Chapter 47
The Environmental Impact of Retrofitting Heritage Buildings in New Zealand

Rachel Paschoalin, Nigel Isaacs, and Fabricio Chicca

Abstract As nations develop CO_2 reduction targets, the retrofit of heritage buildings creates an opportunity for achieving energy and carbon savings while mitigating Climate Change. This paper explores through three NZ theoretical case studies the benefits from energy retrofits of heritage buildings, including how improvements to the building envelope can reduce carbon emissions while protecting historic significance. Energy efficiency measures were assessed in terms of thermal comfort, life-cycle carbon and life-cycle cost. Results were used in interviews with experts to develop recommendations for assessment methods and criteria that could be incorporated into practice and policies. The analysis of different energy retrofits showed a decrease in heating energy, and a lowering the carbon footprint over 90 years when compared to the existing buildings. The paper discusses how balanced retrofits could be incorporated into policies targeting carbon reductions, and the benefits to be gained from promoting building reuse.

Keywords Heritage conservation · Life cycle analysis · Energy retrofit · Carbon footprint · Environmental sustainability

47.1 Introduction

The environmental impacts associated with the construction sector suggest annually globally buildings are responsible for at least 36% of energy use and 30% of Greenhouse Gas (GHG) emissions (Nations Environment Programme 2007). At the current pace of action, global warming impacts are likely to be irreversible if GHG emissions are not reduced (Barros and Field 2014). As nations develop 50-year CO_2 reduction targets, the retrofit of heritage and historic buildings creates an opportunity for achieving energy and carbon savings while mitigating Climate Change. The retrofitting of historic and heritage buildings have now come into a wider debate on their potential contribution to reducing GHG emissions and energy consumption

R. Paschoalin (✉) · N. Isaacs · F. Chicca
Wellington School of Architecture, Victoria University of Wellington, Wellington, New Zealand
e-mail: rachel.paschoalin@vuw.ac.nz

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(Hosagrahar et al. 2015)–(CEN 2017). In the past 10 years, the adoption of new policies and voluntary standards, including the European 16883:2017 and American ASHRAE 34P:2019 guidelines for renovation of historic buildings (CEN 2017; ASHRAE 2019), has contributed to the enhancement of historic building envelopes and services, diminished energy consumption and carbon emissions, and improved user comfort. Despite many conservation challenges arising from the energy renovation of historic buildings, ICOMOS has recognized the importance of cultural heritage supporting the sustainable development (Hosagrahar et al. 2015; UN 2017). Many heritage organizations in different countries have also developed guidance the insulation of walls, windows or even the adding of photovoltaic panels (Heritage 2011; Victoria 2009).

The topic of historic retrofit has been widely explored in the last 10 years from both technical and conservation aspects; however from a practice perspective, retrofits are still limited by regulatory, social and technical barriers (Buda et al. 2021). Compared to Europe and USA, New Zealand (NZ) discussions on historic building energy retrofits are at the initial steps, despite many old and vacant historic and heritage building in town centers in need of multiple improvements to be fit for purpose (Aigwi et al. 2018). One of the reasons energy retrofits are not yet in the forefront of discussion is due to the national concern with mandatory structural strengthening due to the high seismic activity. Even so, NZ recently implemented a zero-carbon policy (Nations Environment Programme 2019), but (at the time of writing) it focuses exclusively on new construction, hence there are no country-specific historic building retrofit guidelines. Most existing historic buildings remain untouched by energy upgrades due to the lack mandatory energy efficiency requirements and exemptions due to only 'if practicable' clauses in building regulations (Ministry of Business 2016). When coupled with the perception that old buildings are cold, damp and leaky as well as earthquake-prone, this poses risks of demolition for many neglected historic buildings (Wolfe 2013).

The retrofit of historic buildings allows for improvements and adaptations for future needs, contributes to a more comfortable and healthy indoor environment, and reduces environmental impacts while protecting historic values, fabric and embedded carbon from demolition (Troi and Bastian 2015; CEN 2017). There is a national gap in policy and practice, with no research regarding historic building energy retrofits compared to international best practice (Besen and Boarin 2020). This case-studies paper explores the use of international energy efficiency guidelines for NZ historic retrofits, examining how improvements can reduce the carbon footprint while protecting historic significance and enhancing thermal comfort. In this paper the term "historic building" includes both officially listed and protected buildings as well as older buildings without an official designation. The terms "retrofit" and "renovation" are interchangeably used to refer to fabric and service upgrades.

