Parameter Study of a Prefabricated Retrofit Façade System

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ABSTRACT: In the field of energy efficient retrofit of buildings the improvement of the building envelope is central to gain a low energy demand and user comfort in modernized buildings. The reduction of the heat transmission through the hull of the reused building fabric binds a reasonable amount of new resources for a long time. A life cycle model for façade retrofit implementation is missing. The aim is the optimization of life cycle design parameters of a newly developed façade retrofit system which fulfills fundamental sustainability issues throughout its life cycle e.g. efficient use of resources, good performance in terms of building physics during operation, less maintenance, and handling when becoming waste. The introduced system describes a retrofit method based preferably on timber and other renewable resources. A pre-evaluation of a recently completed case study project has featured relatively high results for resource consumption of certain retrofit scenario. The resulting target has to be the reduction of value at risk of the entire system due to resource inefficiency, complexity and even end of life. These issues may restrict the market access of a firm solution although it shows positive results to the aspect of environmental impact. The challenge is to balance and improve the performance of the interdependent sub-systems parameters. In timber construction it is necessary to compose material layers in order to ensure the technical properties of the final prefabricated element in combination with the existing exterior wall. In the same line it allows to leverage the properties of the appropriate panels, components etc., and to optimize the used components. The most important parameters of the system behavior are identified for life cycle relevant component characteristics e.g. material use, maintenance, repair, dismantling, separation, recycling. They raise the awareness of flaws, allow a management of risks, and finally demand new technologies for the improvement of the elements' resource efficiency.

1 INTRODUCTION

The energy efficient refurbishment of existing dwellings has to be observed particularly from a sustainability point of view. The primary energy inflow for refurbishment is predicted to be higher, than the outflow from dismantling and the cumulated energy savings over a certain amount of time. The reason will be the building performance indicators to fulfill regulations along with demand.

The ageing building stock in Germany and most of Europe is in a change phase. An amount of around 45% of the existing buildings from the age class of 1950 to the eighties of the last century is dedicated to a fairly renewal, that goes beyond ordinary maintenance and repair. Their building performance neither fulfills the actual technical and functional requirements nor the demand of owners and tenants.

There are several risks for doing such types of refurbishment that deeply interferes with the physical and behavioral aspects of dwellings, (Thomsen & van der Flier 2011). One is the input of resources with bound primary energy (PEI). The new construction segment is reducing the energy demand due to regulations which were tightened by politics over the last decade. New construction is also the benchmark when building performance of existing buildings has to be improved. This causes an increase of the share of the embodied energy for construction material during the erection phase. It is the carbon-footprint of the building. Whereas the amount of operational energy per year decreases to the regulation level and even below. The long-term perspective is a further decrease of operational energy because the political will in Europe tends toward the net zero energy or the plus energy house.

Furthermore new operation concepts demand a very high quality of the building envelope and strong passive elements to reduce heat loss by transmission or ventilation. An improvement of the building envelope towards the passive house level is a necessity and a extra reason for material consumption. Building systems tend to follow up and could stimulus the trend of this balance. The environmental impact of an increased material consumption is not only related to the carbon footprint. It causes damages to the environment on several levels; fresh water consumption, acidification, ozone layer depletion should exemplify that negative potential.

The path to energy efficient dwellings shifts the observations towards the material balance of buildings, which was not on the agenda before.

There is a notable change in ratio of carbon-footprint to direct CO2-emissions of energy efficient buildings, (Lane 2007). The ratio for old, existing buildings was often stated as 20:80. In new, energy efficient construction it is 60:40 and will further change, (Wallbaum & Heeren), (Sturgis & Roberts 2010).

Apart from the ecologic problem the economic burden will shift to other phases of a buildings life cycle and social interference is hardly to foresee in the interrelated built environment. A multi-dimensional methodology has to be applied, reacting on complexity and interweaving, (Moffatt & Kohler), (Scholz & Tietje 2002). It should offer a sustainable perspective by thinking in systems life cycle and takes care of the refurbishment and dismantling phases of a dwelling. Because the material outflow and inflow has to be paid back over a decreased time span whilst operation.

