The sustainable approach to building refurbishment: Energy efficiency of individual refurbishment measures and refurbishment packages

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Abstract
A large proportion of European building stock, which was constructed before the 1970s, when the first energy building regulations were introduced, poses an enormous potential to decrease energy consumption and environmental impacts of aging building stock. Accordingly, refurbishment of buildings, which are currently responsible for about 40% of final energy consumption and 35% of CO_2 emissions, was acknowledged by the EU as an opportunity for reaching the ambitious 2020 and 2050 energy and climate objectives.

Building retrofit is a comprehensive process, therefore it should consider not only energy but also structural, economic, architectural and social aspects, all of these forming interaction of main viewpoints of sustainable design.

The main aim of this paper is to assess the energy efficient refurbishment of three existing multifamily buildings. The impacts of individual refurbishment measures and carefully selected complex refurbishment packages on the energy efficiency of refurbished buildings in comparison with the case study buildings concerning their building typology is examined. The findings of this research are transferred into educational process and can serve architects and engineers in their decision making and early design stage.

Keywords: Building refurbishment, energy-efficiency, refurbishment measures, refurbishment packages, building typology.

Trajnostni pristop k prenovi stavb: Energetska učinkovitost posameznih ukrepov obnove in obnovitvenih paketov

Povzetek
Velik delež evropskega stavbnega fonda, ki je bil zgrajen pred letom 1970, ko so bili uvedeni prvi predpisi glede energijske učinkovitosti stavb, predstavlja ogromen potencial za zmanjšanje porabe energije in okoljskih vplivov obstoječih stavb. Zato je EU prepoznala prenovo stavb, ki trenutno povzročajo približno 40% končne porabe energije in 35% emisij CO_2, kot priložnost za doseganje ambicioznih energijskih in podnebnih ciljev za leti 2020 in 2050.

Prenova stavbe je celovit proces, zato bi morala upoštevati ne le energijsko učinkovitost, temveč tudi strukturne, ekonomske, arhitekturne in družbene vidike, ki tvorijo interakcijo glavnih stališč trajnostnega oblikovanja.

Glavni namen tega prispevka je ocena energijske učinkovitosti prenove treh obstoječih večstanovanjskih stavb. V prispevku preučujemo vpliv posameznih ukrepov obnove in skrbno izbranih celostnih paketov prenov za povečanje energijske učinkovitosti tako prenovljenih stavb v primerjavi z energijsko učinkovitostjo obstoječih stavb z ozirom na njihovo stavbno tipologijo. Ugotovitve te raziskave se ponovno implementirajo v izobraževalni proces ter hkrati služijo arhitektom in inženirjem v zgodnjih fazah odločanja za prenove stavb.

Ključne besede: prenova stavb, energijska učinkovitost, ukrepi prenov, paketi prenov, tipologija stavb.

1. Introduction

Building sector is responsible for about *40%* of the total final energy consumption and about equal portion of CO_2 emission in the EU [1]. At the same time a substantial proportion of European building stock is older than 50 years with more than *50%* of residential buildings constructed before the 1970s, when the first energy building regulations were introduced [2]. Accordingly, the building sector alongside with transport sector was considered by the EU as the first concern when reaching the ambitious 2020 and 2050 energy and climate objectives [3].

Many researches and overviews into renewable and sustainable energy, for example in Ref. [4], have been carried out. Several studies [5, 6] address energy saving potential based on energy-efficient refurbishment. A strong argument supporting the need for complex building refurbishment is also seen in a relatively low percentage of the new build representing only 1% of the total housing stock in the period from 2005 to 2010 [2]. In a recently conducted research by Abdul Hamid et al. [7] literature regarding multifamily buildings in temperate climate was reviewed according to several categories; status determination, renovation strategies and renovation measures. Moreover, many research studies [8, 9, 10, 11] examine the influence of various renovation measures on energy saving potential and economic implications. Studies looking for systematic procedures to be applied to energy-efficient refurbishments of buildings [12, 13] are less frequent. They all exhibit the importance of the complexity and holistic approach in the process of energy efficiency refurbishment.

