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# Life-Cycle Costs of a Minimally Invasive Refurbishment Approach in Comparison to a Standard Refurbishment

# Life-Cycle Costs of a Minimally Invasive Refurbishment Approach in Comparison to a Standard Refurbishment

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**Abstract**. The decision on constructing or renovating buildings is often based on construction costs; consequently, follow-up costs are not considered. *Life-cycle cost analysis* is a common method for assessing the economic viability of buildings over their entire life-cycle. In this project, life-cycle costs of a minimally invasive refurbishment with component activation are compared with those of a standard refurbishment approach with an external thermal insulation composite system (ETICS) and radiators. Although the follow-up costs approximate the life-cycle costs after a period of 50 years in this analysis, the additional erection costs of the minimally invasive refurbishment approach cannot be compensated. In order for the system to become economically competitive, the erection costs regarding the façade system and the associated building technology must be reduced by 36 %, assuming that the nominal follow-up costs remain the same. Since the current implementation is still a prototypical one, cost-saving potential is expected on basis of the experience of the executing companies. However, in addition to the economic efficiency, the non-monetary added value of the system in the form of a more homogeneous heat output, more ecological building materials, less stress for the inhabitants due to the minimally invasive approach, reduced use of floor space and increased sound insulation due to the sound insulation façade, should also be taken into account in the decision-making process.

## 1. Introduction

Due to the climate policy in the European Union and consequently in Austria, the energetic renovation of buildings is becoming more and more important. According to Statistics Austria, an average of 21252 new buildings were built each year between 2011 and 2017 [1]. In addition, 49.5 % of the existing buildings in Austria and 43.4 % in Salzburg were constructed between 1945 and 1980 (as of 2011) [2]. The age structure of these buildings will cause various problems and challenges in the near future. The object of investigation, an apartment building with twelve apartments, can be assigned to the early post-war architecture of the 1950s. The challenges and problems which need to be overcome concern the energy standard of the building envelope, building technology, sound insulation and the comfort of the occupants of the buildings. A thorough examination of the existing building stock will therefore be indispensable. The analyzed object is characterized by a lack of thermal insulation and the windows were last replaced in 1993 and require renovation. This is accompanied by high transmission heat losses and thus a high heating energy demand of 241.6 kWh/m²a (according to the energy performance certificate) in the existing building. Moreover, the heat supply system of the considered object is heterogeneous. Seven apartments are equipped with individual stove heating and five apartments are connected to the district heating grid. The refurbishment is currently in progress, but has not yet been completed.

The erection costs as well as the follow-up costs associated with such renovations vary over the entire life-cycle of a building depending on the chosen construction method, components and technologies. In most cases, the choice as to which components and construction method to use takes place without considering the follow-up costs and the decision is made solely on the basis of the investment or erection costs [3]. The refurbishment measures for this object are carried out in the course of a research project focusing primarily on a novel façade technology. A minimally invasive multifunctional façade is being tested, which combines thermal insulation, sound insulation, heat dissipation and façade cladding in prefabricated wooden elements. This contribution wants to compare the life-cycle costs of a minimally invasive refurbishment with those of a standard refurbishment (see description of the approaches in chapters 4.1 and 4.2), in which the refurbishment costs are kept as low as possible.

