Life-cycle Oriented Renovation Strategies for Social Housing Stock

Iva Kovacic
Vienna University of Technology,
Department of Industrial Building and
Interdisciplinary Planning, Austria
Iva.kovacic@tuwien.ac.at

Markus Summer,
Vienna University of Technology,
Department of Industrial Building and
Interdisciplinary Planning, Austria
msummer@industriebau.tuwien.ac.at

Christoph Achammer
Vienna University of Technology,
Department of Industrial Building and
Interdisciplinary Planning, Austria
christoph.achammer@tuwien.ac.at

DOI 10.5592/otmcj.2013.2.7
Research paper

BUILDINGS CAUSE 40% OF TOTAL ENERGY CONSUMPTION, AND 20% OF CO2 EMISSIONS WORLDWIDE. IN THE EUROPEAN CONTEXT, THE MAIN POTENTIAL FOR THE ACHIEVEMENT OF ENERGY EFFICIENT BUILT ENVIRONMENT REMAINS WITH THE EXISTING STOCK. This paper will present the life-cycle oriented renovation strategies for historic, especially large social housing stock, in order to meet the increased requirements in terms of energy efficiency simultaneously providing affordable housing and meeting the demands for monument conservation. Specific renovation-issues such as insufficient standard or size of housing units, demographic change (aging of society), thermal insufficiencies and partial obsolescence of building structure are bound to the age and typology of this specific stock. The developed strategies are based on the variations of façade-insulation technology and in further step on variation of building-hull refurbishment-level and energy system, applying the methodology of life cycle analysis (CO2-equivalent assessment) and calculation of amortization-periods for refurbishment-investment. The developed renovation strategies were evaluated in terms of cultural-historical, ecologic and economic criteria.

The findings demonstrate the importance of operation-phase in the building life-cycle, which is crucial for the economic and ecologic impact causing the largest energy consumption and related CO2 emissions. Due to the very long payback periods for refurbishment in the context of social housing, incentives for owners as well as support for the use of more sustainable heating systems for the tenants are necessary.

Keywords

Social Housing, Refurbishment, Life Cycle Costs, Life Cycle Assessment, Sustainability

Thermal refurbishment of social housing – current issues

The Viennese social housing stock is especially large one, with more than 220.000 housing units (Wiener Wohnen, 2013). The specific stock of Red Vienna – a protected historic monument, counts 65.000 housing units (Lexikon der Wiener Sozialdemokratie, 2013) in 382 buildings (Lexikon der Wiener Sozialdemokratie, 2013 a). These are marked with an insufficient state of repair and a dwelling supply, which does not fit with modern demand considering the size of housing units and facilities. This paper presents the evaluation of life cycle oriented, holistic refurbishment strategies of a specific housing block from the Red Vienna period. The Red Vienna stock has been erected in the period of time since 1922 till 1934, fulfilling the urgent needs for proper housing, in front of all for working class, under motto: light, air and sun. The stock is 80 years old and in need of structural, but also thermal refurbishment, considering the Nearly Zero Energy Buildings Initiative by 2020 (EBPD, 2012). The considered refurbishment must comply with economic constraints (limited economic means since manager is non-profit organization, and minimisation of operational costs, such as heating), minimization of emissions and carbon footprint, and protection of cultural heritage as well as of social interests such as up keeping of affordable housing and accessibility, keeping in mind that built heritage is "non-renewable" capital (Hassler, 2009) This is a novel approach, considering social and cultural aspects, which are mostly neglected in current approach for stock refurbishment. The recent literature focuses on energy assessment of stocks (Loga and Diefenbach, 2012) or improvement of energy-efficiency and minimization of CO2 emissions, mostly through application of external insulation, window-improvement or improvement of the heating system (Uhlein and Eder, 2010, Veerbeck and Hens, 2005, Balaras et al, 2007).

Figure 1. **Elderschhof (own photography)**

Appropriate renovation strategy considers the type of building-hull refurbishment and energy system with the most sustainable effect over the life-cycle for owners, tenants and society.

Research design and approach

For the compilation of refurbishment strategy, which would optimally comply with the multiple stakeholder perspectives and diverging interests of sustainability, a case study methodology was chosen, combining qualitative and quantitative approach. As quantitative methods the life-cycle costing (LCC) for calculation of economic impact (Kohler, 2008) and life cycle assessment method (LCA) represented through assessment of global warming potential (GWP) for calculation of ecologic impact (Garrido- Sorianoa, 2010, Ramesh at al 2010) was applied. For the qualitative evaluation the cobweb diagram method was chosen, ranking the variants along the different criteria of sustainability.

As specific reference object a housing block "Elderschhof" in the second Viennese district was chosen. The Elderschhof (11.414 m2 gross floor area, six floors) is a housing block owned by the state Vienna and administered by Wiener Wohnen. It was erected in the years 1931 to 1932 and is an example of the building activity during the era of Red Vienna.

The building is currently under reconstruction, in the course of which, the elevators are refurbished and thermal refurbishment of façade, using exterior thermal insulation composite system based on extruded polystyrene core (ETICS EPS) is carried out.

