strapped Ceiling with two layers of 120mm of sheep wool batt insulation.	R-49 = 0.12 W/m^2K
Doors	≤0.85-1.10 W/m^2K	Wescon passive certified Wood exterior doors	0.70 W/m^2K
Ventilation	Whole house MVHR ventilation rate of 30 m^3/h per person and a minimum efficiency of 75%	Whole house MVHR with a ventilation rate of 30 m^3/h per person and a minimum efficiency of 91% (Mohammadpourkarbasi, Riddle et al. 2023)	MVHR ventilation rate of 30 m^3/h per person and a minimum efficiency of 80%
Heating	25 kw/m^2a and 10 W/ m^2 heating load	Air source heat pump	25 kw/m^2a and 10 W/ m^2 heating load

Energy Demand	-	-	-

* Indicated rating due Restriction of material inventory in HOT2000 software

3.4. WHOLE LIFE CARBON ASSESSMENT

Whole-life carbon assessments were conducted for both scenarios: the existing building and the EnerPHit retrofit. The scope of this study aims to follow the cradle-to-grave system, with additional allowances such as transportation and construction, which One Click LCA offers in addition to manufacturing operational and disposal stages. This approach will provide a more holistic evaluation of the LCA associated when attempting to reduce the embodied carbon of the material selection, assuming that non-petrochemically derived construction materials may be uncommon and require additional transportation to be utilised in the greater Toronto area. For the deep retrofit to be declared beneficial in meeting Canada's 2050 net-zero goals, the annual energy consumption must result in substantial energy savings that outperform the sum of operational carbon calculated within the LCA of the retrofit by 2050. If the amount of embodied carbon surpasses the sum of the operational carbon by 2050, the deep retrofit strategy will not be considered beneficial in meeting Canada's 2050 net-zero goal. Data included in the LCA calculations include the insulation of proposed materials as well as the disposal of the existing components. Table 3 indicates the inventory of materials considered in the deep retrofit strategy and quantities used in HOT2000, and One Click LCA calculations.

Table 3. Inventory of materials considered in the deep retrofit strategy and quantities used in HOT2000, and One Click LCA calculations

Material Quantities	
Material Type	Quantity
Self-adhering air barrier (ACL)	582 m2
Secondary weather control layer (WCL)	582 m2
Internal continuous membrane	582 m2
38mm x 180mm Wood Studs	12,152 Kg
120mm Sheep's Wool Insulation	1,164 m2
150mm Rigid Board Insulation	64 m2
Gypsum Wallboard	582 m2
Ceiling Battens	7,738 Kg
Passive approved triple glazed windows	18 units
passive certified Wood exterior doors	4 units
Concrete	64 m2

Some of the simulated materials were not available in the Canadian database of the software; alternative options were used from other countries in those instances. To ensure the validity of the study it should be noted that material manufacturing localisation in One Click LCA adjusts the environmental impact of those materials to account for the differences in electricity production in the country where it's used (One Click LCA 2025). Therefore, in this scenario, a localisation factor was implemented for those materials not available in the Canadian database to reflect the material's impact in the context of the case study location.

4. Results and discussion

4.1. OPERATIONAL CARBON PERFORMANCE COMPARISON OF EXISTING AND DEEP RETROFITTED SCENARIOS

Figure 3 indicates the reduction of operational carbon emissions with the adaptation of a deep retrofit strategy using EnerPHit guidelines. The results showed the deep retrofit strategy emits 11.3 tonnes/year of CO_2e compared to the existing house's 28.1 tonnes/year CO_2e. A total reduction in annual operational carbon emissions of 60% compared to the existing house performance.