## 2. Objectives

*Life-cycle costing* is a widely used method for assessing the economics of a whole building or individual components over its entire life-cycle. Accordingly, the literature on life-cycle cost analysis (LCCA) in general is extensive, but there are only a few detailed studies on the analysis of facade systems. Floegl and Ipser [4], for example, examine the life-cycle costs of six different residential complexes of different construction years and sizes. Höfler and Kunesch [3], on the other hand, compare the life-cycle costs of different refurbishment concepts in the course of the e80^3 project. Furthermore, a facade module and a building services module have been developed and implemented in a demonstration building. One of the objectives was the prefabrication of energy-efficient elements. The present research project differs from the described system as it integrates the heating system within the façade in the form of a component activation, as well as the installation of wood cement panels as sound absorbing elements. Schmidt et al. [5] have developed and tested an external component activation in the course of the research project "LEXU" and "LEXU II". In this case, the system was combined with an external thermal insulation composite system. Höfler et al. [6] have investigated prefabricated systems for the refurbishment of residential buildings in the course of the IEA ECBCS Annex 50 and developed prefabricated modules with a focus on thermal refurbishment for a demonstration object in Graz-Dieselweg. A life-cycle cost analysis has not been carried out for the latter two projects. At the moment, the available data for a detailed LCCA is insufficient; therefore, the basis for this contribution is a rough estimate of the costs of the refurbishment method currently being carried out with a prefabricated multifunctional façade and component activation on the basis of an apartment building in Hallein, Salzburg. The chosen renovation method represents a prototype and is planned to be applied to other buildings with similar characteristics. The life-cycle costs are calculated on the basis of the tool Lekoecos, which in turn is based on the corresponding standards ÖNORM B 1801-1 [7] for the calculation of the erection costs and ÖNORM B 1801-2 [8] for the calculation of the follow-up costs. The applied calculation method uses the present values of the follow-up costs for the selected period of 50 years. The costs for the minimal invasive refurbishment are to be compared with those of a conventional renovation with a similar energetic standard.

## 3. Research process

In this chapter, basic data for the calculation of the life-cycle costs as well as the boundaries of the treated costs are expounded.

### 3.1. *Basic data*

The considered life-cycle costs are based on data about the minimally invasive refurbishment still under construction as well as the estimation of the renovation costs of a standard approach. Based on the current data situation, the estimated costs are thus made up in part of actual costs, obtained offers and estimated costs. The following documents are available for the calculation and input:

- as-built and execution plans (architecture and building technology)
- energy performance certificates (stock and renovation)
- simulation of heating demand
- invoices of measures already carried out including redensification by adding a story in solid wood construction, multifunctional façade, building technology of the minimally invasive refurbishment, renovation of the existing bathrooms and planning services
- offers and estimates of the work still to be carried out and the standard refurbishment including façade cladding of the added story, roofer and plumber, electrician, dry construction, outside facilities, measurement and control technology, external thermal insulation composite system (ETICS), building technology of the standard refurbishment

The calculation parameters are based on the tool LEKOECOS of the Danube University Krems in beta version 1.3. The input of the object parameters refers to the execution and as-built plans as well as the energy certificate. In addition, the respective invoices, if available, are used to determine the construction costs. With regard to the minimally invasive refurbishment, the existing offers serve as a basis for the input of construction measures that have not yet been carried out. If there is neither an invoice nor an offer, a cost estimate based on the ÖNORM B 1801-1 [7] is made. The calculation of the erection costs for the standard refurbishment is also done on the basis of existing offers as well as cost estimates based on the ÖNORM B 1801-1 [7]. The heating energy demand results predominantly from the simulation of the two divergent heating- as well as construction variants. Furthermore, the heat losses of the heating system are obtained from the respective energy performance certificate, since only the simulation of a part of the building and the building technology system is carried out. The energy required for hot water preparation is similarly obtained from the energy certificate. Any energy gains from the photovoltaic system are not taken into account. The assessed costs per kWh for heat supply correspond to the costs actually charged. The operational life spans for calculating the usage costs of technical building systems were obtained from the VDI 2067-1 [9], and the operational life spans of the building components originate from the Federal Ministry of the Interior, Building and Community Germany [10].