This paper is structured as follows: after introduction and problem outline in the first and second chapter we will continue with development and evaluation of several thermal refurbishment variants of façade-systems for thermal refurbishment in chapter three. The façade-system based on interior insulation complying with the economic, ecologic and socio-cultural sustainability in terms of monument protection, will be chosen for further exploration and evaluation of thermal refurbishment of complete building-hull and improvement of energy system in the chapter four. Chapter five will be dedicated to the comparison of the refurbishment using interior insulation versus EPS-based exterior thermal insulation composite system (ETICS), which represents business as usual in refurbishment practice. We finally conclude with the chapter six, listing benefits of thermal refurbishment and modernization of energy system,

Evaluation of the façade-systems

In the first step, the life cycle costing (LCC) and life cycle assessment (LCA) methods were used for the assessment of the ecological and economic

	λ [W / m • K]	d [cm]	u-value [W/m^2 • K]	Heating Demand (HD) [kWh/m^2 • Ka]	Savings potential to stock
Existing State	-	-	1,694	123,74	0
ETICS EPS	0,035	20	0,159	39,16	68
ETICS MW	0,040	20	0,179	40,37	67
TIP	0,130	7	0,886	79,18	36
II	0,040	6	0,520	59,88	51
VIP	0,008	5	0,179	40,36	67

Table 1. **Thermal characteristics of the façade-systems according to OIB (2012)**

impact of different facade-system refurbishment variants, using the software Legep (Weka Media, 2013), based on ökobau.dat (Ökobau.dat, 2013) for ecologic data. The software and database was chosen since these are, next to the Baubook (Baubook Eco2Soft, 2013) the only available tools with verified data in the German and Austrian market.

LCA was carried out for the life cycle phases of production and maintenance (material-oriented); and production, operation and maintenance (energy-oriented).

For the calculation of the life cycle costs (LCC), the "total cost of ownership" approach was used, considering only the emerging costs over the life-cycle of a building, which have to be carried by the owner (König et al., 2009). Outpayments are discounted to the present value of the date of investment (discount rate of 5,5%) and are the base for LCC-evaluation of the investigated buildings, which is calculated over the period of 50 years.

Quantitative evaluation: LCA and LCC

Following refurbishment systems with different thermal characteristics (Table 1) were developed:

1. Refurbishment of the façade without thermal insulation measures (without TIM)
2. Refurbishment using Exterior thermal insulation composite system based on extruded polystyrene core (ETICS EPS)
3. Refurbishment using Exterior thermal insulation system mineral wool (ETICS MW)
4. Refurbishment using Thermal insulation plaster (TIP)
5. Refurbishment using Interior insulation (II)
6. Refurbishment using Vacuum insulation panel (VIP)

The evaluation of the operational phase - savings of heating energy demand (HED) resulting from façade refurbishment compared to the existing state of Elderschhof (Table 1), is determined through calculations of energy certificates along the lines of the OIB (2012).

The life cycle assessment of the façade-system variants for the primary energy demand (PED) and the global warming potential (GWP) is shown in the Table 2 and 3 for the phases production, maintenance, operation and demolition ("end of life"). This evaluation implies that the impact of so called "grey energy" for the material production and construction plays secondary role in the overall-lifecycle impact – the energy demand for the operation is up to 35 times larger than the grey energy. Therefore, the focus should primarily be on the optimization of operation phase, through reduction of heating energy demand.

Façade-systems with high insulation properties, like ETICS EPS, ETICS MW and VIP require high financial effort for

Façade systems	PED [MWh]				
	Production	Maintenance	Demolition	PED (P+M+D)	TOTAL LC PED
Without TIM	4.052	280	-28,92	4.304	153.472
ETICS EPS	4.985	1.422	-771,75	5.636	120.006
ETICS MW	5.159	1.519	-157,51	6.521	121.388
TIP	4.040	457	5,47	4.502	135.338
II	4.124	423	-47,11	4.499	127.394
VIP	4.760	827	-520,54	5.066	119.930

Table 2. **Results summary for LCA of façade-systems for primary energy demand**

production, maintenance and replacement and simultaneously generate a high ecologic impact. Especially the respective version VIP has enormous production costs compared to the other options. The alternative modernisation of the façade without thermal insulation measures and thermal insulation plaster - TIP offer low economic and ecological values concerning production and maintenance.

The whole life-cycle costs of an extensive thermal modernisation for the phases of production, maintenance, operation and demolition (Table 4) over the period of 50 years with the variation of the façade system, and the rental payments according to the availability of subsidy by the federal state of Vienna (Wohnfons Wien, 2013) are shown in table 4.

Façade systems with high insulation properties EPS, MW, II, VIP are more sustainable over the life-cycle of 50 years, than the options without-TIM or TIP. The low costs and the low GWP of the production and maintenance of the variants without TIM or TIP are neutralised through the high heating demand. The amount of produced GWP of the ETICS EPS, ETICS MW, II, VIP over 50 years is 20-25 % lower than that one of the variants without TIM or TIP, through large reduction of heating energy demand and related emissions.

Comparing the LCC of façade systems with high thermal insulation properties (high investment costs and low heating costs) and of the variants without TIM or TIP (low investment costs and high heating costs) shows that the break-even point is reached after 20 years of operating. Over the life-cycle of 50 years the variants ETICS EPS, ETICS MW, II or VIP generate obviously lower LCC due to the low heating demand, which is to the hirers´ economic advantage. Low heating costs can only be reached by high investment costs, of thermal refurbishments, which will have an impact on rent-increase. The rental payment increase over the period of 10 years for the variant without TIM is 15-70 % lower than compared with ETICS EPS, ETCS MW, II or VIP.

