



APPROACH TO REFURBISHMENT OF TIMBER PRESCHOOL BUILDINGS WITH A VIEW ON ENERGY AND ECONOMIC EFFICIENCY

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Abstract. The refurbishment of educational buildings usually involves a variety of measures aiming at reducing energy demands and improving building functionality to achieve higher living comfort. This paper aims to develop an approach for determination of comprehensive refurbishment strategy upon existing preschool buildings in Slovenia from the aspects of energy and economic efficiency. The main idea of the approach is to separate and individually analyse the investments into those related to energy efficiency improvements and those related to improvements of building functional quality through the step-by-step evaluation of individual measures. The proposed approach was applied on the case study of the existing timber preschool building in the city of Maribor. Generally, the highest energy savings are detected only in the case of combination of multiple renovation measures. Moreover, the economic indicators show low efficiency for almost all measures if they are treated separately. Additionally, the analysis reveals that certain measures are totally inefficient in terms of energy, yet they are highly beneficial from the viewpoint of building functional quality, which indicates the importance of the multi-perspective assessment of renovation process. The conclusions of this study can be implemented to similar building types and construction ages in similar climatic and economic environments.

Keywords: educational buildings, timber buildings, energy renovation, functional improvement, energy efficiency, cost of conserved energy.

Introduction

Built environment is considered as a focal point of socio-economic human activities. A predominant part of our daytime being spent inside buildings makes living comfort vital to well-being and work effectiveness of their users. The living environment is an important factor especially for preschool children who are in the early stages of their development, and thus it influences their welfare and growth (Yun et al., 2014; Mijakowski & Sowa, 2017). The building quality assessed by a set of various parameters with the most general ones attributed to functionality and safety along with other criteria related to thermal comfort, health, aesthetics, etc., is therefore one of key goals in design and construction of new buildings. Unfortunately, the current situation regarding the quality of existing preschool and educational buildings is relatively poor. In fact, buildings in Europe date from different periods with specific building strategies and regulations typical of the time. Approximately 50% of the existing European building stock dates from the period before 1970 (Eurostat, 2010; Norris & Shiels, 2004; Poel, Cruchten, & Balaras, 2007),

when building regulations mandating thermal properties of building envelopes were rather loose and inadequate (Konstantinou & Knaack, 2013). Only after the Energy Performance of Buildings Directive (EPBD) (Directive 2002/91/EC, 2002) came into force, significant efforts to increase the energy efficiency in the operational phase of the building were put forth and became even more pronounced after the implementation of the EPBD recast in 2010 (Directive 2010/31/EU, 2010). The listed data referring to the age of buildings is in accordance with the situation in the field of energy use within which buildings in Europe account for approximately 40% of the final energy consumption, with the largest share spent on heating. Among non-residential buildings across Europe, the educational buildings represent 17% with the 12% share of total energy use (BPIE, 2011). Construction techniques of non-residential buildings, including preschool buildings, are very similar to those of residential buildings, therefore for all building types erected before the introduction of stricter national directives, the refurbishment represents

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an enormous potential to improve their energy efficiency. A strong argument supporting the need for comprehensive building refurbishment encompassing functional performance and energy efficiency results from a relatively low percentage of the new build, representing only 1% of the total housing stock in the period from 2005 to 2010 (BPIE, 2011), in fact, the renovation rate is also very low, only around 1.2% to 2% per year (European Commission, 2010; Semprini et al., 2016).

In addition, many factors from the economic perspective stimulate investors to support complex building renovation and modernization. Whereby economic evaluation is provided by various project appraisal methods, such as calculations of payback time, net present value (*NPV*) and internal rate of return (*IRR*). These approaches are relatively easy to use, but do not cover overall benefits of comprehensive energy efficiency and functional refurbishment projects.

1. Literature review

A lot of scientific literature investigates strategies and principles of building renovation. Many studies focus solely on energy efficiency; several include also the aspects of functional renovation, while others deal mainly with the economical viewpoint.

Consideration of different energy retrofit procedures for educational buildings can be found in Semprini et al. (2016), Causone, Carlucci, Moazami, Cattarin, and Lorenzo (2015), Pagliano, Carlucci, Causone, Moazami, and Cattarin (2016), Tahsildoost and Zomorodian (2015), Tanic et al. (2015), Stankovic et al. (2015). Semprini et al. (2016) discusses the energy retrofit measures for the particular educational building in Bologna, where non-invasive interventions with a lower impact had to be considered, since the study treats a case of historical public building. Even with limited modifications, the potential for energy saving of 32% was achieved. Causone et al. (2015) analyze the retrofit measures for the single-storey concrete kindergarten built in Milano in the 1980s. Selection of a comprehensive renovation approach included measures on thermal envelope, lighting, appliances and use of hybrid ventilation strategy, so the primary energy need for building operation was reduced for almost 85%. Moreover, Pagliano et al. (2016) analyse a deep energy renovation of the childcare centre in Milano based on future climate scenarios. The study reveals a serious problem in building design because even the high-performance and zero-energy buildings use current meteorological data files that usually base on 20 year or longer time span average. However, climate patterns are expected to be different in the future, so the analysis identifies that the expected climate change might require far more focus on building cooling strategies. Further, Tahsildoost and Zomorodian (2015) present experimental study of energy refurbishment techniques for two typical school buildings in Tehran. The study introduces a three-step procedure implicating first retrofit measures on building envelope and technical systems, second, optimization of scenarios as a function of energy simulation

and simple payback time, and third, assessment of implemented measures. Studies (Tanic et al., 2015; Stankovic et al., 2015) present the possible revitalization principles for preschool buildings in Serbia with a special focus on possibilities for reduction of transmission and ventilation losses in study by Tanic et al. (2015).

Focusing mainly on educational buildings, we can find multiple studies recognizing the impact of indoor climate on productivity of children, or students and teachers (Yun et al., 2014; Mijakowski & Sowa, 2017; Corgnati, Filippi, & Viazzo, 2007; Corgnati, Ansaldo, & Filippi, 2009; Pereira, Raimondo, Corgnati, & da Silva, 2014; Baker & Bernstein, 2012). Some of these studies point at an important problem related to energy efficiency renovation measures which are not always in correlation with the development of building indoor climate. Improvement of energy efficiency therefore has to be followed by an adequate control of indoor air quality, thermal, visual and acoustic comfort in order to achieve acceptable living quality conditions.