The building stock and its refurbishment is a promising part in the whole puzzle. It can offer an appropriate way of solving the dilemma between carbon-footprint and CO2-emissions by reusing as much as possible of the already embodied energy of the stock. When the building life cycle is prolonged, this embodied energy will not be destroyed in demolition anymore but is used in a more intelligent way than today. This includes a more efficient operation of the dwelling by updating its building performance.

2 FAÇADE RETROFIT LIFE CYCLE

Sustainable solutions are needed in order to justify the high ecologic impact and physical effort of a total retrofit solution. Planning in life cycles connotes a consideration and choice of future oriented retrofit solutions and partial deconstruction or full dismantling phases. Additionally it will influence the preventive maintenance to avoid deterioration of subsequent operation and full demolition of the building at its very end. It influences a building on multi-level: functional, technical, and behavioral; in order to allow flexibility, recyclability and reusability of the structure.

2.1 *Ecologic building retrofit*

Higher Growth rates can no longer fascinate whilst its impact and the side effects are ignored in the construction business, (Kohler et al. 2009). The buildings from the post-war era up to the end of the last century demonstrate this by high material flows and energy consumption in erection and operation. The change in perspective towards the building stock gradually gives insight to the economic and social resources lying there, sleeping. Refurbishment that is largely driven by ecologic reasons, can activate them when the material input and resource consumption are bargained at the same time.

Because of the reduction of the building performance of existing buildings compared to new ones, they are going to be less attractive and lose worth on distinct quality criteria. A lower quality leads to devaluation and the obsolescence of the object, (Thomsen & van der Flier 2011). If an object is no longer used literally it is gone lost and can be erased or replaced by a substitute. A sustainable development has to take care of that the life cycle of buildings is prolonged, (Thomsen et al. 2011). Finally Thomsen et al. point out how challenging it is; because scenarios are complex and decision processes are not linear.

This is a chance for the application of alternative methods in refurbishment. New-developed methods like large format, prefabricated TES façade elements in timber framework construction for energy efficient retrofitting of existing building are exemplary, (Heikkinen et al. 2010). Retrofitting with timber based systems causes reasonably lower carbon footprint, (Fürer). It combines practicable solutions with a visionary standard in façade technology for higher resource efficiency. Besides the promoted ecologic aspect it has to deliver social criteria and must be economically viable. It can combine the advantage of a structure made of renewable resources with an added value as a durable solution and positive impact on the built environment and its users.

The Swiss research project *CCEM Retrofit*, which is connected to European research programme *Annex 50 - Prefabricated Systems for Low Energy Renovation of Residential Buildings*, develops the *Retrofit Advisor* for static simulation of different refurbishment scenarios as a multi-criteria assessment method. The *Retrofit Advisor* is a decision tool for the early project phases in retrofit; it is neither a planning nor a design tool. The results are based on generic statistical assumptions. For example, the environmental impact is calculated on a rough assumption of age-specific constructions with average material mass and environmental impact data.

The assessment systems for environmental performance of construction products have developed during the last decade. They are bundled on the European level in CEN/TC 350 - *Sustainability of con-*

struction works; and internationally in ISO TC 59/SC 17 *Sustainability in buildings and civil engineering works*, (EN 15643-2:2009, ISO 15686-1:2011, ISO 21931-1:2006). The performance indicators represent both conditions, the carbon footprint and the CO2-emissions output of a building throughout the entire life cycle of a buildings construction.

2.2 *Retrofit performance parameters*

The influence on technical and functional performance is visible in the obsolescence model, (Thomsen & van der Flier 2011). The prolongation of use of existing dwellings needs an examination of the interdependence of performance parameters. Furthermore the restoration of the building performance demands a high amount of material and energy to fulfill the owner and resident demand. The existing planning parameters for sustainable new buildings cannot simply be used in refurbishing the building stock. Rather there is the strong need to verify and adapt the parameters to changed conditions in the existing dwelling.