Although several research studies have already investigated the effects of individual refurbishment measures and packages on energy efficient building refurbishment together with cost and environmental efficiency, none of them discussed the influence of different multifamily building typologies on energy efficient refurbishment.

The content of the article is divided in four main parts. An introduction of the latest research regarding building refurbishment and the structure of the article is given in the first chapter, continued with the description of the methodology and the results with discussions in the second and third chapter. The main findings of the research are concluded in the last chapter.

2. Methodology

2.1. The aim of the study and its basic limitations

The main aim of this paper is to assess the energy efficient refurbishment of three existing multifamily buildings, which represent the three typical multi-family building typologies in Slovenia. Firstly, the impacts of several individual refurbishment measures is evaluated and further combined within complex building refurbishment, targeting different levels of building`s envelope's thermal performance when applied to multi-family buildings of different building typology and orientation. The basis for evaluation of individual refurbishment measures and complex building refurbishment represents the understanding of existing buildings energy balance, which will be assessed firstly, followed by the evaluation of the impact the individual refurbishment measures and complex building refurbishment packages exert on energy efficiency of refurbished multi-family building.

2.2. Energy balance, savings calculation and climate data

The numerical study is computed with the Passive House Planning Package (PHPP) [14] which is a certified software designed for planning low-energy and passive houses. It is based on the EN ISO 13790 standard [15] as well as on other European standards.

The climate data for Maribor are taken into consideration. The city belongs to the Cfb climate zone according to the Köppen–Geiger climate map [16]. The average annual temperature in Maribor is *10.7˚C* with the lowest average temperature of *-0.8˚C* in January and the highest of *20.8˚C* in July. The average length of the heating period is *187 days*. The average annual horizontal solar radiation in Maribor is *1,225* kWh/m^2 with the average heating period radiation of *350* kWh/m^2 [17].

2.3. Description of the case study buildings

The research is conducted on three case study buildings (multifamily building, hereinafter EB), built in 1950s in the city of Maribor, which were selected according to their architectural building type, orientation and erection period before the implementation of the first regulations demanding thermal insulation in buildings in 1790. Selected multifamily buildings and their floorplans are presented in Figure 1, Figure 2and Figure 3.

Figure 1. Existing case study building – EB A (left) and its floorplan (right)

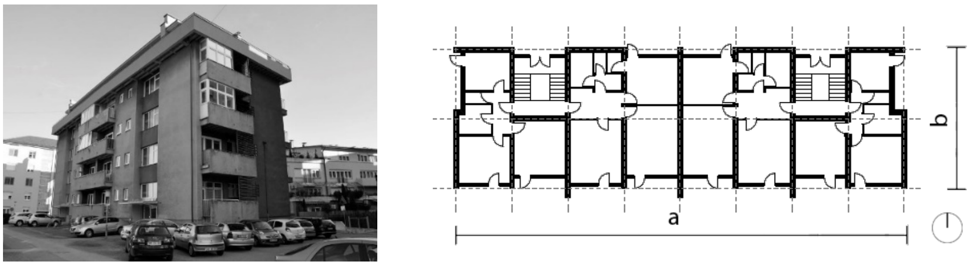


Figure 2. Existing case study building – EB B (left) and its floorplan (right)

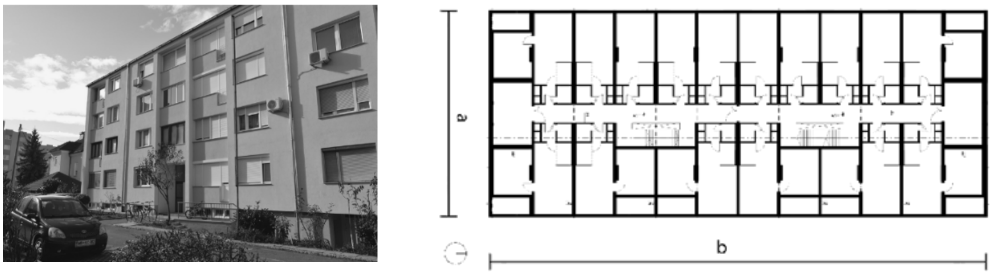


Figure 3. Existing case study building – EB C (left) and its floorplan (right)

