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Refurbishment of residential buildings: a design approach to energy-efficiency upgrades

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Abstract

Refurbishing the existing building stock is an acknowledged issue in the building industry. Even though awareness has been raised, the design phase of refurbishment projects is often problematic. 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.
This paper discusses an approach to the designing of refurbishment projects, as a way to energy-efficiently upgrade the residential stock. Based on a case study multi-residential building of the post-war period in Germany, we assess the impact of the retrofitted building components into the environmental performance of the building. The different options are systematically organised into categories, creating a "toolbox". The compilation of different "tools" composed the refurbishment strategy. In this way, the impact of the refurbishment was evaluated in the early design stages. The toolbox supported the decision-making process of the design, resulting in integrated strategies that improve the performance of the building.

Keywords: Refurbishment; residential building; energy upgrade; design process; decision making

1. Introduction

Refurbishing the existing building stock is an acknowledged issue in the building industry. The existing stock exceeds the number of newly built buildings by far. While new constructions add at most 1% a year to the existing stock [1], the other 99% of buildings are already built and produce about 26% of

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the energy-use induced carbon emissions [2]. 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 [3]. The retrofitting of residential buildings in particular provides considerable potential for energy conservation and further sustainable benefits. Recent figures suggest the domestic sector could potentially make a significant contribution to reducing energy consumption [4]. Residential buildings account for the 2/3 of final energy consumption in the building sector and 70% of building floor area, while the condition and efficiency of a large part of the residential stock needs attention. Dwellings built after World War II and before 1975 account on average for 29% of the stock. A common characteristic of this period is that the buildings were generally poorly insulated at the time of construction and that they need to be renovated. In the Netherlands for instance, the vast majority of dwellings built during that period have an EPC (Energy Performance Certificate) label D or lower [5]. Furthermore, buildings suffer from a variety of physical problems, many of which are connected with the external envelope, as it is the building component mostly confronted with the external conditions. 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 [6], it is understandable that the residential stock façades need refurbishment.

Even though awareness has been raised, the design phase of refurbishment projects is often problematic. One of the issues concerning the refurbishment of multi-residential buildings is that the involved parties do not see the building as a whole. There is an individual and often fragmental approach that results in lack of efficiency and unsuccessful solutions. Most importantly, 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. Finally, studies have identified the lack of knowledge, experience and best-practice examples as barriers in refurbishment projects [7].

The paper discusses an approach to the designing of refurbishment projects, as a way to energy-efficiently upgrade the residential stock. It presents answers to specific technical problems and determines how improvements in the environmental performance can be reached. The study is based on a case study multi-residential building in Germany, which is a representative example of Western Europe post-war residential stock. Different refurbishment options are proposed and systematically organised in the form of a "toolbox". We assess the impact of the retrofitted building components into the energy performance of the building. The compilation of different "tools" composes the refurbishment strategy. In this way, the toolbox supports the decision making process of refurbishment projects. Finally, the paper demonstrates this approach by presenting example solutions for refurbishing the case study building.

2. An approach to refurbishment as a design question: The "toolbox"

Studies have concludes that deep renovation has the potential to be the preferred solution from ecologic and economic point of view and that superficial renovations significantly increase the risk to miss the climate targets and huge absolute savings to remain untapped [8]. Additional studies [9, 10] have identified the potentials of refurbishment to upgrade the energy efficiency of the building stock and the consequent savings in CO2 emissions.

Though the building construction sector and stakeholders acknowledge the need for integrated solutions for maintenance and renovation, there is lack of specialised knowledge on how and when to successfully maintain, manage, adapt, transform and redesign [7, 11]. Moreover, most crucial decisions happen in the first moments of the design process; thus, designers need tools that will assist them in creating better and more sustainable refurbishment projects

The potentials of refurbishment have been researched and identified. However, they come in form of general suggestions. In practice, the detailed carrying out of the measures has to fit to the individual project [9], in terms of the building's existing condition, location, project specifications, budget and ambition of client and, of course, architect's decisions.

Our study approaches the refurbishment as a design issue that varies in every case. The study sought for an approach that would support the decision-making and enable the development of the refurbishment strategy in different cases and for different specifications. We intent to enable the designers of refurbishment project to know the impact their choices will have.

