An Integrated Refurbishment Design Process to Energy Efficiency

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Abstract

Given the very low renewal rate of the building stock, the efforts to reduce energy demand must focus on the existing residential buildings. Even though awareness has been raised, the effect on energy efficiency is often neglected during the design phase of refurbishment projects. This paper discusses an integrated approach to energy-efficiency upgrades of residential building stock, by assessing the impact of retrofitted components in the early stages of the design. Firstly, the key building components of an integrated refurbishment are identified and various solutions are systematically organised into a "toolbox". Moreover, a roadmap to refurbishment design was created. The proposed methodology, applied on case study buildings, resulted in improvement of the dwelling energy demand up to 80%. This approach recognises the diversity of each project, as well as the designer's freedom to his decisions. It assists efficient choices, with respect to the specific requirements of each project. The toolbox information enables designers of refurbishment project to know in the early stages of the design the impact their choices will have.

Keywords – Refurbishment; Energy Upgrade; Design Process; Building Envelope

1. Introduction

In the context of sustainable development and the need to reduce energy demand, refurbishment of the existing, aging building stock is an acknowledged issue. Since the need to reduce the energy demand of the residential building sector is urgent, the efforts must focus on the existing buildings. While new constructions add annually 1% or less to the existing stock [1-3], the other 99% of buildings are already built and produce about 24% [4] of the energy-use induced carbon emissions. Residential buildings account for 70% of building floor area [5], while the condition and efficiency of a large part of the residential stock still needs attention. On the other hand, demolition is not the solution. Regarding materials and waste, studies show that the environmental impact of life cycle extension of a building is definitely less than demolition and new construction [6]. However, buildings suffer from a variety of physical problems. Taking into account that the expectation for the structural life of a building often exceeds 60 years, while

the envelope shows signs of obsolescence after only in 20 or 30 years [7, 8], it is understandable that the residential stock is in need of refurbishment.

Even though awareness has been raised the effect on energy efficiency is often neglected during the design phase of refurbishment projects. The decisions taken in the early stages of the design determine the final result; however, the assessment of the environmental performance only happens at the end of the design process, as a reflection of the design outcome[9].

This paper discusses an integrated approach to energy-efficiency upgrades of residential building stock. Given the importance of the building envelope on the energy demand, our methodology assesses the impact of retrofitted components into the energy performance of the building in the early stages of the design. Firstly, the key building components of an integrated refurbishment are identified and various solutions for each component are systematically organised into a "toolbox". The compilation of different "tools" composes the refurbishment strategy. Subsequently, the toolbox refurbishment options are quantified and the key parameters in the refurbishment strategy development identified. In this way, a roadmap to refurbishment design was created. Finally, the proposed methodology is applied on a case-study building, to demonstrate how the toolbox information support the decision process. The solutions resulted in improvement of the dwelling energy demand up to 80%.

2. Refurbishment potential

The potential of refurbishment have been addressed not only by the building industry, but it has also been well researched. Studies [10] have identify the potential of refurbishment to upgrade the energy efficiency of the building stock and the consequent savings in CO2 emissions. Additional studies have concluded that deep renovation has the potential to be the preferred solution from ecologic and economic point of view. The renovation strategy should integrate different building components; thus, it is referred as integrated refurbishment strategy. Superficial renovations, on the other hand, significantly increase the risk to miss the climate targets and huge absolute savings to remain untapped [11, 12].

Refurbishment of the ageing residential buildings is a complicated task encompassing a number of parameters and involved parties. Throughout this process and the various constrains, the environmental performance is often neglected. It is calculated towards the end of the design process, in the form of regulatory or voluntary certificates [13]. However, the earlier the design decisions are made, they can have bigger impact with lower cost. Evaluation of the performance has proven to be very effective while decision making amongst various available options [13]. If the designer is provided with an indication of how efficient refurbishment options are, it is possible to apply them as part of an integrated strategy rather than try to add measures in later stages, after the strategy is developed.

The present study proposes a methodology to provide indication of the energy performance in the early stages of the design, when the refurbishment strategy is under development. According to Míguez et al. [14], an effective rating of the performance must take into account the freedom of the building designer in designing architectural aspects and installations. Our approach enables the designers of refurbishment project to know the impact their choices will have and, thus, provide a decision-support instrument.