Façade system	GWP [t CO2- Equ.]				
	Production [t CO2- Equ.]	Maintenance [t CO2- Equ.]	Demolition [t CO2- Equ.]	GWP (P+M+D) [t CO2- Equ./a]	LC GWP [t CO2- Equ.]
Without TIM	943	53	169	23	29.078
ETICS EPS	1.044	225	257	31	21.822
ETICS MW	1.211	381	170	35	22.168
TIP	939	154	182	26	25.176
II	960	85	172	24	23.379
VIP	1.008	166	173	27	21.752

Table 3. **Results summary for LCA of façade-systems for GWP emission**

Qualitative Evaluation

The developed façade-systems were qualitatively evaluated, ranking the variants along the triangulation of the ecologic, economic and cultural-historical impacts. The economic impact is represented through median of LCC considering the present value and follow-up costs and rental payments. The ecologic impact is assessed through CO2 emissions over the whole life-cycle (production to demolition). The cultural-historical aspect is represented through the monument protection criteria defined by the guideline from office for federal monument “energy efficiency on historic monuments” (National Heritage Agency, 2012). The façade systems ETICS EPS, ETICS MW

	Rental payment incl. subsidy [€/m2.mth]	Rental payment excl. subsidy [€/m2.mth]	Production	Maintenance	Demolition	LCC Following cost [Mio €]	LCC (present value) [€]
Without TIM	2,88	3,44	266.341	9.665	79.449	42,58	15.788.844
ETICS EPS	2,86	4,27	700.127	20.194	79.449	38,14	15.002.127
ETICS MW	2,95	4,36	745.904	22.133	79.449	38,72	15.079.191
TIP	2,72	3,75	431.377	1.521	79.449	39,19	15.121.241
II	2,50	3,95	419.000	9.584	144.031	38,50	14.642.429
VIP	4,22	5,81	1.504.198	20.791	79.449	38,30	15.877.376

Table 4. **Results summary for façade-systems evaluation for whole lifecycle**

Qualitative evaluation	Following Costs	Present Value	Rental Payment	Economic Ranking	Ecological Ranking	Cultural Historical Ranking	Area		Ranking
Without TIM	6	5	4	6	6	1	20,78		6
ETICS EPS	1	2	3	2	2	4	8,66		2
ETICS MW	4	3	5	4	3	4	17,32		5
TIP	5	4	2	3	5	3	16,89		4
II	3	1	1	1	4	2	6,06		1
VIP	2	6	6	5	1	4	12,58		3

Table 5. **Façade systems, qualitative evaluation through ranking**

and VIP are equally ranked (1=highest score, 6=lowest score) concerning the monument preservation, as exterior applications causing of the same impact on structured facades (Table 5).

The evaluation is carried out with the help of a cobweb diagram (1=highest score, 6=lowest score) (Fig. 1). The sustainability-impacts are pictured as areas, where the façade-system with the smallest area has the best performance.

It must be noted, that the proposed qualitative evaluation is not using weighing of the aspects that would reflect interests of different stakeholders, such as tenants, building owner or monument protection agency.

The qualitative evaluation serves as exemplary of decision support tool in refurbishment process. Through proposed ranking, the evaluation of façade-systems in the context of thermal refurbishment identifies as best performing variant the interior insulation; due to the very good economic performance (low rental payment) and cultural-historical ranking. However, the current refurbishment practice is the ETICS EPS, the second best according to the ranking, which bearing large potential for the reduction of heating energy demand, and significant reduction of both costs and ecologic impact (CO2 emissions). However, the variants based on the exterior insulation of façades are, since 2012 according to the guidelines of the Federal Office for the Protection of Monuments (National Heritage Agency, 2012) not permitted. Only for the not protected parts of the building stock are these variants a feasible option. Already granted subsidies for refurbishments will be accepted by the Viennese Conservatory Department. For further examination, interior insulation façade-system will be used.

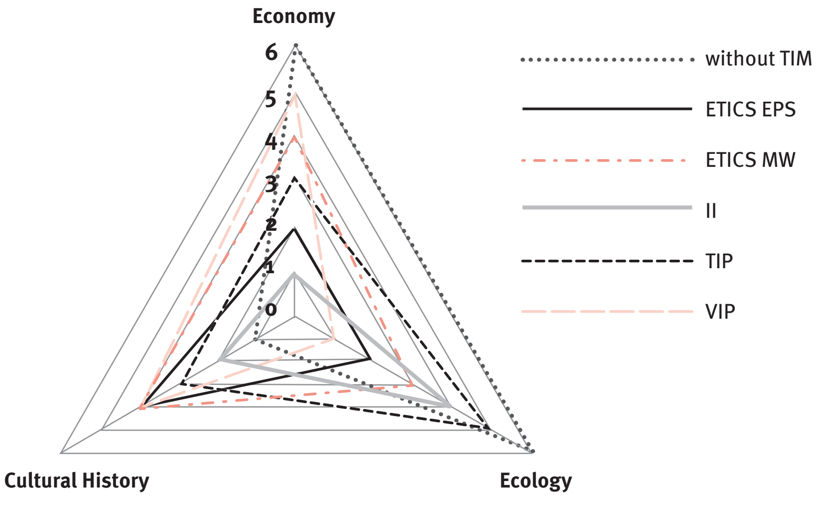

Figure 2. **Qualitative evaluation of façade-systems**

Evaluation of building-hull refurbishment variants

For the holistic refurbishment of the building-hull, several variants were compiled as abstract and simplified options to enable gaining insights on the potentials of the heating energy demand reduction and its impact on life cycle performance. For this analysis, economic (payback periods of production costs) and ecologic (CO2 savings through HD-reduction in relation to the CO2 emissions of the refurbishment variant) amortization periods were calculated.