The broad range of existing evaluation of the improvement of the energy efficiency in building stock seldom balances the necessary changes and additions on an input – output basis. The consideration of new facade components shows a relation between the reduction of energy consumption and the input of resources, (Blom et al.). The examination is done only for the wall openings with windows and not for the heat transmission of the entire exterior hull. There are different scenarios but no optimization of the long-term effects. Low-energy dwellings analyzed, by multi-criteria, tend to be risky due to the economic effort of the initial high investment, (Verbeeck & Hens 2010). Its height is responsible for the economic success, whereas rising energy costs are only in rare cases.

Rather it does not consider the life span of refurbishment action. The consequences of demolition and resource loss are the subject of (Itard & Klunder 2007). They show that the same energy savings effect of new built substitutes can be achieved for retained and refurbished existing buildings. The connection between different refurbishment scenarios and related heat energy demand is shown by (Fürer). The presented case studies have reasonable effort in material input that is compensated by high efficiency in operation, due to the production of building services. A remarkable outcome is the importance of the construction type and materiality of the building envelope and the technology of building services, both are dominating parameters.

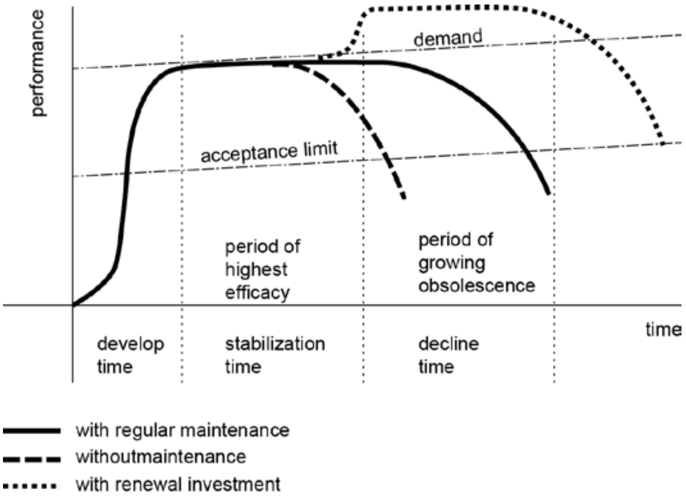


Figure 1. Obsolescence, use time and performance, according to (Thomsen and van der Flier 2011).

2.2.1 *Existing examinations*

The integrated planning of refurbishment, which includes partial decommissioning, conversion, facade and building services, provides high-quality, affordable low-energy buildings in inner-city locations. The example of (König 2009) in the *Quartier Normand*, Speyer, covers material flow analysis with environmental impact performance and energy consumption calculation; for example components of integral planning. The central task involves the review of all parameters and decision making against the background of the overall picture of a building’s life cycle.

Quantities of substances which are calculated with specific material parameters for the renewable and non-renewable primary energy content; reveal the environmental burden of construction materials. The data for the environmental impacts are taken from the database *Ökobau.dat 2009*, which is published by the *German Federal Ministry of Transport, Building and Urban Development* (*BmVBS*), (BmVBS 2010). The phases of transformation are grasped in drawings and digital building models as mass related floor plans, sections, pictures of the demolition, gutted state, and construction work. The flow of materials in the course of time analyses can be accounted for within calculation sheets, on the basis of the refurbishment phases. The mass figures combined with environmental data from the *Ökobau.dat* information allow deriving the corresponding primary energy of material fractions.

The future energy demand and the inflows are calculated based on the selected scenarios for the refurbishment. The energy requirement is determined for the heat transmission demand of the building envelope, because only the building shell and their renewal are considered. Neither the possibilities of energy saving, nor the type of ventilation, the sources of energy and CO2-emission reduction are considered. The primary energy consumption for the operation is calculated only relative to the heat transmission losses.

2.2.2 *Parameter selection and definition*

The basic building parameters are:

- the total floor area
- volume of the exterior envelope
- area of envelope
- (existing) material stock
- material flow of output and input.

All parameters are scenario dependent and can look different in other situations. Hence there are dependent parameters which are related to specific material property or aggregated material property:

- heat transmission (aggregated U-value of the envelope; heat degree days)
- primary energy content not renewable (PEI_{nr})
- primary energy content renewable (PEI_{re}).