On the other hand, some research papers consider complex renovation and analyse the impact of renovation measures from perspectives, energy and economic efficiency (Niemele, Kosonen, & Jokisalo, 2016; Salvalai, Malighetti, Luchini, & Girola, 2017; Stocker, Tschurtschenthaler, & Schrott, 2015; Congedo, D'Agostino, Baglivo, Tornese, & Zacà, 2016). Studies consider educational buildings built in various construction systems, design typologies and located in different climatic regions. They estimate various scenarios of refurbishment in terms of cost/benefit and use different indicators, most using the *NPV*. Niemele et al. (2016) discuss economic viability for energy renovation measures on typical Finnish educational buildings. The results indicate that renovation of building envelope without utilizing renewable energy production systems does not meet the standard of cost-effective retrofit. Salvalai et al. (2017) summarize the result of energy and investment intensity of different renovation measures for two reference school buildings. Investment intensity, given in €/kWh per year, shows that the deeper and more expensive renovation measures increase unit costs. Stocker et al. (2015) analyze the efficiency of renovation measures conducted on eight school buildings located in Alps differing in building age. The results show a strong impact of building age and its compactness on *NPV* and a high effect of investment costs on cost-optimal renovation level. The methodology for the determination of cost-optimal solutions of energy efficient refurbishment was applied also in Congedo et al. (2016) on the case study of two existing educational buildings.

Further research including cost optimal solutions for the renovation of various buildings can be found in Becchio et al. (2016), Bonakdar, Doodoo, and Gustavsson (2014), Pikas, Kurnitskic, Liiasc, and Thalfeldt (2015), Kuusk, Kalamees, Link, Ilomets, and Mikola (2017), Stankevičius, Karbauskaitė, Burlingis, Šadauskienė, and Morkvėnas (2014). The economic analyses are mostly performed for concrete and masonry buildings, while the economic analysis of historic timber apartment buildings is discussed in Arumägi and Kalamees (2015), where comparison of the

effectiveness of different renovation packages is done in terms of investment and energy costs.

The previously presented studies have disclosed few important conclusions, which could serve as starting point for the current study:

- The comprehensive building renovation including measures on thermal envelope and technical systems can lead to the prominent reduction of energy need for building operation;
- The cost-efficiency is not always in correlation with the energy performance, therefore a careful consideration of the economical aspect of building renovation presents a meaningful support to decision makers.

Although treating the issue of complex building refurbishment, the reviewed studies do not integrate a systematic analysis of refurbishment process through the step-by-step evaluation of individual measures from the perspectives of energy and economic efficiency, which presents a valuable scientific contribution of our research. An estimation of individual measures can be beneficial in situations, when investors are obliged to implement steps of renovation gradually due to a lack of financial resources. Therefore, it is highly beneficial to perform analyses in order to determine the optimal solution of the refurbishment strategy in terms of energy performance and costs. In this manner the two-factor method for the assessment of cost efficiency presented in Martinaitis, Kazakevicius, and Vitkauskas (2007) is used also in our study.

Other specifics of the current study are seen in the consideration of refurbishment principles for preschool buildings erected in timber construction system. Finally, an additional contribution of our study lies in the attention being paid to the improvement of building functionality and architectural aesthetic appearance, both factors increasing the building living quality and accounting value.

Despite a high potential to improve the functionality and energy efficiency of educational buildings, many reasons for not implementing such actions prevail more often in practice. Besides the limited financial resources, a strong argument can be found in a lack of knowledge on the systematic renovation concepts. In light of the above mentioned reasons, the objective of the current paper is to present a systematic approach to complex step-by-step renovation based on the case study of preschool building, discussing the aspects of energy efficiency improvement and evaluating cost-effectiveness. Results are evaluated gradually for individual measures and subsequently together for a combination of all the measures. The intensity of measures for the improvement of building functionality is limited in terms of structural requirements of timber construction system and concerning the currently valid national regulations for premises and equipment for kindergartens (Official Gazette of the Republic of Slovenia No. 73, 2010). The regulation based limitations might influence the scope and the cost-efficiency of functional improvements. Finally, the results and conclusions of this study can be drawn for similar building types and construction age in comparable climatic and economic

environments. The current research can serve the potential investors in decision-making process referring to the selection of an adequate level of energy and cost efficient renovation in regard to available financial resources.

2. State of the national educational building stock and in the city of Maribor

Non-residential buildings represent around 28% of the Slovenian building stock, while buildings of general social importance represent 9% (Ministry of Infrastructure & Ministry of Public Administration, 2015). Currently, altogether 1163 kindergartens are organized in buildings entirely or partly used for pre-school educational purposes (Ministry of Education, Science and Sport, 2018). The many of these buildings are designed in the single-panel timber-frame structural system according to data from the regions of Slovenia and former Yugoslav countries, revealing that 360 pre-educational building were erected in this manner in 60s, 70s and 80s (Žegarac Leskovar, Premrov, & Kitek Kuzman, 2012). At that time, and especially until 1980, the minimal national requirements for thermal performance of building envelopes were rather poor with the prescribed U values around $U = 1.28\text{--}1.68 \text{ W}/(\text{m}^2\text{K})$ (Official Gazette of the Socialist Federal Republic of Yugoslavia No. 35, 1970). The aforementioned data indicates a relatively high potential for building energy retrofit, which begun to be implemented more intensively after the adoption of the EPBD (European Commission, 2010) and with a support of financial instruments of EU funds. As a result, 251 educational buildings in Slovenia were subject to energy renovations (partial or complete), among them 65 preschool (Ministry of Infrastructure, 2018). In this research, further analyses relate to preschool buildings.

A representative sample of kindergartens located in the city of Maribor is chosen to describe the building stock situation of preschool buildings in Slovenia. Altogether there are 35 preschool buildings in Maribor, with total net floor area of 26310 m² (Ministry of the Environment and Spatial Planning, 2018). From Figure 1 it is evident that most of them were built in the period from 1950 to 1990, whereas from 1971 to 1980 they were mostly built in timber-frame panel structural system.

So far, only five buildings have been completely energy renovated, while partial renovations were carried

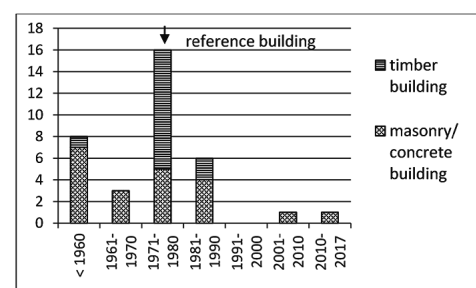


Figure 1. State of the preschool buildings in the city of Maribor by the year of construction and type of structural system (Ministry of the Environment and Spatial Planning, 2018)

out in 28 buildings and, 21 of which after 2010, and 9 of them were subject to renovation of heating system. The implementation of complex renovations (thermal envelope and installation of heat recovery ventilation systems) accounted for about 340 €/m² to 470 €/m² (net floor area), while for building with small usable area is about 970 €/m² (City Municipality Maribor, 2018). In summary, most of the preschool building stock in Slovenia remains energy inefficient.