### *3.2. Boundaries*

The ÖNORM B 1801-4 [11] divides life-cycle costs into erection costs and follow-up costs, the latter in turn includes usage costs as well as object removal and demolition costs. The following economic efficiency comparison is drawn for selected cost groups on the basis of LCC (Figure 1). In this project, the erection costs thereby include those cost groups according to ÖNORM B 1801-1 [7] that are actually generated during the renovation process, namely costs for the building shell (E2), building technology (E3), building extension (E4), outside facilities (E6), planning services (E7) and reserves (E9). In addition, standard refurbishment costs for incidental expenses (E8) are taken into account, since it is assumed that the occupants must be resettled during the renovation. Therefore, this cost group includes the loss of rent during the renovation as well as one-off relocation expenses. Because of the observation of two façade systems and the associated heat release systems, the follow-up costs are limited to the relevant usage costs of the cost groups technical building operation (F2), supply and disposal (F3), cleaning and maintenance (F4) as well as overhaul and modification (F7). Owing to the current data situation, costs for object removal and demolition (F9) are not considered. In addition, according to Höfler and Kunesch [3], when a dynamic calculation method is applied, object removal and demolition costs lose much of their significance when observed for longer periods of time.

IOP Conf. Series: Earth and Environmental Science **323** (2019) 012003 doi:10.1088/1755-1315/323/1/012003

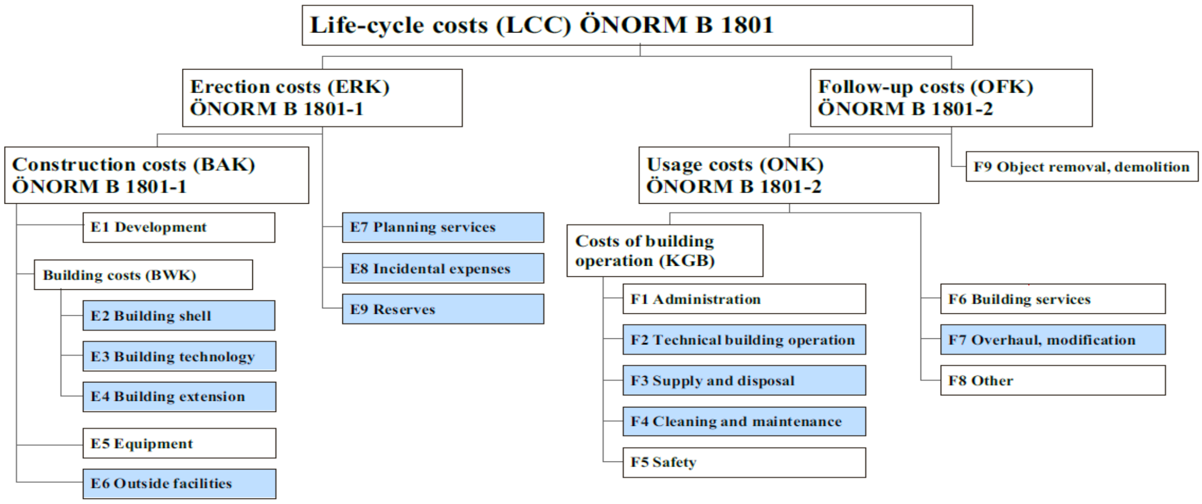



**Figure 1.** Selected cost groups of the considered life-cycle costs according to the ÖNORM B 1801.

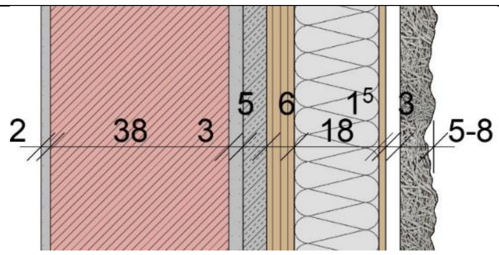
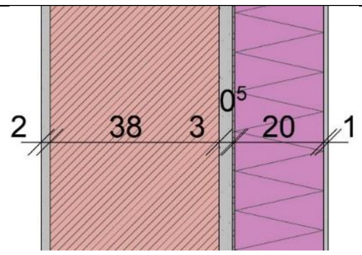
## 4. Life-cycle analysis