The evaluation is step-wise and starts with the basic material flow in all refurbishment phases of case studies. The material flow analysis is the key tool for life cycle analysis where all material masses are balanced. It is a material inventory that registers all inputs and outputs along the system borders and compiles a balance of the product or service, (Deutsches Institut für Normung).

The refurbishment follows different scenarios to restore the performance of a building. In most scenarios, dismantling or partial demolition is intended. The total replacement is not provided as an own scenario, because the material loss of the stock, plus the cost of an average new construction, in sum evaluates to a higher environmental impact, which is generally comprehensible.

If the refurbished building stock is not on the level of the new building, than the building performance is below the expected new-built performance level and shortens the stabilization time and accelerates the obsolescence rate according to Figure 1.

2.2.3 *System boundaries*

The question of the system boundary is crucial for carbon foot printing and energy balancing. For the mass and energy balance, at the physical level, the individual building is a closed system. In the tangible case studies, the boundary extends from the cellar to the roof, includes the façade and all actions to improve the technical and functional quality of the stock. In principle, the boundary could remain the same, because the building impacts on the surrounding context and experiences influence from there.

The framework of prEN 15978 excludes the preconstruction phase, which is dedicated to environmental product declarations, (Pr NF EN 15978:2009). It defines three main modules in the building life cycle, the construction process, the use stage and the end of life stage. The main phases are separated in two classes of modules, the physical, or product related impact, and the operation related aspect in a second class. The refurbishment module is part of the use stage and is located in the class of product.

The border of the modernization of a building must include the following:

- product stage of the new building components
- transport phase of the new building components
- construction phase of the modernization process
- waste management of the modernization process
- after life stages of the exchanged components of the building
- heat transmission energy of the building envelope.

2.2.4 *Planned examinations*

In addition to the definition of the parameters of the inventory, the investigation determines their effectiveness in the context of the system boundaries and mutual dependencies with a wide range of instruments. Available related analysis and diagnostic methods are the comprehensive inventory; containing survey data, building model (BIM) and physical data, see (Göttig & Braunes 2009).

The practical implementation aims at the development of basic discovery mechanisms that will allow linking the influences from analysis, according to their mechanisms of action, that are taken from diagnosis, potential analysis and strategy decisions. In consequence long-term effects of certain scenarios can be determined. Kohler et al. show, that the consideration of different time spans in the building stock allows to evaluate the effectiveness of scenarios, compare (Kohler et al. 2009).

3 CASE STUDIES

The examined case studies get both a complete renewal of the building envelope. The school is experiencing only a deconstruction and renewal of the building envelope. The apartment building is totally rehabilitated and enlarged. Building services do not matter in investigations, because they are outside of the system boundary.

3.1 *School building*

The case study of a school building is a construction system made of reinforced concrete, based on the

Kasseler Modell. It was built in 1980, with 8.40 m span of the primary load bearing structure. It had numerous flaws related to exterior structure of precast concrete façade and understanding of building physics.

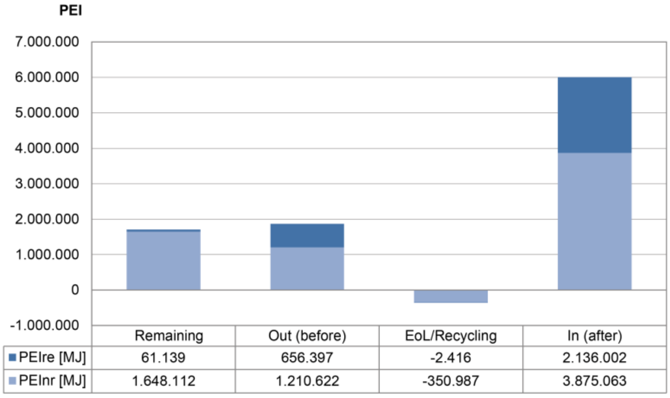


Figure 2. Comparison of PEI over various product stages of school building.