3. Introduction to systematic integrated building renovation process

The complex refurbishment process consists of individual renovation actions, resulting in refurbishment strategy of the building. It is important that already in early design stage the design strategy planning is approached systematically. Typically, refurbishment of preschool buildings is designed by using various strategies, from the basic thermal update of thermal envelope to more sophisticated solutions, within adding of extra space and other functional improvements.

Consequently, systematic integrated approach would be reasonable for supporting the evaluation of individual renovation action. Approach proposes an analysis of energy savings and economic benefits of single measures as specified in refurbishment strategy. In the first phase, systematic compilation of different measures and their organization in terms of energy and functional improvement should be introduced. This is followed by a selection of the refurbishment strategy and precise definition of step-by-step measures. The next approach phase evaluates the way how proposed measures contribute to energy and economic efficiency. First, investment costs are determined, then the effects of energy savings measures and benefits for all measures are evaluated.

3.1. Reduction of energy flows in buildings by energy renovation process

Energy efficiency of the building means the amount of energy required for its usual operation, including the heating (Q_h), cooling (Q_c) and ventilation demands (Q_v) in addition to hot water supply and lighting energy consumption. The energy balance of the building generally consists of the transmission heat losses (Q_t), ventilation heat losses (Q_v), internal heat gains (Q_i) and solar heat gains (Q_s), given in the form of Eqn (1). Based on different temperatures of the building and its surroundings we can distinguish between two opposite heat flow scenarios.

In a heating period of the year when the average outdoor temperature is generally lower than the prescribed indoor temperature, the sum of all heat flows in the building is usually negative, which is mainly due to the energy output caused by transmission and ventilation heat losses. In such cases the ΔQ results in the amount of energy required for heating (Q_h) in order to reach a desired indoor temperature of approximately 20 °C, Eqn (1), in the form of:

$$Q_t + Q_v + (Q_i + Q_s) = \Delta Q = Q_h \dots \text{in heating period;} \\ = Q_c \dots \text{in cooling period.} \quad (1)$$

Renovation phase a: Renovation of thermal envelope elements by adding the thermal insulation

This is the most popular approach in the building renovation process. By adding thermal insulation on the external (or internal) side of the envelope elements, the thermal transmittance (U-value) decreases and consequently results in reduction of the transmission losses (Q_t). It is usually also the technologically easiest and one of the cheapest approaches in building renovation.

Renovation phase b: Replacement of windows by the new type of glazing with reduced U-value and possible increasing of the glazing areas on the south façades

This phase is also one of the most popular approaches in which is many times performed as a single (and the only) renovation phase. In this approach, the old existing windows are replaced by the new type of glazing with essentially lower thermal transmittance (U_w , Q_h), so the transmission losses through the windows can be essentially decreased. However, it is highly recommended to combine the phase 1 and 2.

Moreover, the glazing areas on the south façades can be increased, which is a quite new approach in energy renovation of old buildings. Respecting the fact that dynamic evolution of the glazing in the last decades has resulted in insulating glass products with highly improved physical properties, especially the decreased U-value, and that the g-value does not decrease in the same way (see subsection 4.2.1, RP 2), the solar gains (Q_s) through the glazing can be larger than the transmission losses (Q_t) through the same glazing area, especially on the south side of the building envelope. Respecting Eqn (1) it is obvious that the heat demand (Q_h) can even decrease in this case, but on the other hand, the cooling demand (Q_c) can increase in the summer period. However, we should be very carefully with this implementation. Several parametric numerical studies about this fact are presented in Žegarac Leskovar and Premrov (2011, 2013), Premrov, Žigart, and Žegarac Leskovar (2018).

Renovation phase c: Vertical building extension with lightweight upgrade module

Furthermore, reduction of transmission losses can be introduced by constructing the upgrade module on the top of the existing building. A difference between previously performed renovation possibilities and the proposed one lies in the change of energy flows as the “bottom plate” of the upgrade module becomes a building element between two heated rooms. The optimal upgrade module shape depends on several changeable parameters such as the module shape, the proportion of glazing in the south-oriented façade, in addition to the thermal transmittance of the external walls and the roof. The study of Špegelj, Žegarac Leskovar, and Premrov (2016) shows a positive impact of building extension by the upgrade module with the optimal glazing size in south-oriented façade on energy savings. Implementation of the previously especially developed timber-glass upgrade module with enlarged glaz-

ing size on the south façade is studied in Premrov, Žigart, and Žegarac Leskovar (2017).

Renovation phase d: Installation of heat recovery air-exchange systems to reduce ventilation losses

Ventilation heat losses (Q_v) are usually reduced by improvement of the building airtightness and by insertion of the system of the air exchange (heat recovery). However, technologically this is usually not an easy approach at all, but it can reduce the ventilation losses in average for 4 to 8 times.

3.2. Methods for economic evaluations

At present, there are several economic analysis methods for quantifying benefits of the building complex renovation e.g. simple payback period (*SPP*), *NPV*, *IRR*, and cost of conserved energy (*CCE*). Among these the *CCE* is the most readily and comprehensible criterion for non-economists which stipulates that investment in a measure is economically efficient if *CCE* is lower than the average cost of primary energy in the useful time of the measure (Petersen & Svendsen, 2012). The basic indicator of *CCE* is defined as (Martinaitis, Rogoža, & Bikmanien, 2004):

$$CCE = \frac{I_{measure} \cdot CRF}{dE_{year}}, \quad (2)$$

where $I_{measure}$ is the investment cost, *CRF* is the capital recovery factor, and dE_{year} is the annual energy saving by the measure (e.g. kWh). *CRF* includes annual discount rate (r) and for the benefits of energy efficiency investments, rates are between 2% and 4% (Bonakdar et al., 2014; Pikas et al., 2015). Recently, the *CCE* concept has been used in assessment of economic efficiency for new building (Petersen & Svendsen, 2012) and for renovation (Martinaitis et al., 2004, 2007).

However, applied methods in most cases consider only the reduction of heating costs as sole benefits of energy saving project while other benefits such as improvement of building elements condition, extension of durability and increasing value of the building is neglected. In capturing all benefits of complex improvement project, a two-factor evaluation method should be used (Martinaitis et al., 2007).