Depending on the objectives of the retrofitting required in each case, different strategies can be found. They can range from the basic thermal update of the envelope for the energy efficiency standards to a more integrated refurbishment, in which extra space is added and advanced options for energy upgrade (e.g. renewable energy sources) are available. Given the diverse effect of various measures on the energy demand, the objective is not to dictate an optimised solution, but rather to assist effective choices, without compromising the designer's, client's or user's intentions. For this purpose, the different measures are systematically compiled and organised in the form of a "toolbox", according to the building envelope component they address.

This toolbox is essentially database of the possible measures that can be implemented in refurbishment projects. The information is organised in a matrix, including the key components of the building; namely the external walls, basement, roof, windows, balcony, ventilation and heating sources. Addressing solutions for all the above aspects composes integrated refurbishment strategies. The measures are proposed based on research, practice and experience. Each aspect can be then divided into sub-tasks, which can be dealt with different measures. They can be combined depending on the specific requirements of every project and design.

The measures are scaled according to effort and level of intervention. In this way, each project can be located on the top, middle or bottom of the table according to requirements. Moreover, it is possible to combines various levels, for example apply a more complex solution for the wall and simpler for the rest of the components.

After defining the different possibilities for the refurbishment measures, it is essential to assess how the measures contribute to the energy efficiency upgrade. The first step is to define the individual effect of each measure separately. The study focuses on the heating demand as indicator for energy efficiency. The reason is that heating demand 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, followed by water heating, which also plays a major role (25%) [7]. Even thought the importance of water heating is addressed by the toolbox, e.g. with the use of solar panels, it is not considered for the energy efficiency calculation in the current study.

The software used for the thermal simulation is Capsol by Physibel. This program calculates the thermal dynamical behaviour using the heat balance equation. As a result the indoor temperature can be calculated, as well as the possible heat buffering the walls. Moreover, the energy demand for heating and cooling can be calculated.

The method to isolate the impact of each option is the following: first a model of a room and a balcony in an existing apartment is set up and the energy demand for heating is calculated for every orientation. The inputs and openings adjustments were based on European standards for thermal comfort for required temperature and overheating [12]. Based on this model, every option was simulated separately, by changing only one component in the model of the existing situation. In many cases, variations and optimisations of the measure were also simulated, to test the difference in the energy reduction.

The following figure presents an overview of the impact the individual tools have on the energy demand of the apartment. The impact is quantified as the percentage of reduction to current energy demand. The percentage presented in figure 1 is the average of all orientations and variations for each measure.

Table 1. The "Toolbox" in table form. The different options for measures are organised into sub-tasks, around the key building components

Building envelope					Installations	
Exterior wall	**Windows**	**Balcony**	**Roof**	**Basement ceiling**	**Ventilation**	**Heat source**
no insulation	single glazing	continus slab no insulation	flat roof slab no insulation	no insulation	Window ventilation	Gas boiler for each apartment
little/outdated insulation	double uncoated	seperate slab no/little insulation	Pitched roof no insulation	no insulation, beasement heated space	Controlled mechanical exhaust	Gas boiler per block
Exterior Insulation (e.g. ETICS)	Upgrading the 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	Replacement of windows	Cut out and replace balcony with thermal break	Pitched roof insulation	Insulation under the basement ceiling slab		Air-water heat pump
Exterior insulation, ventilated facade	Shading internal	Non-insulated glass envelope / Winter Garden	Flat roof insulation	VIP panels under the basement ceiling slab		Solar collectors
Double skin facade	Box window infront of existing pane		Green Roofs			Geothermal heat pump
	Box window infront of new pane					
	Shading external	Solar collectors				
Photovoltaic (PE factor 0) *		Integration of the balconies in the thermal envelope	Photovoltaic (PE factor 0) *			District heating / community heating
Annexe to exisitng building	"French windows"	Enlarge the balconies	Additional floor			
One lift for one block (access via gallery)						

