Energy and Buildings 124 (2016) 153–163

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

The impact of future scenarios on building refurbishment strategies towards plus energy buildings

Alexander Passer[a,b,*], Claudiane Ouellet-Plamondon[a,c], Patrick Kenneally[a], Viola John[a], Guillaume Habert[a]

[a] Chair of Sustainable Construction, Institute of Construction and Infrastructure Management ETH Zürich, Stefano-Franscini-Platz 5, 8093 Zurich, Switzerland
[b] Institute of Technology and Testing of Building Materials, Graz University of Technology, Inffeldgasse 24, 8010 Graz, Austria
[c] École de Technologie Supérieure, 1100, rue Notre-Dame Ouest, Montréal (Québec), H3C 1K3, Canada

ARTICLE INFO

Article history:
Received 27 October 2015
Received in revised form 2 April 2016
Accepted 4 April 2016
Available online 9 April 2016

Keywords:
Building refurbishment strategies
Prefabricated façade elements
Future energy supply mix scenarios
Future climate change scenarios
Life cycle assessment (LCA)
Embodied green house gas emissions (GWP)
Embodied energy (CED)

ABSTRACT

Buildings account for 40% of total global energy consumption. The International Energy Agency (IEA) and the European Commission (EC) are attempting to achieve an 80% reduction in global emissions by 2050. The objectives of this paper are to identify the refurbishment scenario with the lowest environmental impact using Life Cycle Assessment (LCA) and to assess the scenario's robustness to future climate change scenarios using a sensitivity analysis. We applied and verified the proposed approach in a residential case study of a reference project located in Kapfernberg, Austria. The environmental assessment included two façade refurbishment proposals (minimum and high quality with respect to energy), onsite energy generation (using solar thermal collectors and photovoltaic (PV) panels), one renewable future energy mix and the effects of climate change according to the Austrian Panel on Climate Change (APCC). The environmental indicators used in the assessment were the cumulative energy demand non-renewable (CED n. ren.), global warming potential (GWP) and ecological scarcity (UBP) over building life cycles. The results indicated that a high-quality refurbishment of the thermal envelope with prefabricated façade elements, including solar thermal collectors and PV panels, represented the optimal refurbishment. In terms of the environmental indicators, the high-quality refurbishment scenario is always beneficial throughout the building's life cycle. Additionally, the sensitivity analysis of the high-quality refurbishment scenario found an increasing production of surplus electricity with increasing PV area. This surplus of energy provides greater benefit in the short term with the current energy mix. Once the energy from the grid is shifted to renewable sources, the added benefit is decreased. Therefore, it is necessary to find an optimal balance between diminishing returns due to changes in the future energy mix and the financial investment made over the lifetime of the building, especially for plus energy buildings. However the findings from this specific case study need to be evaluated for other refurbishment cases, taking into account future local climate change and energy supply mix scenarios in other regions.

1. Introduction

The building sector is a top priority in terms of maximizing energy efficiency because the most cost-effective energy savings can be found in the residential and commercial building sector. Because the building sector accounts for up to 40% of global and European energy consumption, the goal of the International Energy Agency (IEA) is to achieve an 80% reduction in global emissions by 2050. In Europe, the EU Parliament approved a recasting of the Energy Performance of Buildings Directive in 2010 that requires member states to propose measures to increase the number of nearly zero-energy buildings and to encourage best practices for cost-effective transformations of existing buildings into nearly zero-energy buildings [1].

According to the Intergovernmental Panel on Climate Change (IPCC) and related groups around the world (e.g., the Austrian Panel on Climate Change (APCC)) [2], the observed changes and their causes can be described as follows: "Human influence on the climate system is clear, and recent anthropogenic emissions of green-house gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems" [3]. Regarding future climate changes, risks and impacts, the

* Corresponding author.
E-mail address: Alexander.Passer@tugraz.at (A. Passer).

http://dx.doi.org/10.1016/j.enbuild.2016.04.008
0378-7788/

IPCC's AR5 states that "Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. Limiting climate change would require substantial and sustained reductions in greenhouse gas emissions, which, together with adaptation, can limit climate change risks" [3].

The greatest potential for reducing operational energy is found in unrefurbished buildings built between 1950 and 1980 because many buildings were constructed during this period and have high heating demands [2,4,5]. Such buildings were also found to be the most vulnerable to climate change [6]. Therefore, a strategic refurbishment analysis is required to meet the sustainability targets of the EU and other organizations. Retrofitting wall and roof insulation provides the largest number of opportunities for energy savings in residential buildings [7–12]. For prefabricated modules, the contribution of the embodied energy to the total energy requirement is increased [13].