In order to analyze real example of complex building renovation by using a two-factor evaluation method, it is necessary to introduce indexes. The summary for the case study is: *E* related to the pure energy efficiency measures; *A* associated with the measures of adding lightweight upgrade module; *F* addressed to functional improvement measures including structural building improvements and renovation measures; and *T* related to the so-called “two-fold” measures. The “two-fold” measure includes both benefits from energy savings and improvement of building elements. The economic analysis is made by using the following steps:

Step 1: Calculation of total investment costs

Total investment cost ($\sum I_{TAEF}$) is the amount of all types of measures, including construction, finishing and installation works, and can be calculated:

$$\sum I_{TAEF} = \sum I_T + \sum I_A + \sum I_E + \sum I_F, \quad (3)$$

where I_T is the amount of investment of two-fold measures; I_A the amount of investment for adding module measure; I_E the amount of investment of energy efficiency measures; and I_F the amount of investment of functional measures.

Step 2: Grouping of investments using two-factor method

Initially, each of the investments can be classified as homogeneous measures (include I_E , I_F and I_A), or as those related to the two-fold measures (I_T). The latter can be further subdivided into the energy saving (I_{TE}) and the building renovation and improvement (I_{TF}) component. Next, investments are separated into two groups; a) energy saving measures (I_{TEE}), and b) functional improvement measures and adding lightweight module (I_{TFAF}).

Step 3: Evaluation of cost effectiveness of individual investments measure divided into groups

a) Investments in I_{TEE} include two components I_E and I_{TE} and are evaluated using *SPP* and *CCE*. The *SPP* is ratio between initial investment cost of measure, and annual costs for conserved energy evaluated at year 0. The disadvantage of this criterion is neglect of lifespan of an energy saving measure. This aspect is reflected in the *CCE* criterion. The basic definition of *CCE* is used (Eqn (2)) for homogeneous energy saving measure (I_E) and the modified formula of CCE_T is introduced for energy saving of two-fold measures (I_{TE}) by using building rehabilitation coefficient κ :

$$CCE_T = \frac{(1 - \kappa) \cdot I_{measure} \cdot CRF}{dE_{year}}, \quad (4)$$

where κ represents the ratio between the lifespan of building element (in years) and the actual age of an element (in years). In our case study, the linear function for physical deterioration of the building's element condition is applied, while lifespan is summarized by Rules (Official Gazette of the Republic of Slovenia No. 20, 2004).

b) Investments in I_{TFAF} contain three components I_{TF} , I_A and I_F . Benefits of those measures should be expressed with the social and environment effects e.g. indoor living quality (air quality, thermal, visual and acoustic comfort), aesthetics, reduced CO_2 emissions and others. In addition, the measure of new module increases the total net floor area and has direct effect on satisfying the requirements of the modern standards for kindergartens (Official Gazette of the Republic of Slovenia No. 73, 2010) as well as on increasing the value of the property. For these measures, certain standard evaluation methods could be used. Their appraising needs sophisticated tools and includes analysis with large number of criteria, thus such methods are not covered in the scope of this paper. Anyhow, our case study uses the model of valuation of tangible fixed assets according to accounting standards (Official Gazette of the Republic of Slovenia No. 95, 2015), namely increase of the purchase value of fixed assets. The increased value represents investment for I_{TF} , I_A and I_F by using coefficient κ .

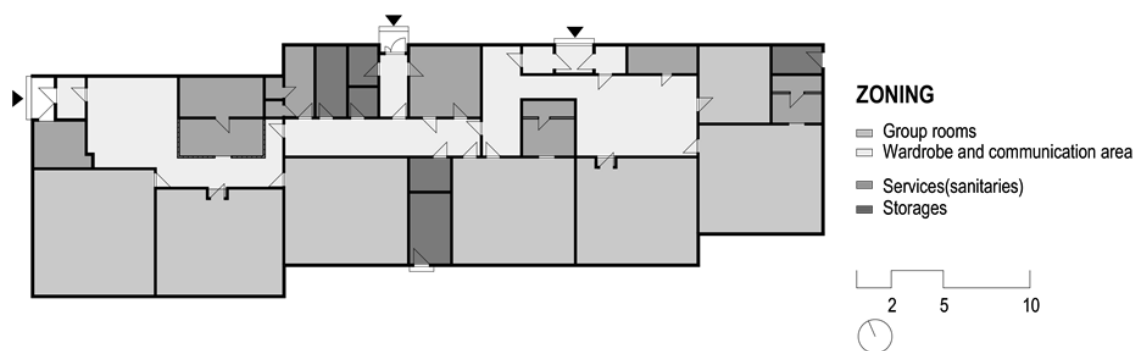


Figure 2. Ground floor plan of Kindergarten Mojca (adapted from Ivačić, Jashanica, Lešnik, & Stopar, 2014)

4. Case study

The study focuses on the complex renovation of typical Slovenian preschool building built in 1970s. The modernization approach requires functional adaptations alongside with energy efficient measures in order to reduce energy consumption and to establish an adequate indoor living climate for children and staff.

4.1. Description of the existing building

The research is based on the case study of Kindergarten Pobrežje, Unit Mojca (hereinafter referred as Kindergarten Mojca) presenting the typical preschool building type built widely in 1970s and 1980s in Slovenia and also in the other areas of former Yugoslavia. The Kindergarten Mojca was built in Maribor in the year 1978 and until now the building has not been renovated; only the basic maintenance works were carried out. It is built in a single-panel timber-frame structural system and has north-south orientation with service, storage, communication areas and wardrobes mostly oriented to the north and group rooms oriented to the south (Figure 2).

According to its physical condition (Figure 3), the building requires deep renovation alongside the need to increase the usable floor area and the standard of living comfort. The playrooms on the south side of the building suffer from overheating in summer due to light timber construction with thin insulation layer in combination with large south-oriented old wooden windows with inefficient shading. In winter, the building has high infiltration air rates, and the natural ventilation is not adequate in cer-

tain times of the day. The layout of the rooms is organized properly according to orientation, but it lacks functional spaces, such as multipurpose room, gym, play areas, offices for preschool teachers, space for medical treatment, terraces, etc.