In this chapter, a description of the considered renovation variants is given. In principle, the costs of the entire renovation are included in the consideration of the life-cycle costs, whereas differences between the two variants only affect parts of individual cost groups. The basis for the two renovation variants is an apartment building in solid brick construction, which contained twelve apartments before the renovation. In the course of the refurbishment, the building gets extended and seven apartments are added, resulting in a total of 19 apartments after the refurbishment. The differences between the two variants are limited to the chosen façade and heating system. The two variants share the following measurements regarding to the construction costs:

- redensification by adding a story in solid wood construction
- roofer and plumber
- electrician
- renovation of the existing bathrooms and planning services
- installation of a photovoltaic system
- installation of home transfer stations in each apartment
- outside facilities
- district heating connection
- dry construction

Below, the differences between the two variants are explained and the considered construction systems (Table 1) and technologies are described.

**Table 1.** Comparison of the selected variants.

| | Minimal invasive refurbishment | Standard refurbishment |
|---|---|---|
| **Component structure** |  |  |
| **U-Value** | 0,182 W/m²K | 0,182 W/m²K |
| **Thickness** | 81,5-84,5 cm | 64,5 cm |
| **Heat dissipation** | Component activation | Radiator |

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### 4.1. *Minimally invasive refurbishment*
The exterior walls of the existing building are constructed as externally and internally plastered standard format brick walls. The so-called *multifunctional façade* comprises a thermally activated mortar layer (8 cm), in which the heating coils for the external component activation are positioned, a composite wood panel (6 cm), cavity insulation using cellulose (18 cm), and all-over MDF-cladding (1.5 cm). Externally, there are both a ventilation level (3 cm) and sound-absorbing wood cement panels (5-8 cm). A schematic structure of the actual wall structure can be seen in Table 1. This wall structure reaches a U-value of 0.182 W/m²K.

The façade elements, i.e. the composite wood panels, the cellulose insulation and the planking, are prefabricated and displaced as floor-to-ceiling elements. The resulting space between the existing masonry and the prefabricated façade element is filled with injection mortar after the installation. This layer contains the heating coils for the component activation. The distance between the coils is usually 20-25 cm. These are multi-layer composite coils with an outer diameter of 20 mm and a material thickness of 2.25 mm, and are attached to the existing wall before the façade modules get displaced.

### 4.2. *Standard refurbishment*
In order for the standard refurbishment to be compared to the minimally invasive refurbishment, a wall structure is chosen that has a similar U-value to that of the minimally invasive refurbishment. Thus, the external thermal insulation composite system, which is often used in renovation procedures, represents the standard refurbishment. This variant comprises a façade insulation consisting of expanded polystyrene (20 cm) and reinforced synthetic resin plaster (1 cm) attached to the existing wall. The wall structure described above obtains a U-value of 0.182 W/m²K. A schematic structure of the standard refurbishment can be seen in Table 1.

In minimally invasive refurbishment, the building is heated via the façade, whereas in standard refurbishment heating is provided by radiators. The additional costs for the standard system cover the installation of the surface-mounted heating pipes and the radiators as well as the corresponding material costs. Since risers and transfer stations in the individual residential units are installed as part of the bathroom refurbishment, additional costs in standard refurbishment have to be taken into account only for the distribution pipes within the apartments, as opposed to the minimally invasive refurbishment, where additional distribution pipes need to be installed starting from the distribution stations in the basement.

### 4.3. *Comparison of life-cycle costs*
The results of the minimally invasive refurbishment are now compared with those of the standard refurbishment. Therefore, the life-cycle costs of selected cost groups are displayed in the following figures.