Variant (A) illustrates the existing building und serves as a reference value for the following different refurbishment variants and its savings potential.

Variant (B) represents a thermal refurbishment including the insulation of the topmost and the basement ceiling.

Variant (C) represents the existing building with an insulated façade only.

Variant (D) combines variant (B) (insulated basement and topmost ceiling) and variant (C) (facade insulation)

Variant (E) determines the impact of the windows-replacement only, as single measurement

Variant (F) is a holistic thermal refurbishment of the building-hull (insulated topmost and basement ceiling, façade insulation and windows-replacement)

The thermal refurbishment variants are based on following parameters concerning the insulation quality:

- The basement ceiling insulation is 10 cm, the topmost ceiling insulation

Refurbishment variants	HED (kWh/m2.a)
A: Existing building	127,32
B: Existing building – topmost ceiling and basement ceiling insulated	107,17
C: Existing building – facade insulated	107,51
D: Existing building – topmost ceiling, basement ceiling and facade insulated	87,36
E: Existing building – window replacement	119,57
F: Existing building – topmost ceiling, basement ceiling and facade insulated, windows replaced	79,61

Table 6. **HED (energy certificate) of developed thermal refurbishment variants acc. to OIB 6 (2013)**

is 20 cm exterior thermal insulation composite system XPS.

- The façade insulation is carried out as an interior insulation of the outside walls with 6 cm MW, vapour barrier, gypsum plasterboard and interior plaster only. The renewal of the exterior plaster is considered as well. The facade without interior insulation (ceiling, interior walls) has an approximate share of 20% of the whole façade area. Its heat transfer coefficient equates the existing outside walls without insulation.
- The existing wooden windows are replaced through windows with triple- high-value insulated glass and wooden high-value insulated window frames.

Potential of heating energy demand reduction: Energy Certificates

For the calculation of reduction potentials of heating energy demand (HED) the energy certificate calculation methodology according to the OIB (2012) was applied based on existing as-built planning documentation. The HED of the developed variants is shown in Table 6.

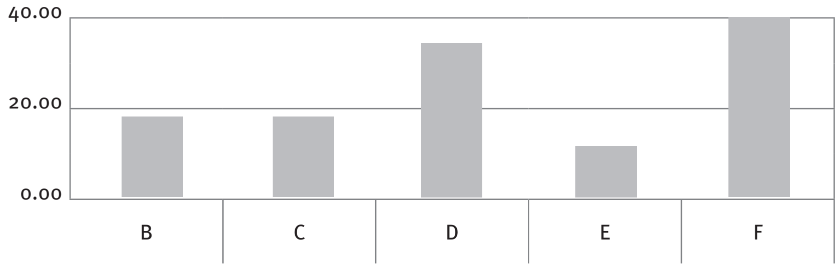

Figure 3. **HED savings potential**

The saving-potential of the refurbishment variants in annual heating energy demand per m2 gross-floor area compared to the existing building is shown in Figure 2.

The weakest potential for HED reduction as sole measurement shows variant E - replacement of the windows, through improvement of approximately 6%. Variant C - the refurbishment of façade, with the greatest share (~60%) of the building-hull, and the Variant B - insulation of the topmost and basement ceiling show the same potential of HD reduction of 15%. A holistic thermal refurbishment, Variant F, shows the highest HD reduction potential up to 37%. These figures are only guidance values, which have to be seen with a range of fluctuation. The real potentials are depending on the state of repair and refurbishment quality. Therefore a specified database (call for bids) is necessary, but not available.

Energy supply

The greatest challenge for the ecologic assesment is the lack of data, including the information on number of reference housing units supplied with gas or district heating (DH). A GWP assesment was based on HED calculations (OIB, 2012) for three cases for emissions-assesment related to the

Refurbishment variants	A	B	C	D	E	F
Heating system	GWP [CO2 Equ. kg/a]					
Gas	264.959	223.026	223.733	181.800	248.831	165.672
DH	81.958	68.987	69.206	56.235	76.969	51.246
Gas/DH (50%)	173.458	146.006	146.470	119.018	162.900	108.459

Table 7. **GWP for different energy supply systems and refurbishment variants**

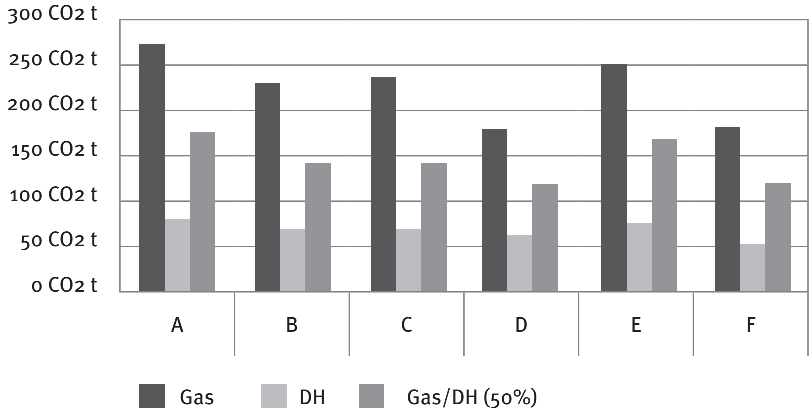

Figure 4. **GWP for different energy supply systems and refurbishment variants**

energy supply – for only gas supply, only district heating and a proposed mix of 50% gas and DH (Table 7). The three cases represent the theoretical energy supply scenarios in the housing units, since the tenants of the social housing are not obliged to transfer to the new heating system, despite the renewal, so often there are several energy systems in use one single building.