4.1.1. Calculation methods and software

The software Passive House Planning Package – PHPP 8 (Feist, 2013) is used for the calculation of the energy balance of individual refurbishments phases. Results are energy performance indicators including energy need for heating Q_h and cooling Q_c . Based on detailed data on implemented renovation measures and associated results for energy balance, each renovation phase is economically assessed. A two-factor evaluation method is used. The cost effectiveness is evaluated with indicators *SPP* and *CCE* for energy saving measures, while the method of increasing value of the building is used for functional measures.

4.1.2. Climate data

The building is located in the city of Maribor. The average annual temperature is 10.7 °C with the lowest average temperature in January of -0.8 °C and the highest average temperature in July being +20.8 °C. The average daily temperature range in summer is recorded to be ± 10.9 °C. The average length of the heating season is 187 days. The average horizontal solar radiation is 1225 kWh/(m²a) (Meteonorm Software, 2018). The average number of solar hours in the period from 1981 and 2010 is approximately 2000–2050 annually (Environmental Agency of the Republic of Slovenia, 2018).



Figure 3. South (left) and north (right) façade view of Kindergarten Mojca Maribor (2014)

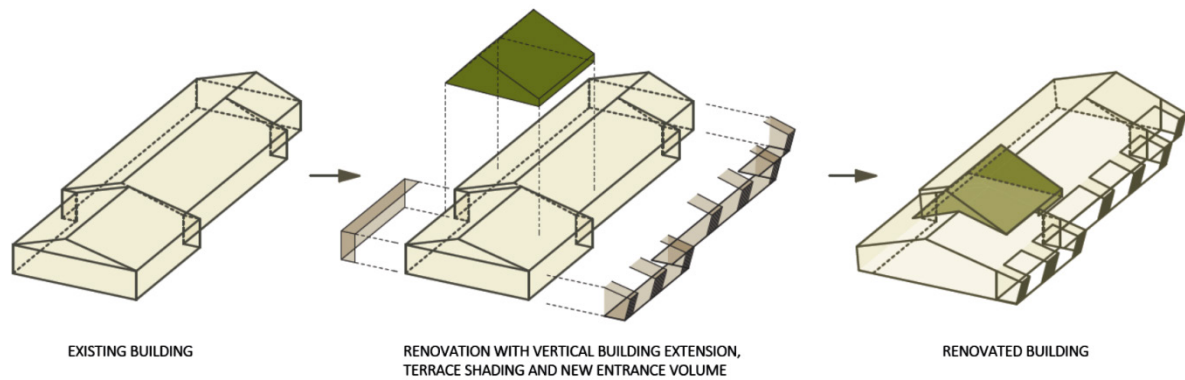


Figure 4. The scheme of the renovation concept (Ivačić et al., 2014)

4.1.3. Default indoor conditions

Thermal comfort conditions are set by the minimum interior temperature of 22 °C during the heating period and 25 °C during the warm weather period. The internal gains in value of 2.80 W/m² are determined by PHPP software. Infiltration air change rate at pressure difference of 50 Pa prior to renovation is assumed to be 5 h⁻¹. The assumption is based on the analysis of similar buildings (Norris & Shiels, 2004). The natural ventilation with average air change rate (n) of 0.5 h⁻¹ is selected.

4.2. Renovation concept

As the kindergarten usable floor area no longer suffices today's needs, the main functional requirement is to extend the building. Since the scale of horizontal extension of the building is limited, the vertical extension with the upgrade module (Figure 4) is selected and to obtain additional spaces for employees. Another architectural intervention such as addition of new entrance volume on the north and covered terraces on the south are carried out (Figure 4). Moreover, the terraces act as shading elements for the southern facing windows.

Also an important aim of the renovation is related to the energy savings measures resulting from improvement of building envelope (described in 4.2.1). The implementation of the above mentioned measures enable the positive impact on the indoor building climate. Apart from the improvement of structural building elements, the modernization of active technical systems is implemented as well. The old system with heating generator on oil is substituted by the heat pump, while the central heat recovery ventilation system is installed for the ventilation. However, the improvement of interior electrical installation and artificial lighting is not treated in this paper.

4.2.1. Description of implemented measures for complex renovation

Complex renovation includes measures contributing to energy and functional improvements and is divided into ten consecutive renovation phases (RP), described in detail below.

RP 1: Renovation of the thermal envelope components

RP 1.1: Renovation of floor plate

Removal of existing layers: flooring, cement screed, PE foil, thermal insulation (polystyrene) –2 cm;
Replacement with new layers: flooring, cement screed, PE foil, thermal insulation (aerogel) +4 cm.

RP 1.2: Renovation of external walls

Removal of existing layers: corrugated asbestos-cement panels;
Replacement with new layers: gypsum fibre boards, thermal insulation +15 cm, final plaster.

RP 1.3: Renovation of ceiling

Addition of new layers: thermal insulation +12 cm;
Removal of roof and ceiling structure in the area of module upgrade.

RP 2: Replacement of glazing

Removal of existing windows: $g = 77\%$, $U_g = 2.3 \text{ W}/(\text{m}^2\text{K})$, $U_f = 1.6 \text{ W}/(\text{m}^2\text{K})$, $\psi_{\text{spacer}} = 0.04 \text{ W}/(\text{mK})$;
Installation of new windows: $g = 50\%$, $U_g = 0.64 \text{ W}/(\text{m}^2\text{K})$, $U_f = 0.72 \text{ W}/(\text{m}^2\text{K})$, $\psi_{\text{spacer}} = 0.035 \text{ W}/(\text{mK})$.

RP 3: Terrace shading

Installation of timber roof structure over the terraces;
Installation of blinds with support structure made of aluminium profiles.

RP 4: Building extension with lightweight upgrade module
Prefabricated timber-frame macro-panel structural system;

Additional 130 m² of treated floor area and 392 m³ of volume in the 1st floor;

Extension with: walls $U = 0.153 \text{ W}/(\text{m}^2\text{K})$, roof $U = 0.136 \text{ W}/(\text{m}^2\text{K})$, roof windows: $g = 53\%$, $U_g = 0.50 \text{ W}/(\text{m}^2\text{K})$, $U_f = 1.6 \text{ W}/(\text{m}^2\text{K})$, $\psi_{\text{spacer}} = 0.04 \text{ W}/(\text{mK})$, skylights: $g = 77\%$, $U_g = 2.4 \text{ W}/(\text{m}^2\text{K})$, $U_f = 1.6 \text{ W}/(\text{m}^2\text{K})$, $\psi_{\text{spacer}} = 0.04 \text{ W}/(\text{mK})$.

Airtightness is gradually improved through individual renovation measures to the final value of 1.5 h⁻¹, which is fairly under the maximum limit (2 h⁻¹ for energy-efficient buildings with mechanical ventilation) prescribed in the national technical guidelines (Ministry of the Environment and Spatial Planning, 2010).