The primary energy demand is located at 125 kWh/m^{2}a and has been reduced in the context of rehabilitation on 35 kWh/m^{2}a, for further basic data see Table 1. The complete old façade will be dismantled during operation and replaced with highly insulated TES timber-framed elements with a continuous ribbon of windows. The case study makes it clear that improving the building performance leads to a higher entry of resources than were previously removed from the stock by demolition and dismantling. According to the predefined disposal routes, which are published by the *German Federal Ministry of Transport, Building and Urban Development*, the overall balance figures are calculated for recycling and disposal, Table 2 and (BmVBS 2010). The gains from recycling the waste stream will not really affect the balance. The same picture is also shown in other case studies. The savings in primary energy in operation pay off for the material costs of the refurbishment period in around eight years.

The outflows of not renewable primary energy content (PEI$_{nr}$) comprise only about a third of the inflows, see Figure 2. The share of renewable primary energy content (PEI$_{re}$), due to the wooden facade elements increases by a factor of four. However, the proportion of PEI$_{re}$ is low. Demolition materials contain no renewable resources.The share of PEI$_{nr}$ of 200 GJ comes from the reasonable portion of aluminum.

Table 1. Basic data of retrofit scenario for school.

	Before	After
Gross Floor [m^2]	6905	6905
Gross Volume [m^3]	27822	27822
Facade Area [m^2]	6110	6163
Windows [m^2]	1060	1007

The input content of PEI$_{nr}$ is triggered by the new 3-layer insulation glazing with aluminium profiles on timber studs. The surface of the window openings is somewhat reduced, approximately minus five percent. For school buildings, a particularly high primary energy savings can be achieved by the passive house standard. The low falls from the primary energy consumption for the operation of the school are achieved by intelligent integration of envelope quality and building services by renewal of lighting, efficient ventilation system with heat recovery and minimized heating technology.

3.2 *Multi-storey dwelling*

The scenario shows the total restructuring of a three-storey multi-family house from the year 1954. The interventions in the building envelope, in addition to improving the building envelope thermal, include increasing the window openings. The building is completely gutted, for rearranged and redeveloped floor plans. The building height and floor space is increased by roof-top extension. The size of the extension covers roughly two-thirds of the surface area of the roof. The building's shell and the roof top-up are made of prefabricated timber construction.

Table 2. Recyclingpotential of outflow material.

waste scenario	material	mass [kg]	output, PEI [MJ] not renewable	renewable	recyclingpotential, PEI [MJ] not renewable	renewable
landfill	concrete	93045	43382	787	14887	986
sum		193614	43382	787	14887	986
recycling	reinf. steel	15149	187848	14922	-177243	-189
	sheat metal	3210	139956	6067	-40767	-190
	aluminium	5617	1067322	281436	-612306	-208970
sum		8209	1395125	302425	-830316	-209350
possible rec.	glazing 2-layer	21480	6143331	82484	k.a.	k.a.
sum		21480	6143331	82484	k.a.	k.a.
thermal use	sealings	917	116415	1091	-5537	-50
sum		917	116415	1091	-5537	-50
total					-820966	-208413

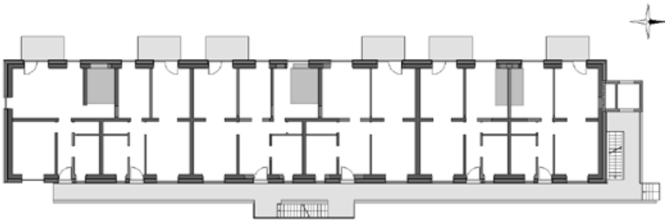


Figure 3. Floor plan of dwelling with existing (dark grey) and new (light grey) parts.

A particularly high share accounted for plasters and rubble (formerly included the floor construction) masonry (exterior and interior walls), concrete (balconies, stairs), see Figure 3. The resulting rubble is fed to the recycling or landfill. The chart in Figure 4 shows the mass distribution of the resulting demolition materials. The peaks PEI_{nr} feature the highly processed, mineral based construction materials. They exhibit the highest amount of PEI_{nr}, while the renewable materials at low PEI_{nr} have a very high proportion of PEI_{re}. The latter should keep in the recycling or can be used thermally as energy and replace non-renewable energy sources. The thermal use should always be the second choice otherwise all embodied PEI_{nr} will be lost.