The study focussed on the building envelope, as it regulated the energy use and the indoor condition. Research [12] have specify that the building envelope has to reach depth of refurbishment beyond 70%, in order to reach the European 2050 decarbonisation targets [15]

3. Method to evaluate refurbishment options

In order to be able to assess the environmental performance of the refurbished building in the early stages of the design phase, firstly, different refurbishment options are systematically organised, according to the building envelope component they address, composing a façade refurbishment toolbox. This toolbox is essentially a database of possible measures implemented in refurbishment projects. The information is organised in a matrix, as presented in Table 1. The measures are state-of-the art refurbishment solutions, proposed based on research, practice and experience. They can be combined depending on the specific requirements of every project and design, resulting in the integrated refurbishment strategy.

After defining the different possibilities for the refurbishment measures, the possible effect of individual option on the energy consumption is calculated. In this way, not only is the designer provided with the knowledge of the measure benefit but also the options are becoming comparable. The energy efficiency indicator in the present study is heating demand, as it accounts for the largest percentage of the energy consumption in residential buildings. Namely, more than half (57%) the final energy consumption of residential buildings in the EU is used for space heating [5]. Cooling loads, if necessary are also included in the energy demand. However, in the case of residential buildings cooling is not as important as in non-residential, as most dwellings rely on natural ventilation [5]. The usage patterns prior and after the refurbishment are assumed to be comparable; thus, no significant change in the use of appliances is expected.

Table 1. The toolbox matrix in table form

Building envelope					Installations	
Exterior wall	**Windows**	**Balcony**	**Roof**	**Basement ceiling**	**Ventilation**	**Heat source**
no insulation	single glazing	continuous slab no insulation	flat roof slab no insulation	no insulation	natural ventilation	gas boiler for each apartment
little/outdated insulation	double uncoated	separate slab no/little insulation	pitched roof no insulation	no insulation, basement heated space	controlled mechanical exhaust	gas boiler per block
exterior insulation, ventilated facade	upgraded existing window (glass, fittings, etc.)	insulation of the balcony slabs	insulation on the top floor	insulation on top of the basement ceiling slab	ventilation system with heat recovery (HR)	CHP installation
interior insulation	"box window"	cut out and replace balcony with thermal break	pitched roof insulation	insulation under the basement ceiling slab		air-water heat pump
exterior thermal insulation	window replacement 2ble glazing	non-insulated glass envelope / winter garden	flat roof insulation	VIP panels under the basement ceiling slab		solar collectors
double skin facade	window replacement 3ple glazing	integrated balconies in the thermal envelope	green roofs			geothermal heat pump
Photovoltaic (PE factor 0) *	shading internal	enlarged balconies	Photovoltaic (PE factor 0) *			district/ community heating
addition to exisitng building	shading external		additional floor			
one lift for one block (access via gallery)	"French windows"					

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The method used to isolate the impact of each option is the following: first we set up a model of an existing apartment and simulated the heating energy demand. The software Capsol by Physibel [16] is used for the thermal simulation. This program calculates the thermal dynamical behaviour using the heat balance method. The simulation is based on European standards for

thermal comfort for required temperature, overheating and ventilation [17]. The energy calculated refers to energy need for heating. Based on this model, every option was simulated separately, by changing only one component in the model of the existing situation. The toolbox database addresses different buildings and for this reason a range of building construction, opening proportions and orientations are calculated. The calculations were conducted by dynamic simulation of the building condition. In this way, not only the annual heating demand is measured, but also the internal thermal comfort in checked.