RP 5: Installation of the heat-recovery ventilation system
Central ventilation unit within the thermal envelope with effective heat recovery efficiency of 84% and average air change rate (n) of 0.5 h^{-1} .

RP 6 to 10: Functional improvement measures

Replacement of roofing and internal doors, new internal walls and entrances, supporting structure for shading terraces, and renovation of heating system.

The renovation measures of floor plate (RP 1.1.) were limited to the thinnest possible insulation in order to preserve the prescribed clear ceiling height of playrooms (Official Gazette of the Republic of Slovenia No. 73, 2010). The measure of adding terraces is divided into energy improvement, including the building of new structure and adding blinds for shading (in RP 3), and into functional improvement, including the renovation of wood pavement. The measure to increase the glazing areas is not carried out because the building already has suitable glazing on the south façade. Table 1 gives a description of technical and geometrical properties of the building. The input data is based on the existing technical drawings and plans and the U -values are calculated according to the assembly of the thermal envelope.

4.3. Results of the complex renovation

In order to follow results easier, they are separated. First, the results of energy efficiency analysis are described in steps. Then, the cost data are added and economic analysis is provided.

4.3.1. Results for energy efficiency

The energy efficiency analysis is made for RPs 1–5. The overall treated floor area of Kindergarten Mojca accounts for 522.46 m^2 . In Table 2 we can see that energy need for heating prior to renovation is $148.9 \text{ kWh}/(\text{m}^2\text{a})$, while energy need for cooling accounts for $9.3 \text{ kWh}/(\text{m}^2\text{a})$. The

U -values (Table 1) of the thermal envelope are calculated on the basis of individual element composition, whereby the long term deterioration of the material's thermal conductivity is not taken into account.

Table 2 presents the state of energy flows and energy demand after the implementation of individual RPs. The values of energy indicators are given on annual basis in two columns, firstly normed per square meter of usable floor area and secondly as an absolute value, and are calculated using Eqn (1).

The results presented in Table 2 show the influence that certain RPs exert on energy demand reduction. The strongest influence on the reduction of transmission losses is achieved by RP1- renovation of the building thermal envelope components ($\Delta Q_t = -54.5 \text{ kWh}/(\text{m}^2\text{a})$). Further observation shows that the renovation of 1 m^2 of external wall causes the reduction of Q_t for 33.07 kWh/a , reduction of Q_t caused by the renovation of 1 m^2 of ceiling is 19.18 kWh , while for 1 m^2 of floor plate the Q_t saving accounts only 13.28 kWh/a . On the other hand, the influence of the building extension with lightweight upgrade module (RP 4) on transmission losses is lower, which is rather expected due to an overall increase of thermal envelope surfaces, even though the roof of existing building is not covered in total by the upgrade module. Ventilation losses (Q_v) mostly depend on the system of the air exchange (RP 5), but there is also an important decrease evident by RP 1 and glazing replacement (RP 2) due to the improved air-tightness. The internal gains (Q_i) remain constant throughout all renovation phases. The solar gains (Q_s) are almost constant for all considered RP 1 phases, whilst a higher decrease is caused by RP 2 on account of lower g -value of newly installed 3-pane windows. The installation of the timber-glass upgrade module (RP 4) with glazing designed predominately on the south façade significantly increases the solar gains ($\Delta Q_s = +3.80 \text{ kWh}/(\text{m}^2\text{a})$) and has a positive impact on total energy demand in the building.

Table 1. Technical and geometrical properties of the Kindergarten Mojca

Building	Before renovation		After renovation	
	A_{net} [m^2]	Average U -value [$\text{W}/(\text{m}^2\text{K})$]	A_{net} [m^2]	Average U -value [$\text{W}/(\text{m}^2\text{K})$]
treated floor area	522.46		652.46	
north façade windows	30.81	2.30 / 1.60*	28.30	0.64 / 0.72*
east façade windows	2.07	2.30 / 1.60*	2.07	0.64 / 0.72*
south façade windows	66.15	2.30 / 1.60*	66.15	0.64 / 0.72*
west façade windows	3.36	2.30 / 1.60*	5.31	0.64 / 0.72*
horizontal windows	0.00	/	29.54	0.64 / 0.72*
exterior door	16.83	1.07	16.83	1.07
exterior wall	296.8	0.59	296.80	0.17
exterior wall of new module	/	/	90.00	0.15
ceiling	575.9	0.42	570.00	0.17
floor slab	575.9	0.18	575.90	0.28
total thermal envelope	1567.82		1681.00	

Note: * U_{glass} / U_{frame}

Table 2. Energy demand indicators on annual basis by individual renovation phases (RP)

Measures	Heating period						Cooling period				
	Q_t [kWh/ (m ² a)]	Q_v [kWh/ (m ² a)]	Q_s [kWh/ (m ² a)]	Q_i [kWh/ (m ² a)]	Q_h [kWh/ (m ² a)]	Q_c [kWh/ (m ² a)]					
Existing building	128.7	54.8	28606	22.1	11534	12.5	6553	148.9	77774	9.3	4840
RP 1: Renovation of thermal envelope components											
RP 1.1 Renovation of ground floor plate	114.1	51.4	26867	22.1	11534	12.5	6553	130.9	68389	8.6	4508
RP 1.2 Renovation of external walls	95.3	45.8	23910	20.1	10504	12.5	6553	108.4	56651	7.6	3958
RP 1.3 Renovation of ceiling	74.2	41.8	21822	20.1	10504	12.5	6553	83.3	43532	6.5	3370
RP 2. Replacement of glazing*	52.3	27337	20693	13.1	6821	12.5	6553	66.4	34672	4.9	2542
RP 3. Terrace shading	52.3	27337	20693	13.1	6821	12.5	6553	66.4	34672	2.1	1108
RP 4. Building extension with lightweight module	47.7	31095	26105	16.9	11003	12.5	8184	58.3	38067	2.7	1776
RP 5. Installation of heat-recovery ventilation system	47.7	31095	11784	16.9	11003	12.5	8184	36.6	23884	2.3	1518

Note: *windows and exterior doors, including the frame.

The analyzed energy flows' behaviour correlates to the reduction of energy demand for heating (Q_h). Comparison of phases shows relatively great reduction of Q_h caused by the renovation measures on external envelope, by replacement of glazing, and with the installation of a heat recovery ventilation system. The influence of the upgrade module installation (RP 4) on Q_h decrease is slightly smaller. However, this particular RP helps to obtain the additional necessary usable floor area resulting in an essentially increased financial value of such renovated building.