Demolition of material and hence the loss of energy, faces an extensive input of material and energy to recover technical and functional features of the dwelling. In balance that affects the mass inflows, which take place mainly for masonry, concrete, new screed and new render.

On the other hand there is the input balance in Figure 5. The high figures for the PEI_{nr} fall on mineral wool insulation, solid construction timber, 3-layer glazing and the insulation material. The values explained from the actually high volume fractions of the substances above, covered only in the mass, are drawn up on the basis of a low density in the weight, such as mineral wool or wood. Glass obtained bound primary energy is that high; hence even low masses cause significant amounts of PEI_{nr}.

The new equivalent building performance requires an inflow of energy in the form of construction material. The annual savings in operating expenses in this example make up for again after 12 years. The transfer of input bound primary energy is three times higher than that of the demolished material and materials remaining in the reused primary construction of the stock.

3.1 *Results*

The parameters of material flow, conservation, reuse, new cost of materials and recycling of materials are collected from the inventory. Energy saving and primary energy content are calculated in the present investigations. Performance rates compared to average new construction, or even above, were the objectives of refurbishment scenarios shown in the cases above. The conservation of approximately fifty up to more than ninety percent of primary energy, reused in the building itself, is a big achievement. But in medium term diminishes the success of savings from seventy-five to eighty-five percent of the operating energy, when it is compared with the material input. This is particularly reflected in the long pay-back period for expenses of input bound primary energy.

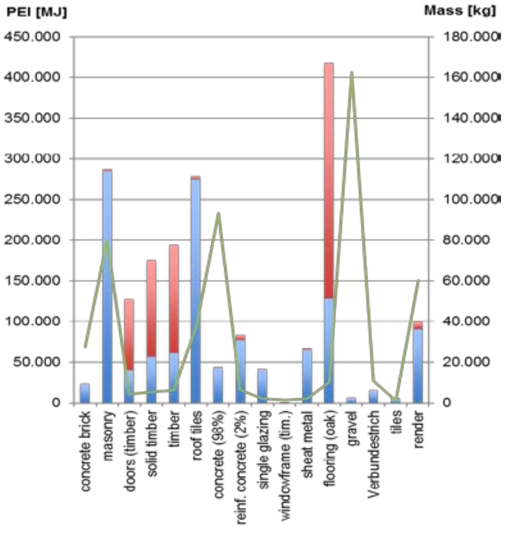


Figure 4. Outflow of PEI_{nr} and PEI_{re} compared to mass flow.

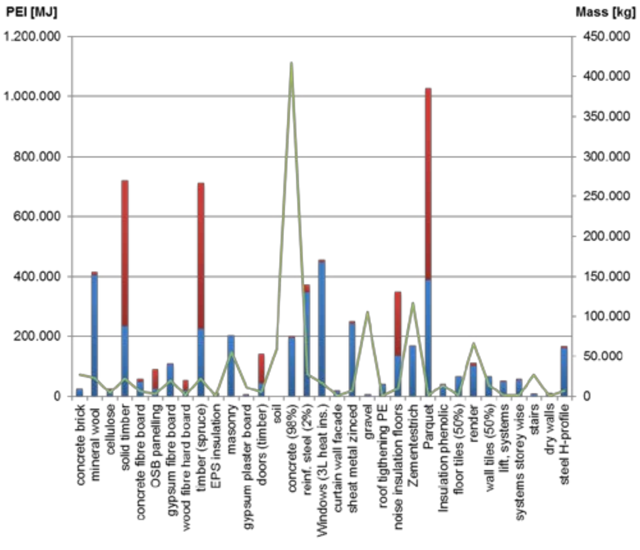
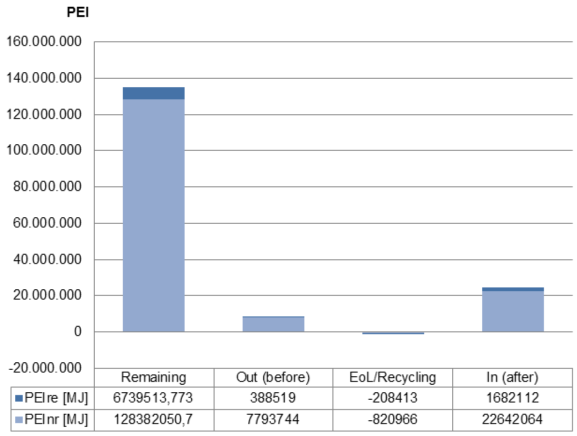


Figure 5. Inflow of PEI_{nr} and PEI_{re} compared to mass flow.