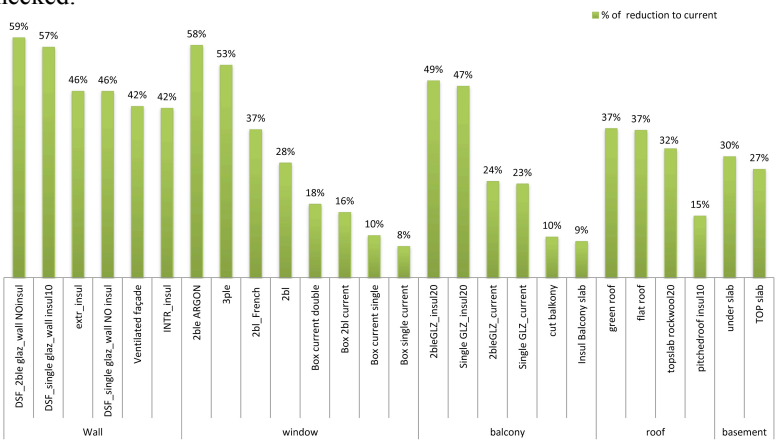


Fig. 1 Average energy demand reduction by the implementation of the individual measures, for one of the variations.

Figure 1 presents the toolbox quantification for one of the building type. The effect of each measure is shown as the percentage of reduction to the current heating energy need of the apartment. The options are grouped according to the building component, namely wall, window balcony and roof. The percentages are average for all orientation.

Finally, the key components and the toolbox input in the design process are highlighted. It is necessary to investigate how refurbishment strategies are developed, identify the decision-making points and determine what the input of the toolbox can be. If we combine all the considerations accounted in the decision-making of the refurbishment strategies, a roadmap to building envelope refurbishment is composed.

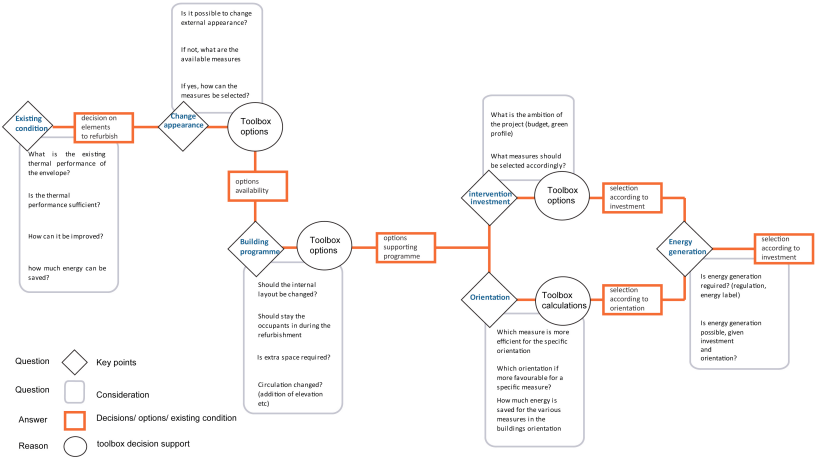


Fig. 2 Visualisation of the key points, considerations and toolbox influence in refurbishment design process

The roadmap indicates at which point are the parameters considered, which options are excluded then and when the toolbox information is adequate to support the decision. This process served to emphasise on the key points that shape the decisions. They are the following, as they appeared during the study of the building envelope components.

i. Existing condition
ii. Changes in the external appearance
iii. Building programme
iv. Level of intervention-investment
v. Orientation
vi. Energy generation

In order to demonstrate how the above points interact with the decision making of the refurbishment strategy, the following section describes the development of the strategy for a case-study building. During this process, the impact of the toolbox database and calculations is clarified.

4. A Roadmap to Case-study Refurbishment Design Process

This section guides thought the decision making process for a case-study building. It addresses each individual building envelope component- as does the toolbox- and explains what the considerations behind each decision were. In this way, the roadmap to refurbishment toolbox is composed.

The case-study project is the refurbishment of a multi-residential-building complex of the post-war period in Germany. The subject of the study was assigned by the housing corporation that owns and manages the estate. It concerns residential buildings constructed in 1967, located at the area Gartenstadt at the outskirts of the city of Krefeld.



Fig. 3 The front façade of the three- storey and the four-storey apartment blocks

According to data given by the housing corporation, the complex comprises 120 apartments, most of which are still in their original situation. Moreover, 22% is vacant, which is one of the issues the housing corporation would like to eliminate with the upgrade of the apartments. A more diverse tenants population mix is aimed, this is why the building programme requires of better quality flats, diverse layouts and an appealing, refreshed design. The current tenants will be removed and the buildings will be empty during the refurbishment construction work.