In fact, the summer period in Maribor is relatively warm and the approximate number of solar hours is high, therefore, the energy need for cooling (Q_c) should be taken into account as well as the control of the overheating risk. The results for Q_c listed in Table 2 show an important influence of energy decrease for cooling caused by all the considered renovation phases and the values with the highest contribution of terrace shading.

Finally, taking into consideration the sum of heating and cooling energy needs as the total annual energy need ($Q_h + Q_c$) is important for the buildings located in the moderate climate with cold winters and warm summers.

4.3.2. Results for economic efficiency

Economic analysis is carried out for all RP of complex renovation. The present average heat price is 106 €/MWh. Investment costs for the renovation works are set on the prices obtained from the companies in the Slovenian market and include VAT. In addition, different lifespans (in years) are applied for individual building element summarized from Rules (Official Gazette of the Republic of Slovenia No. 20, 2004), representing the basis for the calculation of the coefficient κ .

Calculation of the *CCE* indicator is performed using $r = 4\%$. However, the problem of accurate prediction of growth rate and expected time of evaluation remains when this value should be determined. The factor namely considers the return on investment in the lifespan of the building, which can differ from the expected profitability, increasing the investment risk and consequently changing the value of r .

According to two-factor evaluation method, all RPs are divided in two groups I_{TEE} and I_{TFAF} (see Table 3). Measures related to I_{TEE} are considered in RPs 1–3 and RP 5. First two phases are related to I_T elements (divided in I_{TE} and I_{TF}) and include the total cost for all new added layers, while RP 3 refers to measure of cooling, and the value represents costs for energy savings because the element is new. Next, RP 5 represents homogeneous energy savings measure I_E . Further, measures related to I_{TFAF} are considered partly in RP 1 and RP as I_{TF} , in RP 4 as homogeneous measure of building extension I_A , and in RPs 6–10 as investments related to measures of functional improvements I_F . Table 3 presents the main results of economic analysis. Eqn (3) is used for the total amount of the investment. The indicator *CCE* is given for homogenous energy saving measures I_E (Eqn (2)) and for I_{TE} the modified indicator CCE_T is employed by using Eqn (4). For measures which

do not affect the energy efficiency the calculations of indicators are not applicable (N/a).

Total amount of investment (ΣI_{TAEF}) is 1002.11 €/m² (Eqn (3)), where almost 45% accounts for energy renovation measures (I_T and I_E), which is comparable to the costs of complex energy renovations of kindergartens (City municipality Maribor, 2018). Furthermore, demolition works constitute 4.5% of all costs.

a) Economic indicators for energy saving measures

Economic indicators for energy saving measures in Table 3 are given separately and also joined together. Considering measures separately, without regarding two-fold benefits, the economic indicators are unfavorable for almost all measures, because costs of demolition of the existing layers and the implementation of finishing layers are included. In that, a RP 1.1 and RP 5 are significantly cost ineffective, and together represent of 28.1%.

After grouping of investments together, i.e. components of two-fold measures (I_{TE}) and a homogenous energy saving measures (I_E), the results show that investment is sensible. Total investment in energy saving measures (I_{TEE}) is equal to 199.7 €/m², and economic indicators are favorable, namely *CCE* (Eqn (4)) is 96.9 €/MWh, and lower than the current heating price, and the *SPP* is 17.8 years. The main reason is in very high deterioration level of the most building elements and the larger share of costs is intended for the rehabilitation of the element's conditions (reflected in the coefficient κ). For example, investment in renovating of ceiling (RP 1.3) is equal to zero because it must be completely renewed for its further functioning. Consequently, complete refurbishment is economical for a typical timber preschool building, whereas step-by-step renovation is not.

b) Economic indicators for functional improvement measure

The increase of the purchase value of fixed assets model is used for evaluating functional improvement measures. The present value of the building is € 281722 (539.22 €/m²) (Ministry of the Environment and Spatial Planning, 2018). With reference to measure of I_A (RP 4), I_F (RPs 6–10) and I_{TF} (RPs 1–3), the increased value of the building is in total € 758567 and 1162.63 €/m², respectively. Compared to the actual value of pre-school buildings, which were completely renovated, our values are corresponding, because the value of these buildings account from 1020 €/m² to 1560 €/m² (Ministry of the Environment and Spatial Planning, 2018; City Municipality Maribor, 2018).

4.4. Discussion

Energy renovation of a building shows that step-by-step refurbishment can result in energy savings; however, they are higher if they are joined together into a complex process. All steps of renovation should be carried out successively; still they are not necessary economically justified. In the case study for Kindergarten Mojca, the measure RP 1.3 proved to be the most energy and economically efficient. Even though the ceiling is the most critical

Table 3. Economic indicators by individual renovation phases (RP)

Measures	κ	Investments			Energy saving ($Q_h + Q_c$)		Economical indicators		
		For total building [€]	For unit of heated area [$\text{€}/\text{m}^2$]	For energy savings [€]	Savings per unit [$\text{kWh}/(\text{m}^2\text{a})$]	Annual savings [MWh]	CCE [$\text{€}/\text{MWh}$]	CCE_T [$\text{€}/\text{MWh}$]	SPP [years]
RP 1: Renovation of thermal envelope components									
RP 1.1 Renovation of ground floor plate	0.700	113140	216.6	33942	18.7	9.72	542.0	84.5	109.8
RP 1.2 Renovation of external walls	0.875	34380	65.8	4298	23.5	12.29	141.4	17.7	26.4
RP 1.3 Renovation of ceiling	1	14530	27.8	-	26.2	13.71	56.8	0.0	10.0
RP 2. Replacement of glazing	0.700	44119	84.4	13236	18.5	9.69	212.0	63.6	43.0
RP 3. Terrace shading	1.400	8553	16.4	8553	2.8	1.43	381.8	381.8	56.3
Total measure for energy renovation of envelope (I_T)		214721	411.0	60028	89.7	46.83	231.6	64.8	43.3
RP 4. Building extension with lightweight module	0.583	152571	233.8	-	7.5	-4.06	N/a		
Total measure of adding upgrade module (I_A)		152571	233.8		7.5	-4.06	N/a		
RP 5. Installation of heat-recovery ventilation system	1.750	55313	84.8	55313	22.1	14.44	281.8	281.8	36.1
Total new active technical systems (I_E)		55313	84.8	55313	22.1	14.44	281.8	281.8	36.1
RP 6. Replacement of roofing	0.875	28416	43.6	-	-	-	N/a		
RP 7. Implementation of internal walls and entrances	1	14967	22.9	-	-	-	N/a		
RP 8. Replacement of internal doors	0.857	32763	50.2	-	-	-	N/a		
RP 9. Construction of terraces	1	23859	36.6	-	-	-	N/a		
RP 10. Renovation of heating system	1	77808	119.3	-	-	-	N/a		
Total functional measures (I_F)		177813	272.5				N/a		
Total package of measures (ΣI_{TAEF})		600418	1002.1	115341	119.3	57.21	540.0	96.9	99.0
After division of investments									
Two-fold energy saving measures (I_{TE})		60028	114.9	60028	89.7	46.84	64.8		12.1
Two-fold functional measures (I_{TF})		154693	296.1	-	-	-	N/a		
Homogenous energy efficiency measures (I_E)		55313	84.8	55313	22.1	14.44	281.8		36.1
Adding upgrade module (I_A)		152571	233.8	-	7.5	-4.06	N/a		
Homogenous functional improvements and renovation measures (I_F)		177813	272.5	-	-	-	N/a		
After grouping of investments									
Total energy saving measures (I_{TEE})		115341	199.7	115341	111.8	61.28	96.9		17.8
Total adding volume and functional measures (I_{TFAP})		485077	802.4	-	7.5	-4.06	N/a		