IOP Conf. Series: Earth and Environmental Science **323** (2019) 012003 doi:10.1088/1755-1315/323/1/012003

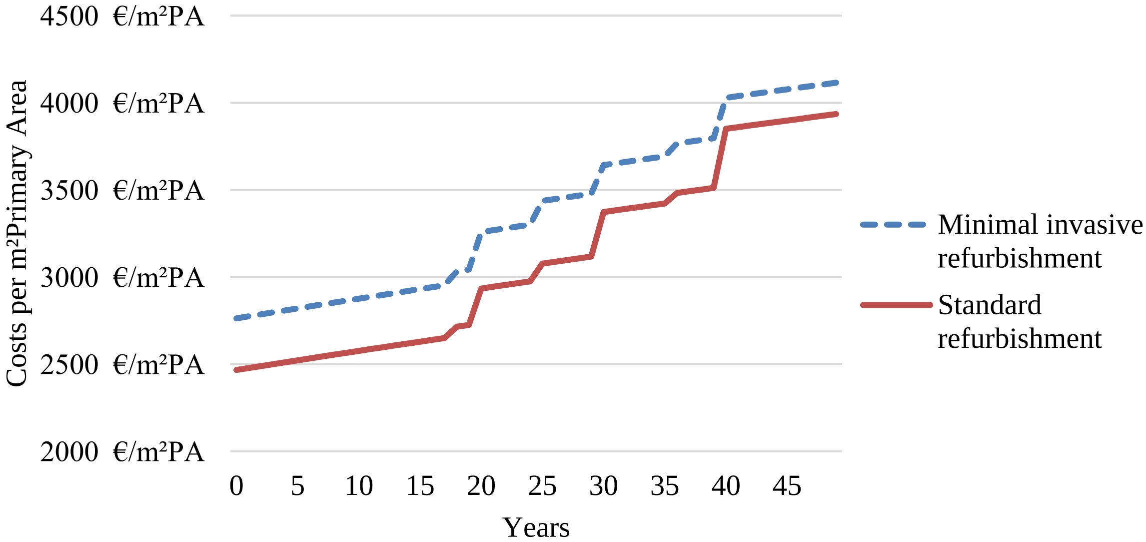


**Figure 2.** Trend of the life-cycle costs of selected cost groups over a period of 50 years.

Figure 2 shows that the minimally invasive refurbishment is more expensive as far as construction costs are concerned, but not regarding usage costs. Yet the benefits as a result of the lower usage costs over the considered 50-year period are not sufficient to offset the higher construction costs. In principle, three major rises can be observed in the course of life-cycle costs. First, the rise in usage costs after 20 years due to required renewals of some building technology components. Second, after 30 years it is assumed that it will be necessary to replace windows. The standard refurbishment involves higher costs, since a renewal of the heat release system is included. Third, after 40 years, the investment once again mainly relates to the renewal of some components of the building technology. The refurbishment of the thermal insulation composite system is taken in standard refurbishment, too. This results in a discrepancy in the rise of the two systems regarding usage costs.