The buildings are constructed in the massive structural system with masonry walls and ceilings made of precast concrete ribbed slabs (EB A) or concrete brick beams with ceiling fillers (EB B and EB C). They all have an unheated basement outside the enclosed thermal envelope and some additional service area on rooftop (EB A and EB C) or skylights (EB B). The detailed characteristics of selected existing multifamily buildings, given in Table 1, correspond to initial condition of EBs, disregarding any eventual partial renovations current buildings may have been subjected to in the past.

Table 1. Characteristics of EBs

		EB A	EB B	EB C
a (m) (south–north oriented façade)		35.42	17.40	15.40
b (m) (east–west oriented façade)		11.10	41.95	18.20
h (m) [1]		18.10	11.70	16.60
A (m^2) [2]		1164.30	2086.03	1047.60
A_{storey} (m^2)[3]		291.08	521.51	209.52
F_s (m^{-1})[4]		0.41	0.35	0.43
NS_{EB} (or NS_{REB})[5]		4	4	5
a/b[6]		3.19	0.41	0.85
AGAW[7]	north	26.9 %	12.1 %	3.8 %
	south	51.2 %	12.1 %	12.0 %

	east	13.2 %	34.1 %	28.6 %
	west	13.2 %	32.6 %	28.6 %
Orientation of longer façade		south-north	east-west	east-west
U (W/(m^{2}K))	windows:			
	frame	2.50	2.50	2.50
	glass	2.20	2.20	2.20
	g = 0.8			
	external wall	1.45	1.46	1.44
	roof	1.83	1.99	1.46
	basement ceiling	1.59	1.46	1.01

[1] Height of the EB,
[2] Total net floor area of EB,
[3] Net floor area of a single-storey,
[4] Factor of shape, defined as the ratio between the total area of the building thermal envelope and the total heated volume of the building,
[5] Height of the EB or REB, expressed in the number of storeys,
[6] Aspect ratio, defined as the ratio between the length of the south–north and the east–west oriented façade,
[7] Glazing-to-wall area ratio.

Selected EBs no longer correspond to the current energy efficient requirements, therefore the first interest of this research is to improve the energy efficiency of EBs. Apart from their insufficiently insulated thermal envelope, inefficient old windows without shading devices, the airtightness of the buildings is weak and accounts for app. n_{50} = *7.0 1/h*. The EBs are naturally ventilated.

2.4. Refurbishment measures and packages

The influence of refurbishment measures on energy efficiency of the EBs in this research is firstly assessed separately as individual refurbishment measures (hereinafter IRM). Selected IRMs target mainly the improvement of building thermal envelope and reduction of heat transfer by ventilation due to air leakages in the building envelope.

This research regards the following IRMs:
- IRM A - Replacement of old windows and doors,
- IRM B - Improvement of the exterior wall thermal performance,
- IRM C - Improvement of the roof thermal performance,
- IRM D - Improvement of the basement ceiling thermal performance,
- IRM E - Installation of the heat recovery mechanical ventilation system (hereinafter HRV).

Since the energy efficiency of IRMs depends on the targeted thermal transmittance (*U*) of envelope elements, two targeted levels of thermal envelope performance were assessed within this research. The first one corresponds to current energy efficient regulations in Slovenia (PURES [18]), furthermore improved values of IRM thermal transmittance were applied. The values of thermal transmittance (*U*) and other characteristics of applied IRMs for both targeted levels of thermal envelope performance are given in Table 2.