element regarding energy losses, it presents the easiest renovation measure and the price of insulation is relatively low. The least energy efficient measure is RP 3 that contributes only to the overheating in the summer time. Despite the poor energy and cost efficiency results, this measure significantly contributes to the improvement of building functionality.

The indicated low level of economical inefficiency of the RP 1.1 and RP 5 measures resulted in an additional study. RP 1.1 is a very ineffective measure due to high investment costs including demolition of existing pavements, installation of thermal insulation, screed and floor finish. The highest share of investment costs includes installation of the thermal insulation, which is 150 €/m² (aerogel, 4 cm), and which choice comes from the limitation of the clear ceiling height of playrooms, because the existing height is already on the permitted limit. In order to rationalize the measure, we suggest cheaper insulation, e.g. EPS ($\lambda = 0.034 \text{ W}/(\text{mK})$), 10 cm thick, which costs account for 15 €/m² only. The indicator CCE would be 179.80 €/MWh and CCE_T 28.03 €/MWh only. Therefore, the study results show that meeting all of the provisions of the regulation can lead to significant cost increase.

Furthermore, our second suggestion refers to the measure RP5 as central heat-recovery ventilation system that fulfils the requirements for high ventilation rates in playrooms, but results in high costs, especially due to the distribution of new ventilation elements. The rationalization could be achieved by local heat-recovery ventilation units, and this solution would cost only € 18000, lowering the value of CCE measure RP 5 to 91.70 €/MWh. In our opinion, both suggestions do not impact the living quality but enable the investor to carry out the refurbishment in the rational scope of costs.

The overall results of the current study could be compared to study of Martinaitis et al. (2004), which describes the preschool building renovation and study of Martinaitis et al. (2007), dealing with the renovation of multifamily building. The values of the indicator CCE are comparable for individual measures of renovation and for the total energy saving measure I_{TEE} . The results for the school buildings renovation can be compared with the study of Stocker et al. (2015), where the measure effects are given by the cost/benefit parameter in €/kWh year. The results for investment return are similar to the measures for cluster C.1 of renovation of the envelope thermal insulation and replacement of glazing. The latter is less favorable and depends largely on percentage of glass surface and use of innovative materials. Comparison with other studies is not beneficial, because they are focused in particular on different building types, structural systems, and economic indicators. However, it is possible to make some comparison on a general level of energy savings. Research by Congedo et al. (2016) shows that the cost-optimal solution reduces primary energy consumption by 85%, while in our case 76% was achieved, however, our target level is not nZEBs. Stocker et al. (2015) find out that the building age and

compactness have a high effect on the result on cost effectiveness; our case study also includes the importance of the building's age through the coefficient (κ). In addition, the authors Niemelä et al. (2016) and Arumägi and Kalamees (2015) come to the similar conclusions as we, namely, the additional thermal insulation of external walls or deep energy renovation of the building's envelope alone without utilizing renewable energy production systems and considering the building service systems do not increase the cost-effectiveness. Importantly, the study by Arumägi and Kalamees (2015) refers to timber apartment buildings.

Conclusions

Refurbishment of the ageing building stock is tremendously important when following the principles of sustainable building and lowering energy demand in building operation. Moreover, the renovation of the existing educational buildings is one of the most current issue concerning public buildings across Europe. Educational buildings not only present an enormous potential for energy saving, but they also need modernization in terms of functionality, aesthetics and economic efficiency. Although the tools and methods to evaluate those advantages are already well-known, the renovations are not dealt with systematically and separately according to individual measures.

The presented integrated approach aims to provide step-by-step assessment of complex refurbishment projects of preschool buildings. The feasibility is established both for each step and for total package of measures, employing energy indicators and economic analysis. The benefits of the energy saving measures are explained with the economic indicators, by using the two-factor method, which takes into consideration the age of the building while standard model for determining the increased value of assets is used for investments in building renovation.

The suggested approach was implemented in the case study of the Kindergarten Mojca, presenting the typical preschool building in Slovenia. The refurbishment strategy improved the energy need for heating and cooling up to 76%. An economical study proves the inefficiency of almost all measures if they are considered separately, but by grouping them, indicators of total energy saving measures are favorable. Moreover, the analysis results show that the level of reasonableness of the investment depends largely on the level of the desired energy renovation. In conclusion, not only the energy efficiency of the renovation is higher if it is complex, but also the economical viewpoint confirms feasibility of the renovation only in the case when it is not performed partially.

The suggested approach can be implemented in other preschool buildings in Slovenia and other countries with similarly typology of light timber buildings. Moreover, the systematic approach can serve as the basis for investors' decision making when choosing the concept of complex renovation strategy, based on integration of energy savings and economic efficiency according to individual steps and as total value.

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Author contributions

Ideally, people who contributed to the work are listed in this section along with their contributions: Nataša Šuman, Maja Žigart, Miroslav Premrov and Vesna Žegarar Leskovicar conceived the study and were responsible for the development of the data analysis. Nataša Šuman and Maja Žigart were responsible for design, data collection and data analysis. Nataša Šuman, Miroslav Premrov and Vesna Žegarar Leskovicar were responsible for data interpretation.

Disclosure statement

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