Zurich, June 15-17 2016
Sustainable Built Environment (SBE) Regional Conference

Expanding Boundaries:
Systems Thinking for the Built Environment

IMPACT OF BUILDING REFURBISHMENT STRATEGIES ON THE ENERGETIC PAYBACK

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Abstract

The target of the International Energy Agency (IEA) and the European Commission (EC) is to achieve a reduction of 80% for global greenhouse gas (GHG) emissions by 2050. Buildings account worldwide for 40% of global energy consumption and 30% of GHG emission. Due to the fact that the building stock plays a key role in achieving these targets, the aim of the paper is to find an optimal refurbishment strategy in terms of lowest environmental impact through life cycle assessment (LCA). Three façade refurbishment scenarios (none, minimum and energetic high quality) and onsite energy generation (solar thermal and photovoltaic panel (PV)) were evaluated. We applied and verified the proposed approach on a residential case study as reference refurbishment project built in the 1960s. The environmental indicators cumulative energy demand, global warming potential and ecological scarcity were evaluated for the LCA covering all life cycle stages over a reference study period of 60 years. The results showed that the optimal refurbishment scenario from an LCA perspective was a high-quality refurbishment of the thermal envelope by the use of prefabricated façade elements, solar thermal collectors as also photovoltaic panels. In terms of the assessed environmental indicators, this refurbishment scenario will always be beneficial due to its lowest impact throughout the life cycle. However, the sensitivity analysis on the high-quality refurbishment strategies determined that a surplus of electricity production by increasing the PV area is not always feasible as the operational impact burdens react with great sensitivity to changes in the electricity mix towards more renewable resources, likely to occur in the near future. It is thus necessary to find an optimum balance between diminishing returns over time and financial investment over the entire life cycles of buildings, especially for plus-energy buildings.

Keywords:

Energetic payback; refurbishment strategies; life cycle assessment; prefabricated façade elements

1 INTRODUCTION

The target of the International Energy Agency (IEA) is to achieve a reduction of 80% for global emissions by 2050. Buildings account worldwide for 40% of the global energy consumption and 30% of GHG emission. In Europe, the EU Parliament approved the recast of the energy performance of buildings directive in 2010 calling on member states to propose measures for increasing the number of close to zero-energy buildings and encouraging best practices in the context of the cost-effective transformation of existing buildings into nearly zero-energy buildings [5].

In Europe, many buildings erected between 1950 and 1980 are now targeted for refurbishment due to their bad energetic performance. If these refurbishments achieve a high level of energy performance, or even reach a plus-energy standard, they would represent a major step towards achieving the European 2020 targets[4].

The three main strategies of building refurbishment are: 1) heating demand reduction (e.g. insulation of the building envelope), 2) energy efficient equipment and low energy technologies and 3) renewable energy supply. The different energetic approaches of the use phase can be classified as follows: low-energy building are designed to minimize the operating energy [13]. Passive houses are low-energy buildings that use passive technology (very low heating demand that is to be covered by controlled ventilation with air heating) [9]. Net zero energy buildings (nZEB) are required to have an overall balance between the energy needs and excess from onsite renewable energy and energy imported from the grid [1]. Plus energy buildings should be able to deliver more energy to the grid than they consume [14].

In this paper the successful refurbishment of the lead project "e80^3-Buildings" (http://www.hausderzukunft.at/results.html/id5836) - concepts towards energy plus house standard with prefabricated active roof and facade elements, integrated technical systems and energy network integration - of the research program "house of tomorrow – plus" serves as case study to evaluate different refurbishment strategies. More detailed results can be found in [11]. The lowest environmental impact through LCA will then define the optimum refurbishment strategy.

2 METHOD

Based on a case study, different refurbishment strategies are compared by means of LCA for a reference study period of 60 years. The methods applied in this paper rely on to the European Standards EN 15978 [3] for the assessment of the environmental performance of buildings based on the methodology of life cycle assessment (LCA) [2]. By combining the different refurbishment strategies with energy support the issue of the sensitivity with which the impact of a refurbishment strategy reacts to a change in the system is addressed.

2.1 Life cycle assessment

The functional unit for the LCA is 1 m^2 of energy reference area per 1 year of the building's lifetime. All results of the life cycle impact assessment (LCIA) are referring to this functional unit. The modelling of the inputs and outputs based on the proposed real construction measures for the study has been carried out utilizing the professional software (SimaPro version 7.3.3) with the included database Ecoinvent version 2.2 [6]. The different refurbishment scenarios have been modelled in accordance with the methodological approach of EN 15978, as described in [10]. Consequently, only materials, which are replaced or added to the building structure plus transportation task inputs and the operational energy for the building, are assessed. The building elements that are assessed include external walls and roof (only refurbished parts considered), new doors, windows and technical system installations (ventilation, heating, sanitary equipment, electrical equipment). In the case of all these building materials, we assumed a simple final disposal after their deconstruction, and have thus not gone into a consideration here of any potential recycling scenarios. The existing structure and preparatory work inputs were not included in the calculations, owing to the fact that the impact of the refurbishment was exclusively investigated.