The four main categories of building refurbishment are (1) heating and cooling demand reduction (e.g., insulation), (2) installation of energy-efficient equipment and low-energy technologies, (3) installation of renewable technologies and electrical systems, and (4) changes in human factors. The different approaches to energy efficiency in the use phase can be classified as follows: low-energy buildings are designed to minimize their operating energy [14,15]. Passive houses are low-energy buildings that use passive technology (their very low heating demands are met by controlled ventilation and air heating) [9,16–20]. Net zero energy buildings (nZEB) must establish an overall balance between their energy needs, the excess renewable energy generated onsite and the energy imported from the grid [21–23]. Plus energy buildings should be able to deliver more energy to the grid than they consume [8,21,24]. As buildings become increasingly energy efficient, the choice of materials, the methods of construction and end-of-life (EoL) planning are becoming more important [25–27]. When the EoL is included, the assumptions behind the model become important when comparing different construction materials and the use of attributional or consequential modelling approaches [28–31]. Because technical equipment plays a major role in nearly zero-energy passive houses and plus energy buildings, its embodied impact must be considered [32–34].

The method used to assess embodied and operational energy and related environmental impacts is LCA. The application of LCA to the building sector began approximately 25 years ago with an LCA of zero-operational-energy buildings [35] and a comparative assessment of insulation materials based on LCA standards (ISO 14040 and 14044). Various studies have contributed to life cycle inventories (LCI), such as those of energy systems, and to the widely known Ecoinvent database [36]. Recently, the application of LCA to buildings was defined by a European framework for the "Sustainability of Construction Works – Assessment of Buildings" (EN 15643, EN15978, EN 15804). According to this European framework (EN 15978), LCAs of buildings should include the construction stage (modules A1–A3); the preparation of the site for the construction of the building elements (modules A4 and A5); the operational and energy demands; the necessary maintenance, replacement and refurbishment activities (module B); and an end-of-life (EoL) scenario (module C). Recent experiences have shown that environmental product declarations (EPDs) based on these standards are soon to enter the building sector across Europe [37].

Many LCA case studies and review papers have been published in the literature in the last year [9,21,24,25,28,38–41]. A comprehensive overview of the embodied energy and energy efficiency of buildings can be found in [42]. A comprehensive analysis of the life-cycle energy required by 73 buildings in 13 countries shows that, on average, the operating (80–90%) and embodied (10–20%) phases of energy use are significant contributors to a building's energy demand throughout its life cycle [43].

With the overall objectives of slowing down climate change and cost-effectively transforming existing buildings in mind, the question concerns whether today's refurbishment options remain optimal when considering future climate scenarios and changes in the energy supply mix. Climate change is likely to reduce the environmental impact of a building by reducing its operational heating demand, as stated by Berger et al. [44]. However, the environmental impact of its cooling demand will increase, and the net balance is forecasted in, e.g., the UK to produce an increase in emissions due to cooling [45]. In Austria, residential buildings must be designed so that they generally avoid the need for cooling through, e.g., the installation of shading measures and lower transparent openings; therefore, a net decrease in emissions due to a reduced need for heating of 20% is forecasted [2].

In the evaluation of a building's environmental impact, the implication of the available energy mix is non-negligible due to the long operational phase of a building's life cycle. The Swiss Federal Bureau of Energy (BFE) has developed future scenarios for the energy mix available in Switzerland [46], which represent the basis of the scenarios examined in this study.

The objective of this paper is to evaluate different refurbishment strategies in a manner that considers future energy mix and climate change using a case study. The optimal scenario is the one with the lowest environmental impact, identified using an LCA. A sensitivity analysis is performed to evaluate the strategy's robustness under future scenarios with a renewable energy mix and considering the effects of climate change.

2. Methods

The enormous energy demands of existing buildings resulting from their very high demands for heating and the associated high operating costs signal the need to refurbish buildings in Austria from the 1960s. The technical details of the case study were taken from a research project called "e80̂3-Buildings,"[1]; which aimed at highly efficient refurbishments of existing buildings. Examining the future energy and climate scenarios evaluated in this paper appeared necessary for validating the refurbishment concept from the perspective of LCA.

2.1. The case study and the developed refurbishment scenarios

A residential building in Kapfenberg, Austria that was built in 1961 and refurbished to a plus energy building in 2014/2015 served as a case study (Fig. 1). The four-story building has a length of 65 m (eastern and western façades) and a depth of 10 m (northern and southern façades). The existing building was a typical Austrian building from the 1960s constructed using prefabricated sandwich concrete elements without any additional thermal insulation. The insulation of the basement ceiling consisted of approximately 60 mm of polystyrene, and the ceiling of the unheated attic was insulated with 50-mm wood wool panels. The old roof was a pitched roof with no insulation. The existing windows were double glazed and had a U-value of 2.5 W/m^2 K; in addition, no mechanical ventilation system was installed. In the existing building, each flat was equipped with a different heating system (e.g., decentralized gas heating, an electric furnace, an electric night storage heater, an oil heater, a wood-burning stove or a coal furnace).

For the refurbishment of the case study building, the model includes three refurbishment strategies and five strategies for

[1] http://www.hausderzukunft.at/results.html/id5836.