The maximal reduction of 70% of the annual CO2 emissions is achieved with variant A (no measurements) by changing the heating system from gas to district heating (Fig. 4), due the trifold GWP of gas if compared to the DH. The Vienese district heating system has extremely good ecologic performance – the heat is produced thorough waste combustion.

The minimum of CO2 emissions is caused by the Varinat F (holistic refurbishment) supplied by DH.

Ecological payback period

The GWP of refurbishment-variants was assesed for the life-cycle phases: production (cradle to gate), operation (energy demand depending on the energy supply) and demolition (end-of-life). Baubook database (Baubook Eco2Soft, 2013) was used for determining the GWP caused by the production of plasters and windows; and Ökobau.dat database (Ökobau.dat, 2013) for the production of mineral wool, vapour barrier and the gypsum plaster board. The end-of-life of plaster, mineral wool and vapour barrier is determined with the database Ökobau.dat (Ökobau.dat, 2013). The phase maintenance during operation and removal were not considered due to the lack of information. The GWP of heating energy was quantified by the means of conversions factors (OIB, 2012) depending on the used heating system gas, district heating (DH) and a combination of gas and district heating with a share of each 50%.

The employed heating system has the largest impact on the reduction of CO2 emissions for refurbishment-variants with equal HED, since gas produces triple GWP than the same amount of energy demand covered by district heating (Fig. 4). The Vienese district heating system has very good ecologic performace, since the heat is generated through waste combustion.

The heating energy system has also the greatest impact on the ecological payback period - the impact of refurbishment on the GWP-reduction with the variants using energy types with high GWP (such as gas) is much stronger than on DH significantly reducing the ecological payback period - app. 2 years for gas, whereas 5 years for HD (Table 8, Fig. 5).

Economic payback period

For calculation of the economic payback period the production costs of refurbishment variants were compared with the reduction of heating costs caused by the thermal refurbishment (Table 9). The production costs were determined using the software Legep (Weka Media,

Refurbishment Variants	II (cradle to gate + removal)	Annual reduction GWP HD (Gas)	Payback period (Gas)	Annual reduction GWP HD (DH)	Payback period (DH)	Annual reduction GWP HD (Gas/DH)	Payback period (Gas/DH)
	[kg CO2]	[CO2 kg/a]	[a]	[CO2 kg/a]	[a]	[CO2 kg/a]	[a]
B	65.564	41.933	1,56	12.971	5,05	27.452	2,39
C	70.512	41.226	1,71	12.752	5,53	26.989	2,61
D	136.076	83.159	1,64	25.723	5,29	54.441	2,50
E	21.566	16.128	1,34	4.989	4,32	10.558	2,04
F	157.642	99.287	1,59	30.712	5,13	64.999	2,43

Table 8. **Ecological (GWP) payback period**

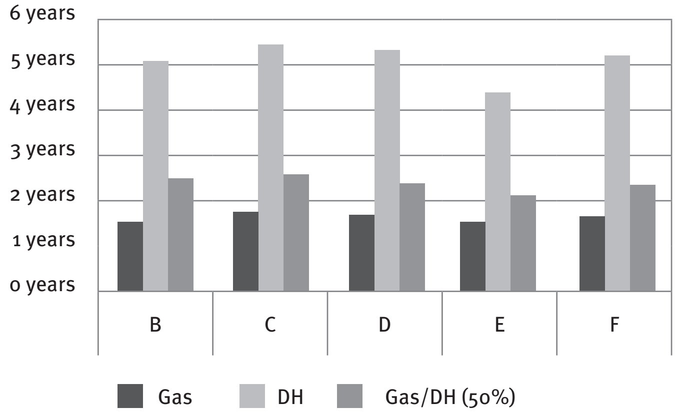

Figure 5. **Ecological payback period of different energy supply systems (Gas, DH, DH/ Gas)**

2012), the direct labour costs per unit for gas and district heating were gathered from Wien Energie (Wien Energie, 2013). Nominal cost values were chosen because gas with a higher price per kWh (Wien Energie, 2013) generally has shorter payback periods than the district heating system.

Compared to the ecological payback periods, the economic are obviously longer (Fig. 5 and Fig. 6). Not only are the periods longer, but the ecologic and economic evaluation display differing results. In the economic evaluation, the shortest payback period of 16 years shows the Variant B (insulation of top and bottom ceiling) using gas; where as the Variant E (renewal of windows) using DH displays the payback period of 144 years which is economically not feasible. Not so in the ecologic assessment – there the Variant E displays the shortest payback period of only 1,34 years; the second best is the Variant B with 1,56 years payback.

A window-replacement integrated in a holistic thermal refurbishment (Var. F) which in general displays the lowest annual GWP also creates better economic payback periods.

Comparative study of the refurbishment variants using EPS and interior insulation

The current refurbishment practice of the existing housing stock is, despite the monument protection, the application of the EPS-core based ETIC system. The reasons are manningfold – the refurbishment is always in occupied state, the tenants cannot be dislocated due to the lacking ressources of the housing association. Since Wiener Wohnen is a non-profit asset manager, the external insulation system, that is easy to apply and to mantain, has relatively low investment costs and causes large heating energy savings is favoured. In order to clearly identfy the differences in the performance of the interior insulation, complying with the monument protection versus ETICS EPS facade-system, a comparative study of economic and ecological payback periods of the building-hull refurbishment variants using II and ETICS EPS of was carried out.