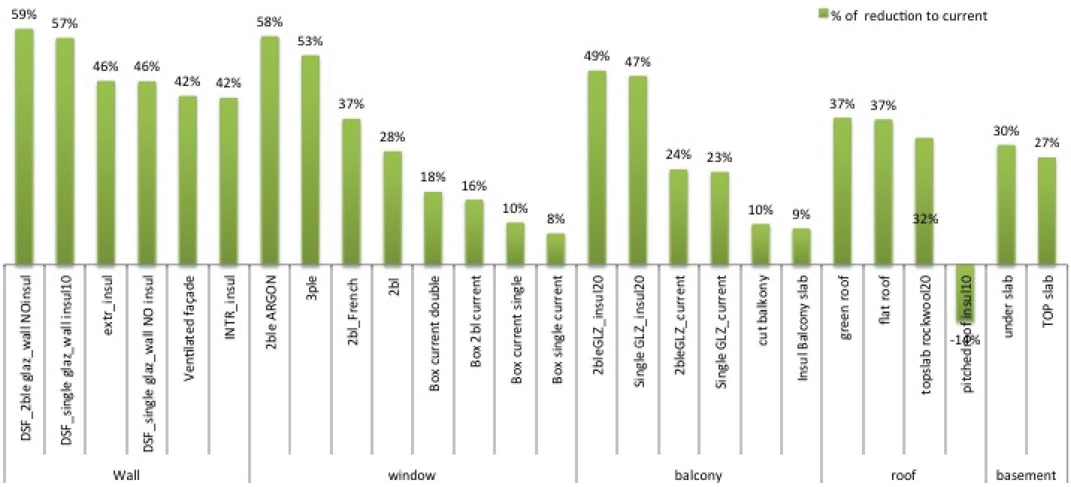


Fig.1. Quantification of the energy demand reduction by the implementation of the individual measures

The results of the energy calculations can be integrated in to the toolbox, which it then re-organised according to the efficiency of the measure, starting from the existing situation and scaling up to the impact they have on the energy demand for heating. Additionally, the calculations determined the specifications of the construction details (e.g. the insulation thickness).

Apart from the information presented in figure 1, detailed calculations for variations such as insulation thickness and orientation are also available. Those detailed information on the effect of the tools may support further the designer’s decisions for each specific measure. For example, with regards to external wall, the calculations have shown that a second glazed façade is more effective for the North orientation. On the other hand, the external insulation has a greater impact on the south façade (fig. 2). Therefore, the designer can select the measure that affects the most according to the orientation of the existing building

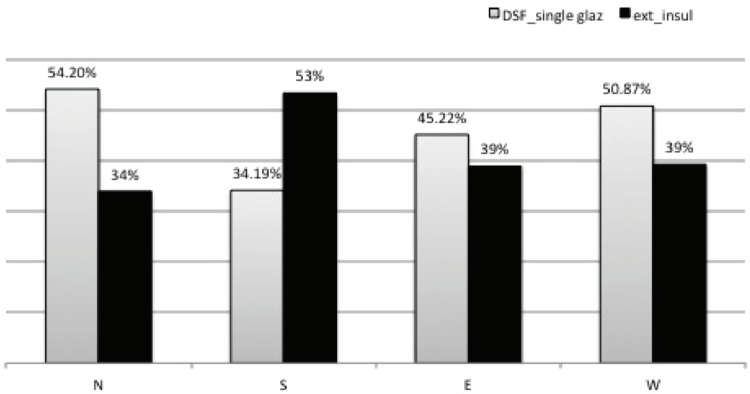


Fig.2. The reduction (%) to current heating energy demand after the implementation of a second skin glazed façade and external insulation, according to different orientation.

The further elaboration of the toolbox data beyond the energy calculations resulted in the design of construction details. Additionally, information for benefits and bottlenecks of each measure are indicated as part of the toolbox database. In this way, the designer will be supported with options and solutions that are proven to meet the energy requirements, throughout the decision-making and the implementation process.

3. Exemplified solutions with the use of the "tool-box"

To understand how the toolbox assists the decision making, the paper demonstrates the design process of refurbishment solutions by combining "tools", resulting in architecturally sound solutions that meet the requirements for improved energy performance. Example combinations of the toolbox will be used to design the refurbishment strategy for case-study buildings. These exemplified solutions do not represent fully developed architectural studies, as this is not the subject of the research. They can be seen as preliminary concept designs.

The tools of the refurbishment strategy for each case are chosen according to several variables. These include the specifications of the project, the budget and the current condition of the building. Additional parameters that determine the choices are preferences of clients and designers, along with the availability of the option for the specific project. For instance, district heating could not be part of the strategy, as it is not available for every building site.