Table 2. Characteristics of individual refurbishment measures (IRMs)

Level	IRM A	IRM B	IRM C	IRM D	IRM E
PURES	U_{frame} = 0.91 W/(m^{2}K) U_{glass} = 1.30 W/(m^{2}K) g = 0.64	U_{wall} = 0.28 W/(m^{2}K)	U_{roof} = 0.20 W/(m^{2}K)	$U_{basement\ ceiling}$ = 0.35 W/(m^{2}K)	η^1 = 85 %
IMPROVED	U_{frame} = 0.78 W/(m^{2}K) U_{glass} = 0.50 W/(m^{2}K) g = 0.50	U_{wall} = 0.163 W/(m^{2}K)	U_{roof} = 0.158 W/(m^{2}K)	$U_{basement\ ceiling}$ = 0.163 W/(m^{2}K)	η^1 = 85 %

[1] Heat recovery efficiency

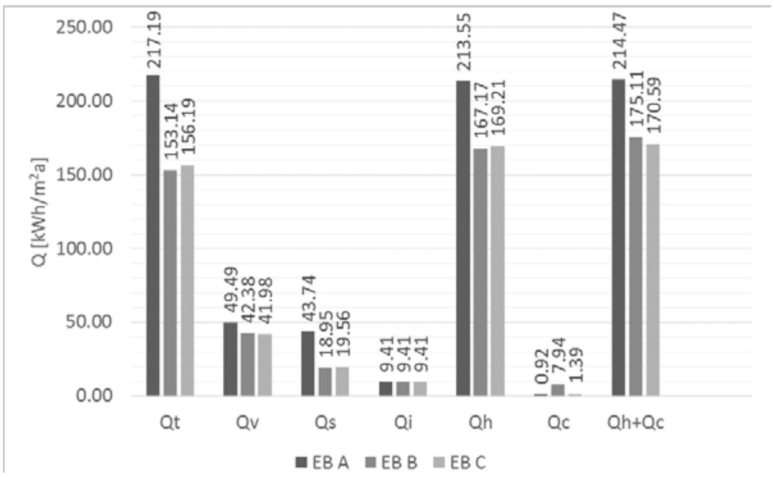
For both targeted levels of thermal envelope performance temporary external shading with shading factor *z = 0.50* was taken into account. As the thermal envelope is improved also airtightness of the building is gradually improved from initial n_{50} *= 7.0 1/h* to predicted n_{50} *= 2.0 1/h*.

3. Results and discussion

3.1. Existing building energy balance

Detailed energy balance calculation of the EBs is crucial for evaluation of different IRMs and complex building refurbishment packages (hereinafter CRPs) energy efficiency, therefore it is presented in Figure 4.

Figure 4. EBs heat flows and energy balance



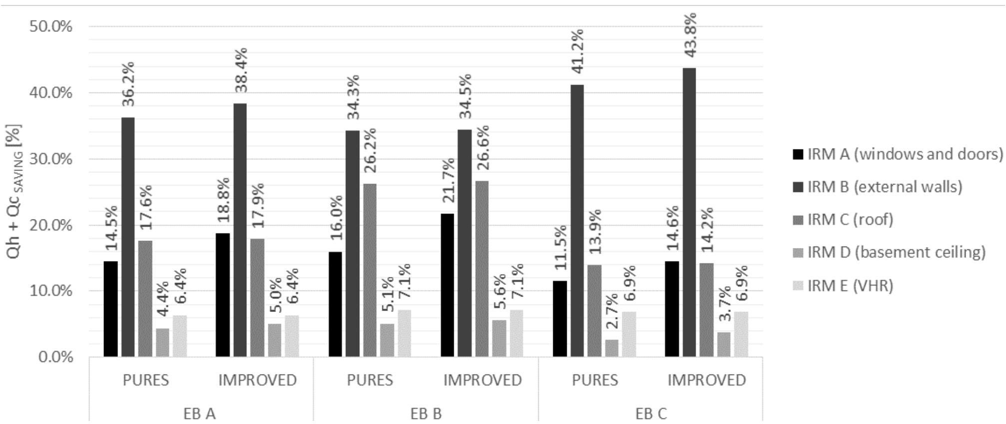
As it is evident from Figure 4, the energy need for heating (Q_h), in selected EBs is evidently stronger than energy need for cooling (Q_c). In the case of EB A and EB C the energy need for cooling (Q_c) is below *1.5 KWh/(m^{2}a)*, which is almost negligible if compared to energy need for heating (Q_h). The highest energy need for cooling (Q_c) is observed for EB B due to two skylights installed in the roof. In contrary the highest energy need for heating (Q_h) among selected EBs is evident in the case of EB A. The latter derives from high heat transfer by transmission (Q_t) during the heating season. The heat transfer by transmission (Q_t) represents the highest share among all energy flows in EBs energy balance and therefore the strongest influence on the energy need for heating (Q_h) and total energy need (Q_h + Q_c). They are the lowest in the case of EB B, influenced by the most favourable shape factor (*Fs*) (Table 1). With regard to relatively comparable thermal transmittance (*U*) of building envelope elements of selected EBs, the divergence in the heat transfer by transmission (Q_t) originates in different building design characteristics like building typology, size and orientation together with glazing share (*AGAW*) and orientation. The lowest total energy need for heating and cooling (Q_h + Q_c) is observed in the case of EB C, which is the consequence of several design characteristics like building typology and factor of shape (F_S) resulting in small roof and basement ceiling area, lower thermal transmittance (*U*) of roof and basement ceiling combined with low *AGAW*, etc.