Energy supply

The higher HED related to the façade refurbishment using II results in higher ecological impact compared to the

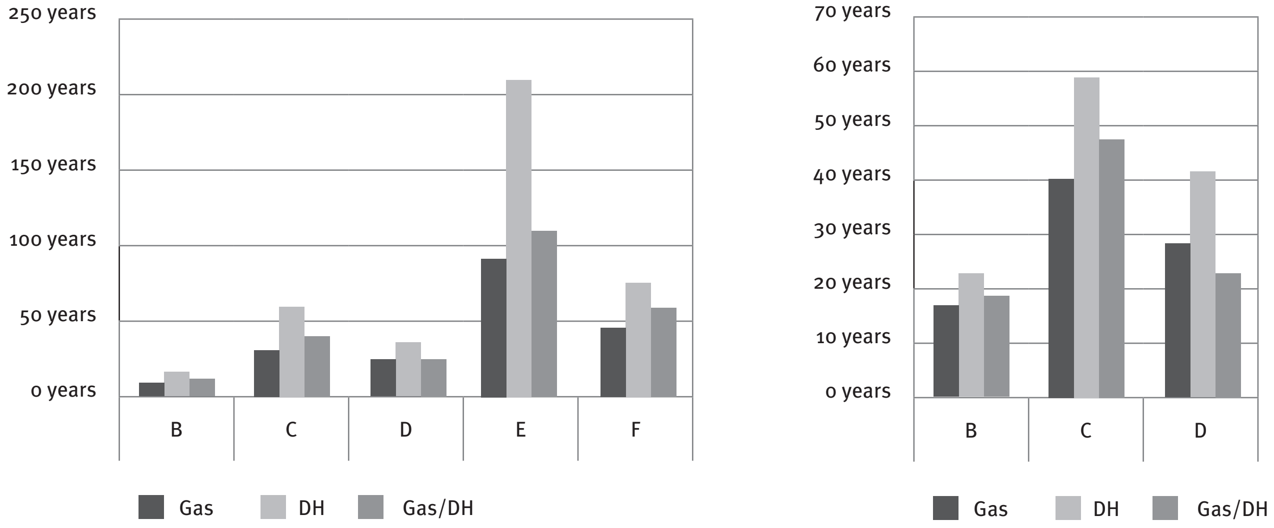

Figure 6. **Economic payback period of different energy supply systems (production costs/ reduction heating costs)**

Refurbishment Variants	Production costs	Annual reduction heating costs (Gas)	Payback period (Gas)	Annual reduction heating costs (DH)	Payback period (DH)	Annual reduction heating costs (Gas/DH)	Payback period (Gas/DH)
	[€]	[€/a]	[a]	[€/a]	[a]	[€/a]	[a]
B	170.256	11.016	16	7.463	23	9.240	19
C	432.604	10.830	40	7.337	59	9.084	48
D	602.861	21.847	28	14.799	41	18.323	33
E	607.032	4.237	144	2.870	212	3.554	171
F	1.209.893	26.084	47	17.670	69	21.877	56

Table 9. **Economic payback period**

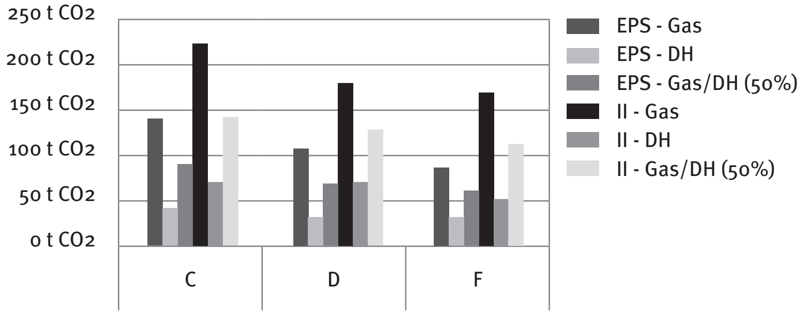

Figure 7. **GWP for different energy supply systems and refurbishment variants for II and ETICS EPS**

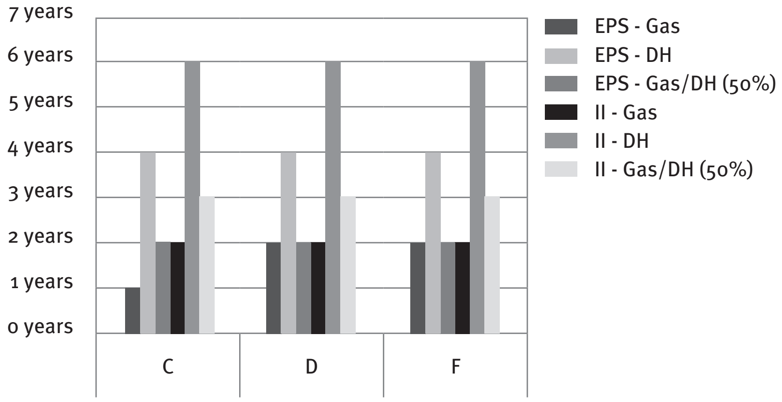

Figure 8. **Comparison of Ecological (GWP) payback period of different energy supply systems (Gas, DH, DH/Gas) and refurbishment variants for II and ETICS EPS**

respective version ETIC EPS. The additional GWP caused by the higher HED of façade system II ranges from 53% (Variant C) to 83% (Variant F) using different energy sytems, as presented in Fig. 7.