The main problems found during the analysis are related to the building envelope, the spatial quality of the apartments and the condition of the mechanical installation. There were complete lack of thermal insulation on external walls and roof, outdated windows and thermal bridging at the balcony slabs. Moreover, façade elements show signs of deterioration, such as plaster fall-off, reinforcement's corrosion of the concrete parts etc. Additional problems were mould growth on the inside of the external surfaces, related to thermal bridging and insufficient ventilation, and outdated technical installations in most cases.

4.1. Refurbishment Strategy Development

The development of the integrated refurbishment strategy addresses the individual building envelope components. The study explains the refurbishment measure selected for each component, taking into account the key points about the building construction, the possibility to modify external appearance, building programme, orientation, level of intervention, energy generation.

Starting with the external wall, the thermal resistance of the envelope needed to be improved and thermal bridging had to be resolved. The option external thermal insulation composite system (ETICS) with 20 cm mineral wool is selected to be implemented on the south, east and west facades. The internal insulation option was rejected because the external insulation is more efficient for thermal bridging. Since there are no requirements to retain the existing external appearance, for monumental reasons or other, the intervention form the outside is preferable.

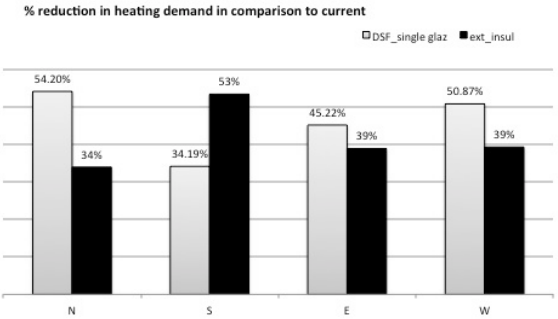


Fig. 4 The reduction (%) to current heating energy demand after the implementation of a second skin glazed façade and external insulation, according to different orientation.

A different option is chosen, though, for the north façade. A double skin façade (DSF), comprising a gallery, through which the apartments are accessed, is introduced along the entrance façade. This decision was mainly due to the toolbox calculation. It performs as a thermal barrier for this north façade, providing the potential for greater energy savings (see figure 4) than the other orientations, without the use of additional insulation. Moreover, the glazed gallery of the North façade can be combined various benefits to the building. Apart from the energy upgrade, it enables elevator access for all the apartments with the use of only one elevator and it acts as a noise barrier towards the highway, which was one of the projects requirements. The single glazing façade was chosen over the double glazing, as the gallery is a semi-open space and does not requite to be integrated into the thermal envelope.

Currently the balconies, in form of loggias, are located in the south façade. Balconies are problematic areas of the envelope, because of the thermal bridging of the continuous slab. To solve this problem, the balconies are integrated into the thermal envelope. Insulating glazing is used to clad the loggia's open side and insulation is applied on the edge of the slab, to prevent thermal bridging In this way, the thermal bridging problem at the balcony slab is solved and up to 36% of heating energy can be saved, as indicated by the toolbox calculations. The energy savings are greater on the south façade compared to other orientations. Moreover, extra space is added to the apartments, are required by the building programme.

Windows are the next elements to be considered. Since there is no monumental protection applied, they can easily be replaced with high performance insulating glazing and new frames. However, not all of the existing windows need to me considered. The windows on the North façade may remain, since the glazing layer of the gallery is applied. The windows between the living room and the loggia on the south façade are completely removed, as the loggia becomes part of the living space. For the remaining

windows of the south facade, the toolbox calculations can help to decide the glazing type.

The existing pitched roof is maintained and clad with PV panels and solar collectors, as it already has a favourable orientation to the south. Since the attic is unheated, the slab of the top-floor ceiling is insulated. The basement is an unheated space, and as such, allows heat flow through the uninsulated ceiling slab. To prevent these thermal losses, insulation needs to be applied on the slab. The height of the ground flour is limited to apply insulation on top of the slab. For this reason, the basement ceiling is insulated from below.