3.1. Existing situation

The study was initiated by a case-study project, the refurbishment of a multi-residential-building complex of the post-war period in Germany. The project was assigned by the housing corporation that owns and manages the estate. It refers to two residential buildings constructed in the late 60's, located at the area Gartenstadt at the outskirts of the city of Krefeld. They are part of 3 identical complexes, consisting of two buildings, one 3-storey and one 4-storey apartment block, laid out in an L-shape. The objective was not to design the strategy for the buildings, but to investigate their refurbishment potentials. Our results were intended as a guideline for the architect that would design a refurbishment solution not only for the specific building, but possibly for other estates as well.

The first part in every refurbishment project is to examine and analyse the current situation of the building, as to identify the problems and thus the actions that need to be taken. Main problems found by the analysis were complete lack of thermal insulation on external walls and roof, out-dated plastic windows and thermal bridging at the balcony slabs. Moreover, there is no sound insulation on floor, ceiling or walls and parts of the façade and prefabricated elements show signs of deterioration, such as plaster fall-off, reinforcement's corrosion etc. Additional problems were mould growth on the inside of the external surfaces, related to thermal bridging and insufficient ventilation, and out-dated technical installations. Spatial deficiencies, such as no handicap access and small apartments, contribute to the problematic situation

The buildings considered in this study are typical for their period, showing similar problems and challenges as other dwellings of the housing corporation. Furthermore, the above-mentioned problems are regarded as typical not only for Germany, but also for the buildings of the relevant period all over Europe. Therefore, the toolbox approach is favourable, as it enables solutions applicable to many different cases.

3.2. The three-storey apartment block

The three-storey apartment block consists of four identical staircases, providing access to six apartments, two in every floor. The block has a north-south orientation, resulting in east and west oriented façades. The programme of the housing company for the apartments specified bigger, higher-quality housing with elevator access. Therefore, the example solution provides a barrier-free development for each staircase, as well as adjustments of the floor plans to increase the size of the apartments. The toolbox helps to organise the refurbishment strategy according to the level of intervention that is allowed by the requirements.

On the external wall, ETICS with 20 cm are applied and the windows are replaced with double, argon-filled glazing. Where possible, the windows are enlarged, providing more natural light, better contact with the outside and less heating demand as proven by the toolbox calculations (fig. 1). The balconies situated on the west façade are cladded with glazing. In this way, not only the thermal bridging problem at the balcony slab is solved, but also extra space is added to the apartments. The choice was supported by the toolbox calculations, which have shown that balcony glazing has a greater effect to the energy demand reduction than other options, such as the insulation of the balcony slab (fig. 1). New, bigger, self-supported balconies are added.

One of the main modifications is the removal of the existing pitched roof and the addition of an extra floor, lightweight constructed to correspond to the existing loads. In this way four spacious maisonette apartments with individual roof gardens are created and the heat losses through the currently non-insulated roof are prevented. The ceiling of the new floor has the possibility to be optimally aligned to the south for the use of thermal solar energy and Photovoltaic panels.

Currently, each apartment has an individual gas boiler. Instead, a central boiler per block will be sufficient. A central boiler is a better option with regards to possible future energy investments, as it can be replaced with a CHP plant or connected to a community heating system, without many adjustments in the apartments.

Fig.3. The existing front façade of the three- storey apartment block (a) and impression after the refurbishment (b).

3.3. The four-storey apartment block

A similar process was followed for the second case study building, the four-storey apartment block of the residential complex. However, the specifications for this block, provided by the housing company, were slightly different from the previous one. In comparison to the other block, more diverse sized and moderated prised apartments are required. Additionally, one of the design requests was noise protection from an adjacent highway. In general, the refurbishment strategy is more budget challenged, as the company aims in lower prices for those apartments. The tools that were chosen from the toolbox resulted in different solution, with lower level of intervention but still improved efficiency.