47.2 Methods

All international retrofit guidelines advocate a multiple criteria assessment. EN 16883:2017 was chosen as the most complete framework, as it included economic viability and impact on outdoor environment (CEN 2017). A historic building energy upgrade will result in lower operational energy, hence lower operational carbon emissions. However, the materials' embodied energy, replacement and maintenance within the whole building life cycle need to be included in the renovation assessments.

Due to the lack of examples of NZ historic building deep energy retrofits, it was necessary to develop three cases studies of hypothetical energy retrofits. These examined the practicalities and challenges of adopting international procedures, methods and best practice solutions. For Phase 1 a series of upgrades with envelope energy efficiency measures were assessed in terms of thermal comfort, and the Life Cycle Analysis (LCA) of life-cycle carbon emissions (LCCA) and life-cycle cost (LCC). Phase 2 interviewed ten conservation experts for their views of each measure.

EN 16883:2017 provides guidance for "historic buildings of all types and ages" (CEN 2017, p. 6). Thus, the choice of case studies does not follow any specific building typology, use or age. It focuses on differences rather than similarities in order to have a comparative scenario investigating possible limitations or the need for specific guidelines for some characteristics. The choice of buildings was supported by the available documentation on their history and current condition (e.g. renovated or not), owner's approval to carry the studies and access to the site. Three buildings located in Wellington, NZ, where chosen. Although located in a single city, they are a good representation of a range of typical historic buildings. Their uses, typologies, sizes, materials and other key facts are listed in Table 47.1. Their ages also differ but all were built prior to 1945 and are statutory protected, varying from local to national significance. The choice of only statutory protected buildings created a more critical and restrictive scenario as the negotiation space between energy retrofit measures and allowable measures is restricted compared to buildings lacking protection (Herrera-Avellanosa et al. 2019).

In the light of their current poor envelope thermal performance, the case studies were designed to explore the benefits of thermal comfort, carbon and cost savings of a deep energy retrofit using thermal insulation and airtightness measures (May and Griffiths 2015). The main energy retrofit goals were: improving indoor thermal comfort; reducing dampness; enabling healthier occupants; while protecting the historic character. Moreover, the energy consumption and carbon emission reductions were based on an ideal 24 h, 7 days of heating use to promote a healthier and drier indoor environment.

Following the existing guidelines on energy renovation of historic buildings, the first stage in the process should be the building assessment (CEN 2017; ASHRAE 2019; Buda et al. 2021). A building survey provided building data including envelope characteristics and surrounding topography. These were translated into a base Sketchup/OpenStudio model and thence to an EnergyPlus thermal simulation model using a typical year local weather file. It is acknowledged though, the use of median

Table 47.1 Case studies characteristics

Building	Chevening apartments	First custodian house	Turnbull house
Year	1929	1901	1916
Architect	Llewellyn Williams	Unknown	William Turnbull
Use	Dwelling	Dwelling	Library
Material	Reinforced concrete	Timber-frame	Brick
Storeys	4	1	3
Heritage list	Category 2—local significance	Local significance	Category 1—national significance
Status	Partially renovated and currently occupied	Partially renovated and unoccupied	Earthquake-prone building and unoccupied
Picture			

future weather data files is recommended for addressing effects of climate change, such as overheating (Tink et al. 2018). The base model and retrofit scenarios were assessed under four quantitative categories—comfort, energy use, CO_2 emissions and cost—as in EN 16883:2017 and according to specific methods (e.g. adaptive model of comfort, dynamic energy simulation, LCCA and LCA). EnergyPlus was also used to generate internal temperature conditions. LCCA was used to assess environmental impacts, not just new material embodied carbon but also the carbon emissions during operation, maintenance and end-of-life.

The NZ developed software LCA-Quick version 3.4 was used following standardized LCA methods (ISO 14040 and ISO 14044, EN 15804 and EN 15978) to systematize the assessments for construction products and buildings respectively (Röck et al. 2021), and because it includes a deterministic national database of material coefficients for product and construction stages. It outputs the environmental impact as global warming potential (GWP) in kg of CO_2 equivalent (kg.CO_{2eq}) consistent with EN 16883:2017. A simplified system boundary was used including the product and construction stage (modules A1–A5), maintenance and replacement (B2, B4), and operational energy use (B6), and only electricity was used as energy source considering the LCA-Quick data on national GHG intensity grid. Finally, the economic viability considering purchasing, construction and heating costs, was assessed as the Net Present Value (NPV), which is the sum of all the discounted future cash flows considering the time value of money over a calculated period of

20 years. These could be used to identify the lowest lifetime cost for different energy options.