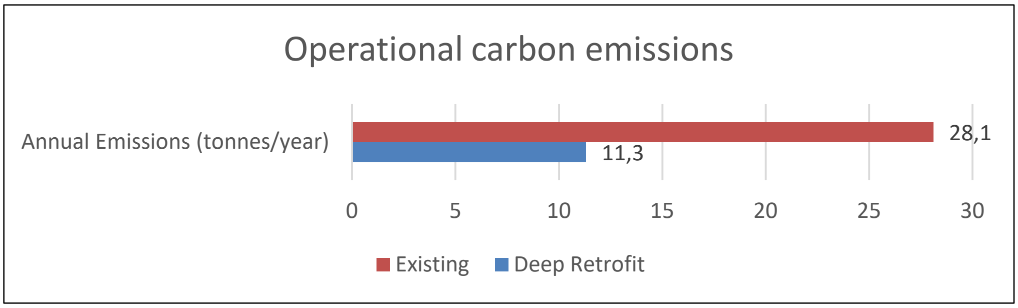

Figure 3: Comparison of annual GHG emissions pre and post retrofit over 1 year

Figure 4 shows the reduction of annual energy consumption compared to the baseline house. The purpose of this comparison is to determine if the switch to an electric-based heating and ventilation system will have a positive or negative effect on annual energy consumption, as this is the highest contributor to residential operational carbon emissions. Annual electricity consumption was reduced by 32% compared to the base model, although alternative electric-based systems such as an MVHR unit and air source heat pump were included in the retrofit. The reduction in energy consumption is associated with a 94% improvement in thermal efficiency and an 85% improvement in airtightness with the fabric-first approach. The reduction in heat loss through the envelope reduces stress on the service equipment, allowing for less operational time.
After removing natural gas-based services the total annual energy reduction in kWh was 94% compared to the baseline consumption values from HOT2000. Other factors affecting the reduction of annual electricity consumption are the use of Energy Star-certified appliances which account for 32% of the annual electricity consumption. And LED lighting accounts for 3.1% of the annual energy consumption. In comparison, these components accounted for 14% less energy consumption compared

to the non-retrofitted scenario. These results match outcomes found in the literature, with studies claiming that the use of electric-based heating and ventilation systems is sustainably beneficial in areas where the use of suitable energy generation was present (Prabatha, Hewage et al. 2020), as is evident in the province of Ontario, with 89.5% of the electricity produced coming from carbon-free sources (Independent Electricity System Operator 2022).

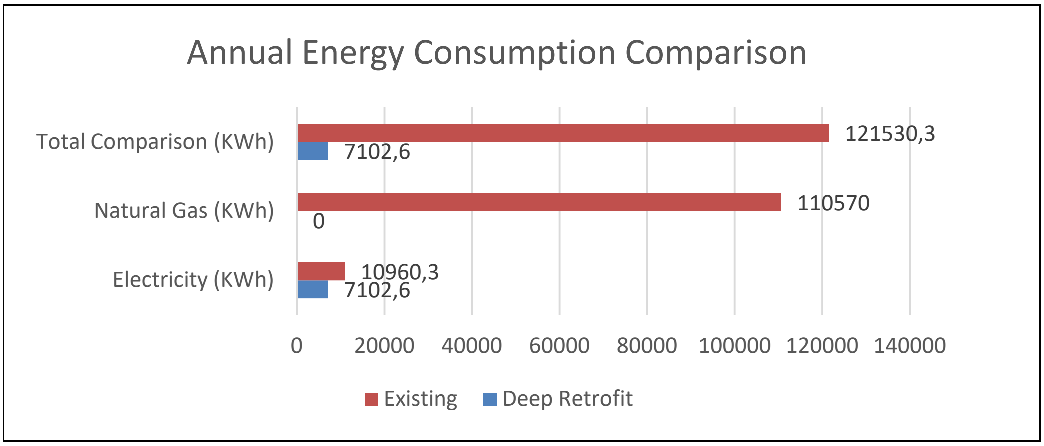

Figure 4: Comparison of annual energy consumption pre and post retrofit over 1 year

4.2. WHOLE-LIFE CARBON ASSESSMENT OF EXISTING AND DEEP RETROFITTED SCENARIOS

Figure 5 compares the whole life carbon assessment of deep retrofit using EnerPHit guidelines to the baseline building over a 60-year period. The outcome of these results determines if a deep retrofit performs better than a non-retrofit scenario and if the embodied carbon of the necessary upgrades will surpass the operational benefits. Results showed that the deep retrofit strategy had a total life carbon impact of 111,328.4 kg CO_2e compared to the service operation of the base model containing 214,707.1 kg CO_2e, a total carbon reduction of 48% over 60 years.