Ecologic payback period

The by 65% higher HED of II facade-systems cannot be neutralised by a better II performance of 40% during the life-cycle phases “cradle to gate and replacement”.

As result, the payback periods of II facade-system based variants are prolonged for 1 year (Gas and Gas/DH) and 2 years (DH) as Fig. 7 shows. Only the refurbishment variant D (insulation of topmost and basement and facade) using gas; or the variant F (holistic thermal refurbishment) using gas do not increase the payback period (Fig. 8).

Economic payback period

From the economic point of view, if compared to the ETICS EPS, the II has the higher heating costs caused through the higher HED. The economic payback periods are therefore prolonged, depending on the refurbishment variant (Fig. 8). With variant C and the changing of the façade system from ETICS EPS to the II, the economic payback period increases up to 90% depending on the employed heating system (Fig. 8). Variant D reaches a raise of 37-40% (Fig. 8). In Variant F the holistic thermal refurbishment with II causes an increase of the economic payback period of 47% compared to the respective version ETICS EPS (Fig. 9).

Conclusion

In the presented research the life-cycle oriented refurbishment strategies for a specific housing block of Red Vienna have been developed and evaluated according to the criteria of energy-efficiency and CO2 minimization, and more over to comply with monument

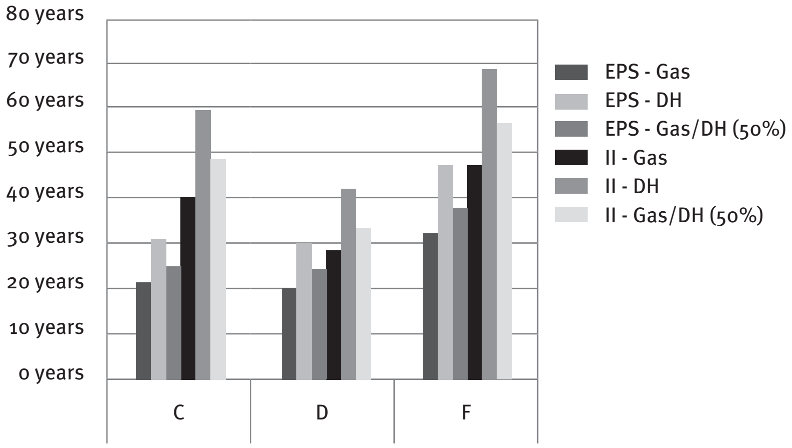

Figure 9. **Economic payback period of different energy supply systems (production costs/ reduction heating costs), refurbishment variants for II and ETICS EPS**

preservation criteria and affordability of housing.

Thereby the quantitative evaluation (LCC and LCA) combined with qualitative evaluation of sustainability impact via cobweb diagram were carried out, in order to determine the most sustainable facade-system, which was then used for the evaluation of the building-hull and energy system refurbishment variants. The façade-variants with low potential of HED reduction (without TIM, TIP) have, despite the low economic and ecologic impacts considering the phases of production and maintenance, high whole life-cycle impact (cumulated over 50 years), which cannot be neutralised by the positive evaluation concerning monument protection. According to the proposed qualitative ranking, regarding lifecycle costs, rental payments, achieved CO$_2$ savings and monument protection, the façade refurbishment variant using interior insulation shows the best performance over the period of 50 years, and was used in further examination of building-hull and energy system refurbishment.

Since the largest energy consumption occurs during the operation phase, the most preferred measure is the holistic refurbishment of the complete envelope – Variant F, through the highest heating energy demand reduction of 37% when comparing to the existing state, but also through the lowest annual CO2 emissions.

Aside from the thermal building-hull refurbishment, the greatest ecological impact has the change of the heating system from gas to the district heating. Only through change of gas to district heating energy supply the annual CO2 emissions can be reduced by 70%. However, the acceptance of the tenants for the district heating is quite low, due to the high basic cost (flat rate) in comparison to the very low basic cost of gas heating; which even cannot be outdone by the additional costs for gas-consumption. The results generally comply with the literature, stating that major percentage of energy consumption occurring through operational phase (Cuellar-Franca and Azapagic, 2012, Kesicki 2012) can be cost-effectively reduced through various conservation measurements and increase of district or biomass heating and warm water preparation.

The economic and ecologic amortization show diverging results – ecologic payback periods are in general much shorter (1,3 – 5,5 years) whereas economic payback periods range from 16 to 212 years. In terms of ecologic payback the Variant E (window-replacement) using gas displays the best performance of 1,3 years; whereas in the same case, the economic payback is 144 years due to the very high production costs and few savings in the operation.

Neglecting the windows, the refurbishment Variant B (insulation of topmost and basement ceiling) using gas displays the best ecologic and economic payback periods of 1,56 respectively 16 years. However, Variant B can contribute to the improvement in HED by only 15% when compared to the existing state, and causes 35% more CO2 emissions when compared to the best performing Variant F using gas, or even four times more than the Variant F using district heating.

Since the current refurbishment practice is based on ETIC EPS, the ecologic and economic payback periods of the thermal building-hull refurbishment variants using interior insulation were compared to the one based on ETICS EPS. It can be concluded, that despite the fact that II has better performance by 40% in the phases production and maintenance, the ETICS EPS reaches better economic and ecologic amortization throughout the lifecycle due to the lower HED – in the best performing variant F both economic and ecologic amortization periods are app. 50% shorter.