The comparison of the EBs energy balance clearly indicates the characteristics of selected individual EBs that influence the energy efficiency the most and can serve as the basis for examining the energy efficiency based on different building typologies.

3.2. Energy efficiency of individual refurbishment measures

The savings in the energy need for heating and cooling ((Q_h + Q_c) $_{SAVING}$) of selected IRMs for both targeted levels of thermal envelope performance (PURES and improved thermal transmittance) are given in Figure 5.

Figure 5. The savings in the energy need for heating and cooling ((Q_h + Q_c) $_{SAVING}$) of selected IRMs



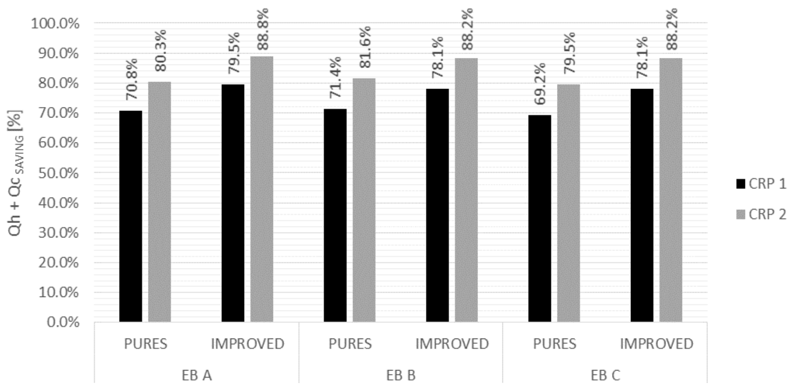
As evident from Figure 5, the savings in the total energy need for heating and cooling ((Q_h + Q_c) $_{SAVING}$) are the highest when introducing IRM B. This IRM has the highest influence on EB C, adding up to *43.8%*, resulting from the exterior wall areas ratio, defined as the share of the external wall area within the total envelope area of the EB, which accounts for *54%*. The same goes for EB A with the area ratio of *48%*. The reason for the weakest influence of IRM B on EB B derives from the same ratio, which is the lowest among all EBs and accounts for *38%*. Contrary the roof areas ratio for EB B is the highest among all selected EBs, therefore the IRM C is the most effective when applied to EB B, resulting in app. *26%* of total energy savings ((Q_h + Q_c) $_{SAVING}$). The highest influence of IRM B on EB B is followed by IRM C and IRM A for both targeted levels of thermal envelope performance, accounting app. *26%* for IRM C and from *16%* up to *22%* for IRM A, depending on the selected level of envelope thermal performance. Observation of the influence IRM A and IRM C have on EB A and EB C, suggests stronger influence of IRM C when adopted to PURES level of thermal envelope performance and contrary stronger influence of IRM A when improved properties of thermal envelope are used. The IRM with the lowest influence on the savings in the energy need for heating and cooling ($(Q_h + Q_c)_{SAVING}$) for all EBs and targeted envelope thermal properties levels proves to be IRM D. The latter finding is related to the lowest heat transfer by transmission through basement ceiling. The results indicate slightly stronger influence of IRM E on the savings in the energy need for heating and cooling ($(Q_h + Q_c)_{SAVING}$). The small differences in total energy savings ($(Q_h + Q_c)_{SAVING}$) between different levels of envelope thermal properties for some IRMs like IRM C and IRM D suggest smaller influence of the selected level of envelope thermal performance. While incorporating IRM A and IRM B induces more divergence in predicted total energy savings ($(Q_h + Q_c)_{SAVING}$), which implies thorough consideration of selecting the targeted level of envelope thermal properties already during design stage of building refurbishment.