47.3 Models, Results and Discussion

Simulations on the thermal performance and energy consumption were carried out for different wall, floor, roof and window compositions and airtightness measures (see Table 47.2). The results showed increased comfort hours, decreased heating energy, and lower 90-year carbon footprint compared to the existing buildings. LCC also showed reduced costs, but these required trade-offs.

For analysis, the OpenStudio/SketchUp building models had interior walls, windows, floor and roof matched surfaces. The base heating set point was 20 °C based on World Health Guidelines of an 18–25 °C range. For testing each baseline model had two initial simulations: one free running (passive with no heating) and one with heating (annual energy demand). Output files, such as the heating energy consumption, were generated to be graphed for analysis. EnergyPlus generated mean radiant and mean air temperatures for a year (8760 h) and the Rhino/Grasshopper Ladybug 0.0.68 'Adaptive Comfort Calculator' used to calculate the percentage of hours considered cold, comfortable or hot. Mean radiant and air temperatures were used as surface radiation temperatures contribute to discomfortable, while the more

Table 47.2 Retrofit measures applied to case studies

Retrofit	Chevening apartments	First custodian house	Turnbull house
A	Base model	Base model	Base model
B	Double glaze thermally broken aluminium frames	Retrofit double-glazing	Add secondary low-E internal windows
C	Internal secondary acrylic glazing	Draughtproof windows, add lined curtains	Retrofit wooden frames and add IGU windows
D	Internal secondary low-E glass	Fiberglass cavity wall insulation (CWI)	Insulate floor & roof cavities
E	External wall insulation (EWI)	PIR board internal wall insulation (IWI)	Insulate floor and roof, add secondary low-E glazing
F	Internal wall insulation (IWI)	Whole house insulation with CWI (R2.8)	Insulate and airtight envelope (EWI)
G	IWI with double glazing	Whole house insulation with IWI (R2.8)	Insulate and airtight envelope (IWI)
H	IWI with acrylic secondary glazing	Whole house super insulation with both CWI and IWI (R5.45)	Insulate and airtight envelope (IWI)
I	IWI with Low-E glass secondary glazing	Whole house super insulation IWI (R5.45)	–

Notes EWI = external wall insulation IWI = internal wall insulation CWI = Cavity wall insulation

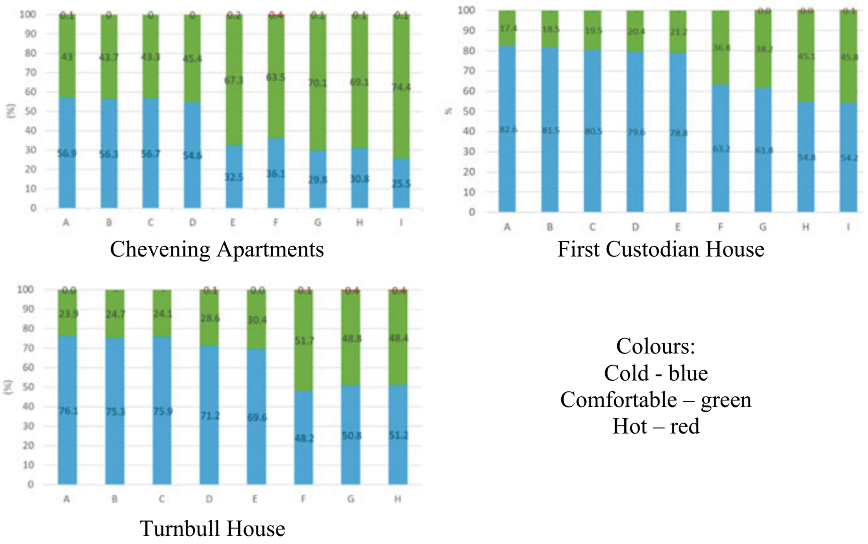

Fig. 47.1 Annual adaptive comfort hours (% of 8760 h)

homogeneous the air and radiant temperatures the better the comfort sensation. These are given in Fig. 47.1.

Figure 47.1 graphs show for each retrofit (A–I) for each building the annual percentage of cold/comfortable/ hot hours based on the adaptive comfort model. The higher the envelope (walls, floor, ceiling and windows) insulation, the more annual comfortable hours compared to the baseline model. The single measure scenarios (e.g. only walls or only windows insulation) had at least 20% fewer comfort hours than the deep retrofit scenarios with reduced airtightness.