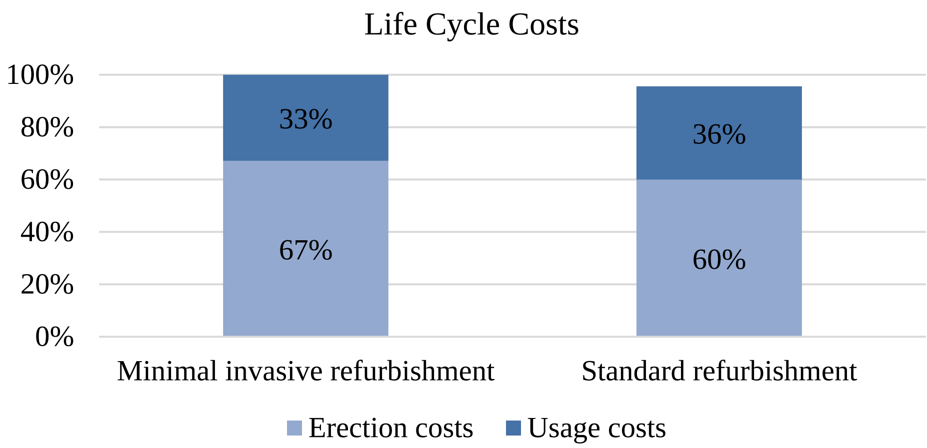


**Figure 3.** Life-cycle-costs in percent based on the minimally invasive refurbishment.

As can be seen by the ratio of construction costs and usage costs in Figure 3, usage costs of the minimally invasive refurbishment are 3 % lower and construction costs 7 % higher than in standard refurbishment. These differences relate to the cost groups technical building operation (F2), supply and disposal (F3) and overhaul, modification (F7). Standard refurbishment only bears lower costs in the cost group supply and disposal (F3), since the minimally invasive refurbishment entails higher heat

IOP Conf. Series: Earth and Environmental Science **323** (2019) 012003 doi:10.1088/1755-1315/323/1/012003

losses due to the positioning of the building component activation on the outside of the existing wall. With regard to the erection costs, the costs of the minimally invasive refurbishment in the cost groups building technology (E3) and building extension (E4) are 2 % and 7 % respectively above those of the standard refurbishment. Standard refurbishment in turn includes additional costs of 2 % regarding incidental expenses (cost group E8). This results in the aforementioned difference of 7 %. Overall, the lower costs of standard refurbishment thus amount to 4 % in comparison to the minimally invasive refurbishment.

## 5. Conclusion

The results of the life-cycle cost analysis, excluding the cost group of object removal and demolition (F9), show that the additional costs of the minimally invasive refurbishment concerning construction costs cannot be compensated by the incurred additional costs of standard refurbishment due to the relocation of the tenants and the associated rent loss. Although usage costs of standard refurbishment with regard to the thermal insulation composite system and the heat dissipation system are now somewhat higher, mainly due to the shorter operational life spans, at the end of the considered 50-year period a difference in life-cycle costs of 4 % remains. In order for the multifunctional façade and the building service system to be economically competitive with a standard refurbishment as described, cost savings regarding construction costs are required. If the construction costs of the façade and the associated building services system could be reduced by 36 %, the difference of 4% in life-cycle costs of the two variants could be compensated, assuming that the nominal follow-up costs remain the same. The calculation of follow-up costs in Lekoecos is in some cost groups based on a percentage of the construction costs. This results in the problem that the advantage of high-quality, innovative components and systems leading to lower follow-up costs cannot be expressed [12].

In addition, it is important to consider the added value of the system, which cannot be monetized. It includes the reduced burden on the tenants due to the minimally invasive refurbishment. The minimally invasive refurbishment approach allows residents to remain in the building during conversion work. This is based on the demands of the building operator (the city of Hallein) and the tenants, surveyed during the stocktaking analysis of the project area [13]. The heat dissipation through component activation instead of isolated radiators and the reduced use of floor space due to the piping on the outside add another aspect. The installation of sound absorbing wood-cement panels has the potential to reduce noise levels in open spaces throughout the district, getting more effective by the number of surrounding buildings reconstructed with absorbing elements. The sound behavior was examined in detail and a potential sound level reduction of 1 to 3 dB was determined [14]. The use of wood-based materials and good decomposability make the variant more sustainable and ecological compared to a thermal insulation composite system. All these added values cannot be taken into account in a purely monetary valuation and analysis.

The life-cycle cost analysis did not take into account any advantages in terms of subsidies.

## 6. Outlook

Due to the fact that this system still is in a prototypical state, a future optimization and cost reduction is quite foreseeable. It is difficult to estimate the extent of possible cost reductions, but savings can basically be achieved by optimizing both the building service system and the construction of the façade. In the course of the research project, further optimizations of the multifunctional façade will be tested in a similar building, starting in autumn 2019.

## 7. Acknowledgments

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IOP Conf. Series: Earth and Environmental Science **323** (2019) 012003 doi:10.1088/1755-1315/323/1/012003

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