These findings reveal the importance of building typology together with shape factor (F_S) and the targeted level of the envelope thermal performance on the selection of appropriate IRMs combined into refurbishment packages.

3.3. Energy efficiency of complex refurbishment packages

Further, the influence of refurbishment measures on energy efficiency of EBs is evaluated by combining different IRMs within CRPs. Due to the already mentioned difficult implementation of IRM E, we composed two complex refurbishment packages with (CRP 2) and without implementation of IRM E (CRP 1). The impact on energy efficiency of REBs of both CRPs is presented in Figure 6.

Figure 6. The savings in the energy need for heating and cooling ($(Q_h + Q_c)_{SAVING}$) of proposed complex refurbishment packages (CRPs)



As it can be expected, CRP 2, which incorporates all of the IRMs including IMR E, generates the highest total energy savings ($(Q_h + Q_c)_{SAVING}$). They are the highest when applying improved values of thermal performance to EB A, accounting for *88.8%*, but are only slightly lower for EB B end EB C, reaching up to *88.2%* as can be seen in Figure 6. The savings in the energy need for heating and cooling ($(Q_h + Q_c)_{SAVING}$) for PURES values of envelope thermal performance in average are only *7.9%* lower. Nevertheless up to *79.5%* of the total energy savings ($(Q_h + Q_c)_{SAVING}$) is achieved without implementation of IRM E (CRP 1). Although the implementation of IRM E contributes significantly to the energy efficiency of REBs, it is usually difficult and expensive to apply to already populated EBs, therefore the results of CRP 1, representing complex building refurbishment without implementation of IRM E are more applicable for real life projects.

4. Conclusion

Aiming at reducing the final energy consumption, the refurbishment of energy inefficient existing buildings is treated as one of the urgent tasks of building sector. Reviewing listed literature and results of this research emphasize the benefits of complex building refurbishment, composed by various renovation measures concerning not only energy-efficiency but also structural, economic, architectural and social aspects. Although this research deals mainly with energy-efficient aspects, at the same time, it affects also indoor comfort and thereby occupants' health and well-being, therefore refurbishment of existing buildings is one of the main social responsibilities.

The individual refurbishment measures demonstrate distinct influences on energy efficiency of refurbished buildings, regarding their different typology, orientation and selected level of envelopes' thermal performance. Among individual refurbishment measures, the improvement of exterior wall thermal performance (IRM B) proves to be the most influential for all building typologies and levels of buildings envelope thermal performance, followed by replacement of windows (IRM A) and improvement of roofs thermal performance (IRM C). Applying several refurbishment measures combined in complex building refurbishment packages (CRP) proves to be more efficient, not only for energy reduction but also for increasing thermal comfort and general indoor conditions, therefore it is recommendable. Accordingly, energy savings up to *79.5%* can be achiever even disregarding installation of the heat recovery mechanical ventilation system (IRM E), which is often difficult and expensive to incorporate in existing already inhabited buildings. Therefore the later findings suggest the importance and the advantages of complex building refurbishment over partial refurbishment.

Further analyses of such refurbishment for different building typologies, orientations and energy standards of buildings together with various combinations of individual refurbishment measures are planned in order to obtain sufficient information for the preparation of general guidelines.

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