Looking at the 3 case studies, the variation due to insulating only walls or windows is due to differences in the window to wall ratio (WWR). For instance, in the Chevening Apartments the results from just glazing measures compared to wall insulation are less effective in increasing overall comfort; however, if only wall insulation measures are also implemented, local discomfort close to cold single-glaze windows will remain. For the First Custodian House, doubling the wall R-value resulted in less than a 10% increase in comfort hours.

For predicting energy demand, only the heating use per conditioned area was assessed on simulations because in the average NZ house the space heating is the largest single energy use (Isaacs et al. 2010). The results of heating demand are considered in the LCCA and LCA as the operational energy use. The NPV considered the investment costs (e.g. purchasing and construction) and discounted future costs (e.g. heating) (Mithraratne et al. 2011). Table 47.3 gives the results.

For Retrofit Scenarios B to I, both carbon emissions and NPV decrease. The greater the envelope thermal insulation, the lower the LCCA and calculated NPV (e.g. over 50% savings). Both results (LCCA and LCC) have a similar pattern, because over

Table 47.3 Results in percentage savings of heating energy, LCCA and LCC

Retrofit scenario	Heating energy savings per year (%)			LCCA (tonnes of kgCO2eq.) savings for 90 years (%)			LCC (NZ$ millions) savings for 20 years (%)		
	Building 1/2/3			Building 1/2/3			Building 1/2/3		
A	–	–	–	–	–	–	–	–	–
B	8	12	10	8	10	9	8	12	10
C	7	9	9	7	9	7	7	9	8
D	13	9	10	13	7	9	13	9	10
E	73	11	21	67	9	19	73	11	21
F	69	57	75	63	52	69	69	56	73
G	79	60	76	73	54	70	79	59	73
H	77	68	73	72	59	67	77	67	70
I	83	69		77	59		83	68	

the examined 90 and 20 year life-cycles, the operational energy and costs have the greatest influence in the final results. Therefore, more insulation reduces envelope heat losses which reduces the cost of maintaining comfort. The LCA enables understanding of which phase(s) most affect the final results, and the impact of materials embodied energy and carbon. The NPV reveals even with a short time period of 20 years, heating energy is still contributing more than construction and replacement costs. This may be due to materials life-service being more than 20 years, therefore only requiring marginal replacements. For a longer LCC analysis period relationship between operational and construction/ replacement costs changes, but it is also dependent on the uncertainty of future energy prices.

The findings from all three case studies confirmed the lifespan benefits of energy renovation, as all had reductions in energy use, carbon emissions and cost. The improvements also created an improved indoor thermal environment. The quantitative results supported the international literature that advocated on the deep retrofit (insulation, airtightness and ventilation) as the best approach (Troi and Bastian 2015; May and Griffiths 2015). Beyond the clear benefits of a deep retrofit approach, the LCA results for carbon and cost also presented similar patterns due to the major influence of operation opposed to embodied phase. This may explain the higher number of international publications focusing solely on the operational phase, instead of the whole life-cycle analysis (Martínez-Molina et al. 2016; Buda et al. Mar. 2021; Herrera-Avellanosa et al. 2019). However, lower material service life will increase the influence of the embodied phase, due to increasing materials replacement.

Overall, this research demonstrated that systematic quantitative assessments can be a successful tool for decision makers to use to compare the different impacts of energy efficiency measures. A key interview finding was that from a conservation perspective there is no one solution fits all, but energy retrofitting historic buildings was considered by all experts as a way of protecting and assuring their longer-term use, as well as having environmental benefits. The experts considered that historic buildings should not be exempt from energy efficiency requirements, but policies should allow flexible targets, even if only for small improvements.

47.4 Conclusions

The findings of this research suggest that New Zealand can learn from international guidelines when dealing with retrofits of historic and heritage buildings. However, there is also a need to adapt and adjust guidelines to local climate, requirements, standards and materials. The benefits from multiple, or deep retrofits, suggest their greater impact that the use of single measure retrofits. The careful use of deep retrofit approach and measures, e.g. combining envelope insulation and ventilation, should help avoid future (for example) moisture problems. LCA was considered as a beneficial tool for promoting better quality, reduced GHG impacts and longer-lasting materials, as well as reducing investment cost barriers by clarifying long-term benefits. It would be beneficial to develop flexible national policies for energy improvements of existing historic buildings.

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