The LCIA focuses on the non-renewable share of the cumulative energy demand (CED), the GHG emissions based on the impact indicator global warming potential (GWP) for a time horizon of 100 years for the emissions and the Ecological Scarcity 2006 (UBP) [7].

2.2 Refurbishment scenarios

A residential building erected in 1961 and refurbished in 2013-2015 to a plus energy building (see Fig. 1)) served as a case study. This four-story building was constructed using prefabricated sandwich concrete elements without any additional thermal insulation. The insulation of the basement ceiling was approximately 60 mm polystyrene and the ceiling of the unheated attic was with 50 mm wood wool panels. The old roof was a pitched roof with no insulation. The existing windows were double glazed windows with a U-value of 2.5 W/m2K and no mechanical ventilation system was installed (Table 1).

Fig.1: The case study building (left side after and right side before refurbishment).

Five strategies of onsite energy generation for heating and hot water and three refurbishment strategies were modelled for the refurbishments in the case study. A "scenario – matrix codex" was developed to make the comparison possible. In this the first digit represents the energy generation options (A, B, C, D), energy supply (a

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DOI 10.3218/3774-6_55, ISBN 978-3-7281-3774-6, http://vdf.ch/expanding-boundaries.html

or b) and the second digit presents the refurbishment strategies (I, II, III), see Table 2.

The first scenario (I “No refurbishment”) tests the environmental impact on the building when retained, as it exists today. By renewing some parts of the façade, the building was kept habitable in terms of health and wellbeing for users as well as improving the structural envelope to some extent.
The second scenario (II “Minimum refurbishment”) fits a minimum requirement of the thermal envelope of buildings after refurbishment in order to improve the efficiency in terms of isolation and energy performance. Within this minimum refurbishment, it is also assumed that the technical systems for heating will be replaced with gas central heating and/or district heating.

In the third scenario (III “High quality refurbishment”), the existing building will be refurbished into a plus energy building. The high-quality refurbishment concept is based on efficiency measures (highly insulated, prefabricated active energy roof (PV and solar thermal) and energy façade elements with integrated building services - mechanical ventilation with heat recovery (85%), on a high percentage of renewable energy sources as well as a smart integration of energy supply towards heat and electricity networks.

Table 1 gives an overview of the different U-values of the proposed construction measures.

	Refurbishment scenario		
	I None	II Minimum	III High quality
Building element	U-value [W/m2K]		
External wall	0.87	0.31	0.14
Window	2.50	1.33	1.00
Top floor ceiling	0.74	0.19	0.10
Basement ceiling	0.39	0.39	0.30

Table 1: The U-values used in each of the three scenarios.

For the technical systems we assessed the base case (scenario A), installation of solar thermal area (B), PV area (C), solar thermal area + PV area (B+C) and solar thermal area + increased PV area (D).

Refurbishment scenario	Code	Scenario energy supply
I:No refurbishment	A: Basis	100% Gas
	Aa: Worst case energy supply	50% Coal + 50% Oil
	Ab: Change to district heating	54% District heat + 46% Gas
II: Minimum refurbishment	A: Basis	54% District heat + 46% Gas
	Aa: Worst case energy supply	100% Gas
III: High quality refurbishment	B+C: Basis	54% District heat + 46% Gas
	B+Ca: Worst case energy supply	100% Gas
All scenarios	B: Solar thermal area C: PV area B+C: Solar thermal area + PV area D: Solar thermal area (B) + increased PV area	

Note: A: Conventional energy supply; B: Solar thermal area; C: PV area; B+C: Solar thermal area

Table 2: The change in energy supply scenario encoding matrix.

Within the scenario evaluation the refurbishment options (I, II and III) of the building envelope are then combined with the technical systems (A, B, C and D). The large roof on top of the building and southern orientated façade enables provision of a large area for active modules such as solar thermal collectors and photovoltaics, which will produce either a large proportion or all of the energy requirements for the users.

3 RESULTS AND DISCUSSION

3.1 Scenario comparison

The results for all refurbishment scenarios are presented in Figure 2. For a better comparison, the results are presented relative to the worst case (scenario I-Aa), which is 100% from non-renewable sources. The results show the trade-offs of the different construction measures in combination with the different technical systems and energy supply. Due to the additional embodied impacts, the high quality refurbishment scenario III B+C is nearly equal to the minimum refurbishment scenario II B+C for the indicators CED n. ren and GWP. The higher impacts in ecological scarcity are driven by the higher weight of embodied impacts.

It can also be observed that the no refurbishment scenario with the installation of solar and PV (I B+C) nearly reaches the minimum scenario based on the worst case (II Aa). In any case, scenario III D shows the lowest life cycle induced impacts overall, mainly due to the energy savings (energy payback) in the use phase.