The whole life cycle assessment revealed that, for the embodied energy, the product stage and site operation stage are two of the largest emitters (see Figure 6). Each phase individually contains 69,521 kg CO_2e and 17,761 kg CO_2e of embodied carbon, respectively, accounting for 78% of the total embodied carbon. The building materials and product stage were comprised of materials commonly accessible and used in retrofit strategies in Ontario. Some naturally derived materials for large quantity components can be found within southern Ontario, such as recycled sheep wool insulation. The literature has shown that the use of naturally derived building materials can reduce embodied carbon by upwards of 68% when including biogenic carbon storage (Mohammadpourkarbasi, Riddle et al. 2023). For the site operation stage, data inputs were based on current typical construction equipment necessary for a deep retrofit, such as the use of gasoline-powered generators for electric equipment, compressors, and product delivery over an estimated construction duration of 5 months. Literature has shown that reductions in the construction phase can have a key impact on reducing embodied carbon; therefore, more sustainable strategies should be implemented that improve site conditions and utilise more sustainable construction equipment (Pomponi, Moncaster 2016) (Monahan, Powell 2011).

Another vital phase of embodied carbon was the disposal phase, considering the disposal of existing components within the house, this phase contained a total embodied carbon of 24,046 kg CO_2e and accounted for 21.6% of the embodied carbon. As this study is focused on deep retrofit, this can generally be considered past the scope of the study; nevertheless, fundamentals of circular economy, such as urban mining, could be applied to the retrofit strategy to reduce the overall carbon emissions of this phase (Heisel Felix, Hebel Dirk et al. 2022).

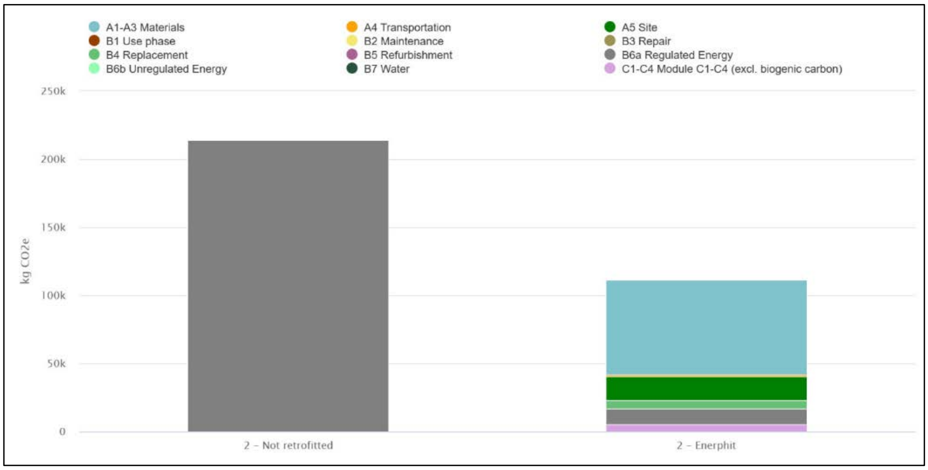

Figure 5: Whole life carbon assessment of existing and deep retrofitted scenarios.