	Remaining	Out (before)	EoL/Recycling	In (after)
■ PEIre [MJ]	6739513,773	388519	-208413	1682112
■ PEInr [MJ]	128382050,7	7793744	-820966	22642064

Figure 6. Comparison of PEI over various product stages of dwelling.

The material total expenditure is higher than the benefits of recycling and reuse, see Figure 6. At the moment even residues remain, which cannot be used and therefore landfilled.

The duration of payback time for energy savings is now related to an alternative retrofit method which is primarily based on renewables. The case of the application of a conventional method of refurbishment means a greater input of PEI_{nr} and thus a poorer amortization of the chosen solution.

3.2 *Challenges*

More case studies are necessary that broaden the database to identify unique samples within the context. A separation might by significant according to the construction and use type performance, as well as normalization to gross floor area and gross volume. How perform both alternatively retrofitted examples in comparison with a conventional renovation system? The comparative analysis of the results with a conventional retrofit system for thermal quality of the building envelope is necessarily one of the next steps.

How can the share of non-renewable primary energy be reduced? What is the consequence of the results for the renewable primary energy? One of the targets has to be an improvement of the presented, alternative retrofit method itself. These include the reduction of the proportion of PEI_{nr}. This can partly be compensated through an alternative insulation to previously used mineral wool. The school example shows low amortization where only mineral wool was used and the employed insulation thickness is higher. The overall balance should be better, if the choice of the materials is targeted to renewable resources. The share of PEI_{re} can still be increased, but this must be respected, at the same time, on economic use of resources.

Are there other facade components partly responsible for the high input of resources? The school has large window areas that lead to a reasonable proportion of PEI_{nr} input because the 3-layer glazing was used.

Could effective savings are made possible by the sole renovation of the building services and heating technology? Can this scenario have at the same time reduced impact on the use of the materials? For this purpose, it must be examined whether the present model, based on the material flow analysis, can be applied also on building services. In principle, a similar application of the model is to imagine.

How does the subsequent maintenance phase impact the long-term result? The impact and influence of the maintenance needs to be evaluated. Data can be taken from the *BmVBS* database of component or construction life span, but this is a very rough first attempt. It would be more promising to apply preventive maintenance methods like condition based maintenance and reliability based maintenance.

The categorization and delimitation of refurbishment scenarios with each other is blurred and very rough. Thus, a weighting of in- and outflows should be connected in order to separate the different construction types. Findings from a reference with a conventional refurbishment method are needed.

3.3 *Conclusions*

A further step has to be done in optimization of the retrofit scenario as a whole. For the different scenarios should each optimum calculated, what expenses in the context of the scenario are sustainable. Interesting in this context is the question whether an optimization of energy levels and the resulting expenditure for the refurbishment makes an earlier time of obsolescence acceptable. For example in buildings, which have functional, social, cultural and urban low quality would require a disproportionate material and economic effort for quality improvements.

The aim should be to achieve a long-term perspective in refurbishment investments to the aspect ratio of the phase of obsolescence, recurring in the future. This should be simulated with the available parameters and their weighing for most effective rehabilitation.

Both case studies show buildings with alternative retrofit façade systems / curtain wall systems. In the case of the total renovation of the apartment, the input to PEI_{nr} is so high, that the return on invest of resources is according to long. Therefore it comes, despite renewable resources of the new outer leaf of the building envelope, not to a considerable reduction of PEI expense.

The integration of social or economic data into an overall model is a further option. The transfer of the multivariate analysis in a joint model needs an own calculation methodology.

4 ACKNOWLEDGEMENTS

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