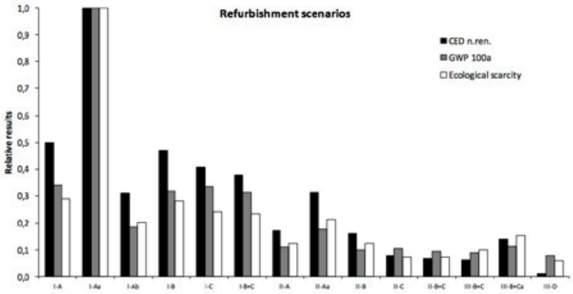

Fig. 2: Relative indicator for the refurbishment scenarios and the energy strategies.

3.2 Energetic payback

As plus energy buildings produce more energy than they consume on a yearly primary energy base, the refurbishment scenarios were evaluated in terms of embodied vs operational energy aspects. The concept of the energetic payback time (PBT) [8], [12] was calculated as the ratio of the embodied energy (blue boxes) over the delivered energy (red and yellow box) as pictured in figure 3.

The comparison of the different refurbishment scenarios by analysing the energy payback time is evaluated in relationship to the existing situation (scenario I-A) (see Figure 4). The distance to an intersection point along the time axis indicates the payback time of the scenario with lower impact after intersection in comparison to another scenario. The impact of each refurbishment scenario (including I-A) is an ongoing summarisation over time according to its building stage phases and there is no energy payback.

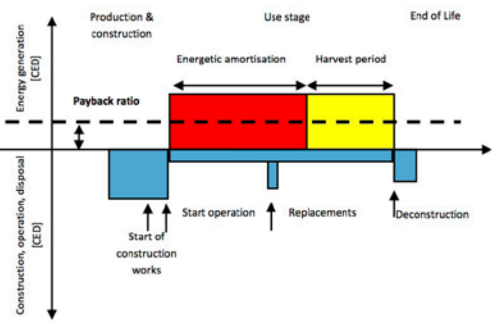

Fig. 3: Concept of the energy payback time [15].

The scenarios II-B+C and III-B+C reach a similar value of overall impact after 25 years. The scenario III-D, with increased photovoltaic area, is the only scenario with an energy payback. It is the best option even reaching “negative impacts” during the operational benefits after 30 years.

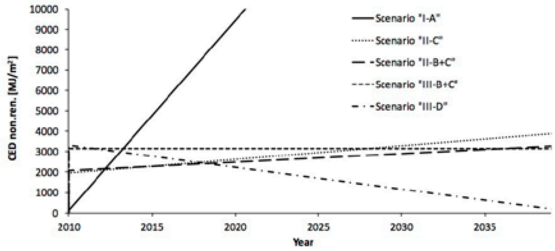

Fig. 4: CED n. ren. payback times of selected cases.

All of the refurbishment scenarios have a very low payback time in relationship with the impact of the existing building (black continuous line in Figure 4), whereas the scenarios of the minimum refurbishment (II) would pay-off after 2 years, the high- quality scenarios (III) would require an extra year due to their additional embodied energy. In addition to the environmental payback, the economic payback of refurbishment is one of the crucial issues, which needs to be further evaluated.

4 CONCLUSION

Based on our methodological approach, the optimal refurbishment scenario is a high-quality refurbishment of the thermal envelope by the use of prefabricated façade elements and solar thermal collectors as well as PV modules. In terms of environmental indicators, this refurbishment will always be beneficial due to its lowest environmental impact from a life cycle perspective. In addition, a change of energy supply to district heating proved to be very beneficial for all construction standards and should therefore be implemented rapidly at least as a first and a relatively easy step to implement.

Additionally, the sensitivity analysis on the high-quality refurbishment scenario determined that a surplus of electricity production by increase of PV area is not always feasible as the predicted operational benefits react sensitively to a change of the future electricity mix to more renewable resources. The benefits from delivering energy to the grid and future grid and climate change scenarios needs to be further investigated. It seems to advisable to evaluate this using a consequential LCA approach.

It is therefore necessary to find the optimum balance between diminishing returns due to the changes in energy mixes and financial investment and embodied impacts over the entire lifetime of the building and this especially in the case of plus-energy buildings.

As there is a great and pressing need for the refurbishment of a large share of the building stock due to the large consumption of energy, another major advantage to be achieved here is the reduction of construction time due to the introduction of a high degree of prefabrication as

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DOI 10.3218/3774-6_55, ISBN 978-3-7281-3774-6, http://vdf.ch/expanding-boundaries.html

shown in our case study. In addition, the façade elements are designed in order to ensure a minimal disturbance of the inhabitants during the construction and replacement phase.

5 ACKNOWLEDGMENTS

The Authors wish to thank Dr. Karl Höfler from AEE INTEC for the excellent collaboration as lead project manager from the research project e80^3-Buildings http://www.hausderzukunft.at which serves as basis for the case study in this paper, published in[11]. The project was funded by the Federal State of Styria and the programme "Building of Tomorrow" of the Austrian Federal Ministry of Transport Innovation and Technology (BMVIT) via the Austrian Research Promotion Agency (FFG). The Authors greatly appreciate the support given by ETH Zurich (Chair of Sustainable Construction), which made the collaboration for work on this paper possible.

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