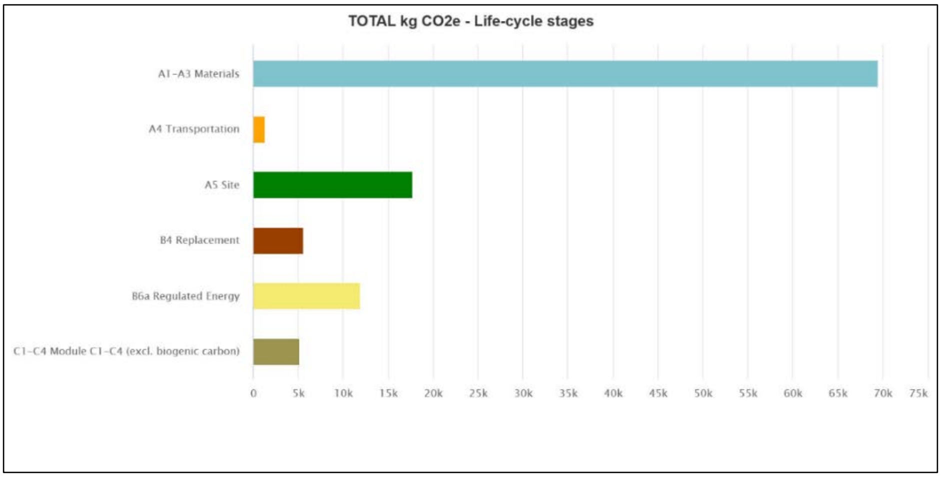

Figure 6: Total carbon per Life Cycle Stages over 60 years.

4.3. CARBON PAYBACK PERIOD

The estimated carbon payback time is the period required for the proposed retrofit to offset its embodied emissions from the materials and construction phases and, as a result, reap the benefits of its operational carbon reductions. One way to reduce the carbon payback period is by including biogenic carbon. Biogenic carbon storage is carbon biologically stored in materials through the process of photosynthesis; as the material has absorbed carbon from the atmosphere, it can be considered to reduce the effects of the climate crisis (Masson Shaun 2023). Based on the data from One Click LCA and HOT2000, the total embodied carbon is 111,328.4 kg CO2e, and the annual energy savings are 16,800 kg CO2e per year, resulting in the carbon payback period of the deep retrofit being 6.8 years, and 5.4 years when including biogenic carbon storage from the use of natural materials.

4.4. LIMITATIONS:

Limitations in the analysis of the case study pertain to specific areas of construction that are not directly accessible such as roof cavities, wall cavities, connection points, fabric below grade, and annual energy consumption. However, assumptions gathered from literature and previous examples of this housing typology have been made within the energy model to achieve the most accurate result currently available. Other limitations include the use of a single case study, further research with multiple case studies could yield more accurate and detailed results. And lastly, financial consideration, due to time constraints the cost could not be factored into this study. Research from (Prabatha et al. 2020) suggests that the economic aspects of a deep retrofit can significantly influence the strategy's outcome.

4. Conclusion

Canada’s goal of reaching net-zero by 2050 requires the deep retrofit of high-emitting housing, such as houses constructed within the 19^{th} to early 20th century. This study investigated the impact of deep retrofitting 19^{th} to early 20th-century homes in southern Ontario using EnerPHit guidelines, considering a whole-life carbon assessment.

The proposed retrofit strategy took a fabric-first approach, making significant improvements to airtightness and thermal performance in combination with electric-based services such as an air source heat pump and MVHR. The results indicated that this approach reduced annual operational CO2 emissions of the house by 60%, with a reduction of annual energy consumption of 32% despite the use of fully electric service equipment. The results of the whole-life carbon analysis comparing the existing building to the EnerPHit retrofit scenario revealed a significant reduction in emissions. Implementing the EnerPHit standard achieved a 48% decrease in carbon emissions over a 60-year period, with a retrofit carbon payback period of 6.8 years, which shortens to 5.4 years when accounting for biogenic carbon storage. The findings highlight the potential of adopting the EnerPHit standard for retrofitting 19th to early 20th-century homes in contributing to Canada’s net-zero target.

References

BASTIAN, Z., SCHNIEDERS, J., CONNER, W., KAUFMANN, B., LEPP, L., NORWOOD, Z., SIMMONDS, A. and THEOBOLDT, I., 2022. Retrofit with passive house components. Energy Efficiency, 15(1), pp. 10.

ENVIRONMENT AND NATURAL RESOURCES CANADA, -04-14, 2023-last update, Greenhouse gas sources and sinks in Canada: executive summary 2023. Available: https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/sources-sinks-executive-summary-2023.html [Oct 22, 2023].

FENG, H., LIYANAGE, D.R., KARUNATHILAKE, H., SADIQ, R. and HEWAGE, K., 2020. BIM-based life cycle environmental performance assessment of single-family houses: Renovation and reconstruction strategies for aging building stock in British Columbia. Journal of Cleaner Production, 250, pp. 119543.