4.2. Evaluation of the solution

Based on the considerations and the decision processes discussed before, the refurbishment strategy is formed as shown in Table 2. The proposed strategy has been simulated, to prove the thermal performance of the refurbished buildings. It has resulted in saving of the heating energy need of 80%. The reduction has been achieved by minimising conduction heat losses through the building envelope components, by increasing their thermal resistance and creating a thermal buffer at the north façade.

Table 2. The “tools” forming the refurbishment strategy for the four-storey apartment block

Building envelope					Installations	
Exterior wall	**Windows**	**Balcony**	**Roof**	**Basement ceiling**	**Ventilation**	**Heat source**
no insulation	single glazing	continuous slab, no insulation	flat roof slab no insulation	no insulation	natural ventilation	gas boiler for each apartment
little/outdated insulation	double uncoated	separate slab no/little insulation	pitched roof no insulation	no insulation, basement heated space	controlled mechanical exhaust	gas boiler per block
exterior insulation, ventilated facade	upgraded existing window (glass, fittings, etc.)	insulation of the balcony slabs	insulation on the top floor	insulation on top of the basement ceiling slab	ventilation system with heat recovery (HR)	CHP installation
interior insulation	“box window”	cut out and replace balcony with thermal break	pitched roof insulation	insulation under the basement ceiling slab		air-water heat pump
exterior thermal insulation	window replacement 2ble glazing	non-insulated glass envelope / winter garden	flat roof insulation	VIP panels under the basement ceiling slab		solar collectors
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Photovoltaic (PE factor 0) *	shading internal	enlarged balconies	Photovoltaic (PE factor 0) *			district/ community heating
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Further saving in the primary energy can be achieved with retrofitting of technical installations. Additionally, refurbishment improves thermal comfort. Required ventilation rates for indoor air quality is achieved trickle ventilation openings in the new windows. Moreover, adequate ventilation, coupled with solving thermal bridging result in eliminating mould growth. Last but not least, overheating risk is reduced to acceptable hours per year, as calculated through dynamic thermal simulation.

Finally, the strategy has spatial benefits for apartment block. Changes in the layout have resulted in more, diverse-sized of apartments. The main input of the façade refurbishment strategy to additional space is the glazing of the balconies and the addition of the gallery. In this way the balcony and the staircase space is added to the apartments.

5. Conclusion

In the context of sustainability and the need to reduce the energy demand of the building sector, refurbishment is a necessary action. Integrated refurbishment, including all building envelope components, has been the preferred solution to achieve energy reduction targets for the next decades. Even thought the potentials have been identified, the energy performance of the building is often neglected during the design phase and does not affect the decisions made. In order to achieve more efficient refurbishment strategies, it is necessary to integrated the environmental performance into the early stages of the design

The present study has proposed the toolbox approach as a methodology to consider the energy demand reduction at the early stages in the refurbishment strategy decision-making. Firstly, the building components for deep refurbishment were identified and measures for each of them were systematically organised. Subsequently, the reduction on the energy demand was estimated for each individual measure. This was calculated thought simulating the thermal performance of the building prior and after the application of the measure. Variations of the existing construction, openings and orientations were offered, to correspond to different possibilities.

In the next level, the study highlighted the decision making process, creating a roadmap to use the toolbox information. The roadmap indicates what are the key points during the design of refurbishment strategy, given the constrains posed by the existing condition of the building and the project, and the relevant consideration. The toolbox options and calculations is possible to organise and support the decision making on several points during the process. The proposed methodology applied to a case study building resulted in 80% of the heating energy need.

The proposed approach recognises projects' diversity, as well as the designer's freedom to his decisions. The objective is not to dictate an optimised solution, but assist effective choices, with respect to the specific requirements of each project. The calculations enable designers of refurbishment project to know the impact of their choices. The roadmap further assists the decision-making, by drawing attention to the key considerations and the toolbox impact on those. Overall, the toolbox approach supports the refurbishment strategy development by defining the choices impact in the early design stages, while the roadmap highlights the key decision points during the design process and how the toolbox

information support it. The result is integrated refurbishment strategies that improve the performance of the building that fit the projects specifications.

Acknowledgment

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