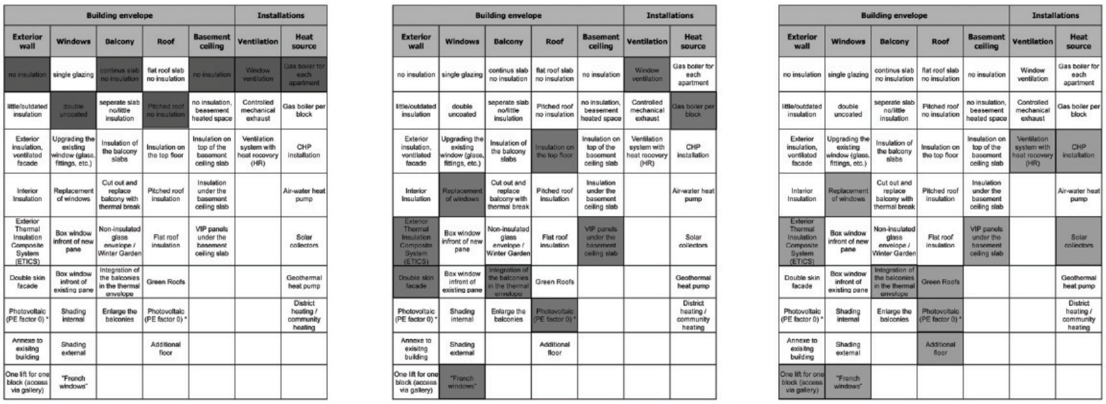
External insulation is added on the south, east and west façade to increase the thermal resistance and prevent thermal bridging. The existing pitched roof is not removed as in the previous case, but maintained and clad with PV panels, as it already has a favourable orientation to the south.

The most important intervention is the introduction of a glazed gallery along the entrance façade, through which the apartments are accessed. This gallery provides various benefits to the building. First of all, it acts as a noise barrier towards the highway. Secondly, it enables elevator access for all the apartments with the use of only one elevator, which is economically viable. The space previously used for the staircase can be now integrated into the apartments, giving the possibility for one extra apartment to be created on each floor, with no compromises in the size of the rest apartments. Most importantly, it contributes significantly to the reduction of the heating demand. As demonstrated by the toolbox calculations, the addition of a glazing layer on the north façade can reduce the energy demand up to 54%, with out the need of additional insulation on that façade.

Fig.4. The existing front façade of the four-storey apartment block (a) and impression after the refurbishment (b).

3.4. Energy upgrade of the solutions

The refurbishment strategies developed for the case studies have been significantly facilitated by the use of the toolbox. Having already compiled the database, the different measures were explained and, thus, the choice was easily available. The toolbox calculations provide an indication of how effective the separate measures can be. In this way, it assisted the compilation of integrated strategies.



Building envelope					Installations	
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no insulation	single glazing	continus slab no insulation	flat roof slab no insulation	no insulation	Window ventilation	Gas boiler for each apartment
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Exterior insulation, ventilated facade	Upgrading the 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	Replacement of windows	Cut out and replace balcony with thermal break	Pitched roof insulation	Insulation under the basement ceiling slab		Air-water heat pump
Exterior Thermal Insulation Composite System (ETICS)	Box window infront of new pane	Non-insulated glass envelope / Winter Garden	Flat roof insulation	VIP panels under the basement ceiling slab		Solar collectors
Double skin facade	Box window infront of existing pane	Integration of the balconies in the thermal envelope	Green Roofs			Geothermal heat pump
Photovoltaic (PE factor 0) *	Shading internal	Enlarge the balconies	Photovoltaic (PE factor 0) *			District heating / community heating
Annexe to exisitng building	Shading external		Additional floor			
One lift for one block (access via gallery)	"French windows"					

Fig.5. Comparison of the toolbox footprint for the existing situation (a) and proposed solutions for the four storey (b) and three storey (c).

To prove the use of the toolbox, energy calculations for the combination of the measures were conducted. It needs to be noted that the calculations of the individual tools, presented in figure 1, do not add up into the total reduction, since, when applied in combination, they do not function individually. The purpose of the individual calculations is to provide an assessment of the impact of the different options.

With regards to the case study buildings, the solutions composed with the support of the toolbox resulted in significant reduction of the energy demand. This refers to the energy demand for heating, which is related to the improved thermal envelope. Namely, the three-storey building was calculated to require 92% and the four-storey building 80% less energy for heating. Further calculations to estimate the energy demand in more detail include the estimation of the demand according to the installation efficiency, as well as the energy production from the PV panels and the solar collectors.