FINNVEDEN, G. and POTTING, J., 2014. Life Cycle Assessment. In: P. WEXLER, ed, Encyclopedia of Toxicology (Third Edition). Oxford: Academic Press, pp. 74–77.

GOVERNMENT OF CANADA, PUBLIC SERVICES AND PROCUREMENT CANADA, -07-01, 2002-last update, 2012 R-2000 standard : M144-223/2012E-PDF - Government of Canada Publications - Canada.ca. Available: https://publications.gc.ca/site/eng/415075/publication.html [Dec 5, 2024].

HEISEL FELIX, HEBEL DIRK, E. and WEBSTER KEN, 2022. Circular Construction and Circular Economy. 1st edn. Birkhauser.

INDEPENDENT ELECTRICITY SYSTEM OPERATOR, 2022-last update, Ontario electricity demand reflects a rebounding economy in 2022. Available: https://www.ieso.ca/en/Corporate-IESO/Media/Year-End-Data [Nov 7, 2023].

MASSON SHAUN, 2023-last update, Biogenic Carbon. Available: https://oneclicklca.zendesk.com/hc/en-us/articles/360015036640-Biogenic-Carbon [Dec 9, 2023].

MOHAMMADPOURKARBASI, H., RIDDLE, B., LIU, C. and SHARPLES, S., 2023. Life cycle carbon assessment of decarbonising UK's hard-to-treat homes: A comparative study of conventional retrofit vs EnerPHit, heat pump first vs fabric first and ecological vs petrochemical retrofit approaches. Energy and Buildings, 296, pp. 113353.

MONAHAN, J. and POWELL, J.C., 2011. An embodied carbon and energy analysis of modern methods of construction in housing: A case study using a lifecycle assessment framework. Energy and Buildings, 43(1), pp. 179–188.

NRCan, -02-05, 2018-last update, HOT2000 software suite [Homepage of Natural Resources Canada], [Online]. Available: https://natural-resources.canada.ca/energy-efficiency/homes/professional-opportunities/tools-industry-professionals/20596 [Nov 27, 2023].

NRCan, -11-19, 2020-last update, Net-Zero Emissions by 2050. Available: https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/net-zero-emissions-2050.html [Oct 19, 2023].

ONE CLICK LCA, Jan 15, 2025-last update, Using Materials Manufacturing Localisation. Available: https://oneclicklca.zendesk.com/hc/en-us/articles/360014865559-Using-Materials-Manufacturing-Localisation [Jan 30, 2025]

PICCARDO, C., DODOO, A. and GUSTAVSSON, L., 2020. Retrofitting a building to passive house level: A life cycle carbon balance. Energy and Buildings, 223, pp. 110135.

POMPONI, F. and MONCASTER, A., 2016. Embodied carbon mitigation and reduction in the built environment – What does the evidence say? Journal of environmental management, 181, pp. 687–700.

PRABATHA, T., HEWAGE, K., KARUNATHILAKE, H. and SADIQ, R., 2020. To retrofit or not? Making energy retrofit decisions through life cycle thinking for Canadian residences. Energy and Buildings, 226, pp. 110393.

STATISTICS CANADA, April 27, 2022-last update, Dwelling type, age and gender: Canada, provinces and territories, census metropolitan areas and census agglomerations with parts. Available: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=9810004601 [December 9, 2023].

STRAUBE, J. and SCHUMACHER, C., 2007. Interior insulation retrofits of load-bearing masonry walls in cold climates. Journal of Green Building, 2(2), pp. 42–50.

WU, R., MAVROMATIDIS, G., OREHOUNIG, K. and CARMELIET, J., 2017. Multiobjective optimisation of energy systems and building envelope retrofit in a residential community. Applied Energy, 190, pp. 634–649.

ZHANG, H., HEWAGE, K., PRABATHA, T. and SADIQ, R., 2021. Life cycle thinking-based energy retrofits evaluation framework for Canadian residences: A Pareto optimization approach. Building and Environment, 204, pp. 108115.