Finally the study shows, that the economic and ecologic interests diverge, and that incentives are necessary for the implementation of long-term oriented strategies in terms of climate protection or protection of cultural heritage. The study has limitations – for the qualitative evaluation, instead of ranking, weighing by stakeholders should be carried out in the real refurbishment process in order to reflect the multiple stakeholder perspectives and interests and find the customized strategy. Further on, instead of the static calculation of economic payback periods of production costs, a dynamic LCC simulation should be carried out, which is currently difficult due to the lack of reliable data, but is intended in the future research.

Acknowledgement

This research was carried out within research project „Re_Co_Re: Resources Conserving Rennovation“ funded by FFG and Eracobuild. We gratefully acknowledge Maja Lorbek, Vienna University of Technology; Department of Housing and Design, the project coordinator, and Michael Höflinger, Vienna University of Technology; Research Center of Building Construction and Maintenance for support in compilation of energy certificates.

References

Balaras C.A., Gaglia A.G. , Elena Georgopoulou E., Mirasgedis S., Sarafidis Y., Lalas D.P. (2007), “European residential buildings and empirical assessment of the Hellenic building stock, energy consumption, emissions and potential energy savings”, *Building and Environment*, No. 42, pp. 1298–1314

Baubook Eco2Soft (2013), *“Baubook Eco2Soft Ökobilanz für Gebäude”*, available at: http://www.baubook.at/eco2soft/ (accessed November 2013)

Cuéllar-Franca R.M. and Azapagic A. (2012), “Environmental impacts of the UK residential sector: Life cycle assessment of houses”, *Building and Environment, No.* 54, pp. 86-99

EBPD (2010), “Directive 2010/31/EU of the European Parliament and of the of 19 May 2010 on the energy performance of buildings”, available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDFMinistry

(accessed November 2013)

Garrido-Sorianoa N., Rosas-Casals M., Ivancic A., Álvarez-del Castillo M. (2012), “Potential energy savings and economic impact of residential buildings under national and regional efficiency scenarios. A Catalan case study”, *Energy and Buildings,* No. 49, pp. 119–125

Hassler U. (2009),” Long-term building stock survival and intergenerational management: the role of institutional regimes”, *Building Research & Information,* Vo. 37., No. 5, pp. 552 — 568

Kesicki F. (2012), “Costs and potentials of reducing CO2 emissions in the UK domestic stock from a systems perspective”, *Energy and Buildings,* No. 5, pp. 203-211

Kohler N. (2008), “Long-term design, management and finance for the built environment”, *Building Research & Information*, Vol. 36, No.2, pp. 189 - 194

König H., Kohler N., Kreissig J., Lützkendorf T. (2009), *Lebenszyklusanalyse in der Gebäudeplanung. Grundlagen, Berechnungen, Planungswerkzeuge*. Detail Green Books, Institute for international architecture-documentation GmbH & Co. KG, Munich

Lexikon der Wiener Sozialdemokratie (2013 a), *„Kommunale Wohnbauten der Ersten Republik*“, available at: http://www.dasrotewien.at/kommunale-wohnbauten-der-erstenrepublik.html, (accessed November 2013)

Lexikon der Wiener Sozialdemokratie (2013), „*Kommunaler Wohnbau“*, available at: http://www.dasrotewien.at/kommunaler-wohnbau.html, (accessed November 2013)

Loga T. and Diefenbach N. (2012), „Gebäudetypologien europäischer Länder – Schema für die energetische Bewertung nationaler Gebäudebestände“, *Bauphysik*, Volume 34, No. 2, pp. 78–83

National Heritage Agency (2012), *„Richtlinie Energieeffizienz am Baudenkmal“,* available at: http://www.bda.at/documents/462396673.pdf, (accessed November 2013)

Ökobau.dat (2013), “*Ökobau.dat”*, available at: http://www.nachhaltigesbauen.de/baustoff-und-gebaeudedaten/oekobaudat.html, (accessed November 2013)

OIB (2013) Österreichisches Institut für Bautechnik, *„OIB-Richtlinie 6. Energieeinsparung und Wärmeschutz“,* available at http://www.oib.or.at/richtlinien11.htm, (accessed November 2013)

Ramesh T., Prakash R., Shukla K.K. (2010), “Life cycle energy analysis of buildings: An overview”, *Energy and Buildings,* No. 42, pp. 1592–1600

Summer M., Kovacic I., Achammer C. (2012), *Renovation strategies for ageing society.* Masterthesis, Institute for Interdisciplinary Building Process Management Industrial Building and Interdisciplinary Planning, Vienna

Uhlein A. and Eder P. (2010), “Policy options towards an energy efficient residential building stock in the EU-27”, *Energy and Buildings,* No. 42, pp.791–798

Verbeeck G. and H. Hens H. (2005), “Energy savings in retrofitted dwellings: economically viable?”, *Energy and Buildings,* No. 37, pp. 747–754

Weka Media (2012), *“Legep - die Software für Lebenszyklusplanung“*, available at: http://www.legep-software.de/, (accessed November 2013)

Wien Energie (2013), “Produkte und Preise”, available at: http://www.wienenergie.at/ eportal/ep/channelView.do/pageTypeId/11889/channelId/-22147, (accessed November 2013)

Wiener Wohnen (2013), *„Der Wiener Gemeindebau“*, available at: http://www.wienerwohnen.at/wiener-gemeindebau.html, (accessed November 2013)

Wohnfons Wien (2013) *„Wohnhaussanierung. Liegenschaftsmanagement und Projektentwicklung“,* available at: http://www.wohnfonds.wien.at/, (accessed November 2013)