However, the accurate estimation of the refurbished buildings' energy demand is not the subject of the present study. We intend to demonstrate how the systematic knowledge of the options and their impact, as they are organised in the "toolbox", can help the designer to make successful choices. The case study refurbishment solution was composed based on the specifics of the project, while it was supported by the toolbox. This process resulted in significant reduction of the energy demand and improvement of the architectural appeal of the buildings.

4. Conclusion

In the context of climate change and the need to cut down on the building sector's carbon footprint, retrofitting the existing building stock is an acknowledged issue in the buildings industry. Although huge potentials for energy savings have been identified, they are limited in general suggestion. There is still the need of specialised knowledge to assist the design of holistic refurbishment strategies in the early stages when decisions have bigger impact

The paper presented an integrated approach to the energy upgrade refurbishment that gives specific answers to key parameters of integrated refurbishment. It also determines how improvements in the energy performance can be achieved. In this approach, different options for each parameter are studied, calculated and designed in a level of constructional detail, providing a database of options and solutions. This systematic approach to the strategies, divided into key aspects and different options, can be organised in the form of a "toolbox".

The importance of this approach is that it recognises the diversity of each project, as well as the designer freedom to his decisions. For this reason, it doesn't aim to dictate an optimal solution that has to be universally applied to reach the energy demand reduction. With respect to the specific requirements of each case, we assist the designer to make efficient choices.

It needs to be clear that the toolbox alone cannot replace the architectural design but rather organise the requirement, support the decision-making and provide answers on the effectiveness of the measures. It can help not only to define the requirements and the choices at the beginning of the design, but also provide solutions for the technical issues to be solved at the implementation face. Therefore, it can be a support instrument throughout the design process. The designer gain knowledge on the effectiveness of the measures, without compromise the project intentions.

Future steps for the development and expansion of the toolbox will be the identification and elaboration of additional measures. Moreover, additional energy calculations can help to define how the measures interact and function in combination to each other. In this way the toolbox will be able to predict the impact of the strategy in more detail.

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References

[1] Power, A., *Does demolition or refurbishment of old and inefficient homes help to increase our environmental, social and economic viability?* Energy Policy 2008;**36(12)**: 4487-4501.

[2] Eurostat, *Europe in figures, Eurostat yearbook 2009*. Luxembourg:Office for Official Publications of the European Communities; 2009.

[3] Thomsen, A.F. and C.L. van der Flier, *Replacement or reuse? The choice between demolition and life cycle extension from a sustainable viewpoin*, in *Shrinking Cities, Sprawling Suburbs, Changing Countrysides* 2008; Centre for Housing Research, UCD.

[4] Gaterell, M.R. and M.E. McEvoy.The impact of climate change uncertainties on the performance of energy efficiency measures applied to dwellings. *Energy and Buildings* 2005. **37(9)**:982-995.

[5] AgentschapNL. *KOMPAS Energiecijfers*. Available from: http://senternovem.databank.nl/.

[6] Chandler I. *Repair and renovation of modern buildings*. New York: McGraw-Hill;1991,p.176.

[7] Itard L and F Meijer. Towards a sustainable Northern European housing stoc. *Sustainable urban areas* 2008; **22**:213**.** Amsterdam: IOS.

[8] Hermelink A and A Müller. *Econimics of deep renovation* 2011. Berlin: Ecofys by order of Eurima - European Insulation Manufacturers Association;2011.

[9] Nemry, F., et al., Options to reduce the environmental impacts of residential buildings in the European Union--Potential and costs. *Energy and Buildings* 2010; **42(7):** 976-984.

[10] Waide P, GP SMITH W. High-Rise Refurbishment: The Energy-Efficient Upgrade of Multi-Story Residences in the European Union, In IEA *Information Paper* 2006. International Energy Agency.

[11] Thomsen A. *Paradigm shift or choke? The future of the Western European housing stock.*, in *Housing: the next 20 years - CCHPR Conference* 2010, Cambridge.

[12] CEN, *EN 15251*, in *Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics*2007, European Standard.

[13] *2009 ASHRAE Handbook - Fundamentals (I-P Edition)*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.