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Section: Sustainable Urban Development

Selection of Retrofit Measures for Historic Buildings

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Abstract

Historic building refurbishment market is expanding and it creates a demand for suitable materials, retrofitting techniques and research for this type of buildings. The differences between refurbishment of new buildings and buildings with historical value are insufficiently recognized today and there is a lack of research on specifics of historic buildings, when due to the valuable building outlook, authentic constructions or traditional materials only some of the retrofit techniques are allowed. In this article the possible retrofit measures are studied and compared. The scientific method for the refurbishment of historic buildings is described. The method is applied in case study of Panemunė castle, which after renovation will be used as a public building, and Raudonė castle, which is used as a school.
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Keywords: historic buildings; retrofit; energy performance.

1. Addressing the Problem

The policy in modern globalizing world is inclined towards preservation of cultural values, regional differences and unique local character. The buildings, being the mirror and historic imprint of culture and lifestyle, are playing the most significant role in achievement of these goals.

In European countries the historic buildings take essential part of total building stock. According to changes in construction market it can be predicted that today's homes will comprise around 80% of the 2050 housing stock. A significant part of these buildings have unique outlook which has to be preserved, but such buildings were often built at a time when energy consumption was not as important as today due to the relatively low energy prices and traditional construction methods.

Buildings are also a crucial sector for controlling energy demand because currently buildings account for around 30% of the total energy use in the world [1, 2, 3]. The buildings as energy consummators are important also because they will consume future energy. Thus, failing to retrofit old buildings to improve their energy and environmental performances may endanger Greenhouse Gas (GHG) mitigation [4]. Figure 1 shows the part of energy consumed in buildings with low energy efficiency.

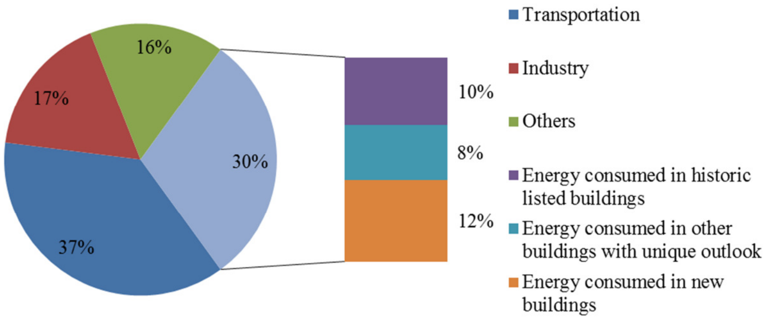

Fig. 1. Energy use and part of energy consumed in historic listed buildings and buildings with unique outlook in Europe [2, 3]

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The current policy attempts to concentrate on creating the building energy performance certification system which will be applied not only to the new, but to all existing buildings, including the ones with historic value. It is clear that the improvement of building energy performance and certification can act as a catalyst for behavior change of all building users [5, 6]. However the historic buildings usually have limited retrofitting possibilities, because only some measures can be taken without destroying the outlook of the building or damaging traditional building constructions. The actual energy performance of such a buildings usually can be shifted by two-three energy efficiency labels only (e.g. from class F to class C or D). The energy performance standards for historic buildings in most European countries are not applied at the moment, but the current trends in policy show that this can change in near future.

Energy efficiency and architectural heritage of brick buildings are two controversial topics [7]. It is important to address these two issues in such a way that obtained result can meet today's requirements of energy efficiency and, at the same time, promote the preservation of historic buildings for future generations [8].

In this research we aim at restoring building that it be ***energy efficient***. According to [26] ***energy efficient buildings*** (new constructions or renovated existing buildings) can be defined as buildings that are designed to provide a significant reduction of the energy need for heating and cooling, independently of the energy and of the equipments that will be chosen to heat or cool the building.

The aim of this paper is to present the methods and the results of restoration of *Raudone Castle*, which is situated in Raudone, Lithuania, and *Panemune Castle*, which is situated on the right bank of the Nemunas river, in Vytėnai, Jurbarkas district, Lithuania, and analyse their satisfaction to be an energy efficient building.

The last part of the paper is structured as follows. Section 2 presents related works on historic building refurbishment. Section 3 describes historic building refurbishment specifics. Section 4 presents the most energy effective retrofit measures for historic buildings. Section 5 presents the restoration method used for Raudone Castle and Panemune Castle. Section 6 describes results obtained in measuring energy efficiency in Raudone Castle and Panemune Castle. And Section 7 concludes the paper.

2. Studies on Historic Building Refurbishment

In the last decade many authors gave an attempt to create usable computer software for decision support in the process of building retrofits. Currently developed simulation and visualization methods and measurement technologies can assist developers and energy managers at different stages of their activity and have the potential to achieve energy savings on a large scale [8–10]. One of the most elaborate attempts is the TOBUS software. This software includes several modules: building description, dimensions, cost coefficients, building diagnosis of the current physical state and functional obsolescence, indoor environmental quality (IEQ), energy use, elaboration of retrofit scenarios, cost analysis, reporting results. The software also includes comprehensive databases on the physical state of degradation, including hundreds of illustrations, refurbishment work details, cost, etc.

Scientists from the UK have developed a building rating system which is designed to assess the sustainability merits of existing home retrofits and to indicate the success of a range of retrofit measures. The authors recommend creating and adopting a purpose-designed building rating system, with escalating mandatory performance levels in energy efficiency, which would help to drive improvement in existing homes. This building rating system would be used to rate existing homes, galvanize stakeholders around a common framework and provide long-term visibility to the marketplace.

Among other modern methods and techniques for finding the most effective retrofit measures in modern buildings it is worthy to mention the EnergyPlus program [11], a multi-objective optimization model to assist stakeholders in the definition of intervention measures aimed at minimizing the energy use in the building in a cost effective manner, while satisfying the occupant needs and requirements [12], the scalable methodology based on Bayesian calibration of calibrated normative models which can correctly evaluate energy retrofit options [10], the framework for handling the uncertainties associated with the prediction of energy savings in the retrofit analysis of a housing stock [13] and others [14–20].

There are number of studies related to decision support when considering between different refurbishment materials but these studies are usually not related to the specific problems of retrofitting the historic buildings. The retrofit measures which can be applied in historic buildings are much more limited due to preservation of valuable properties of the buildings. There is a lack of understanding of historic building energy performance in industry and in policy, and a lack of connection between good research, standards, certification processes, guidance and practice. There is significant uncertainty with regard to the application of models and performance simulation software for this class of buildings. Some methods for assessing traditional buildings are inappropriate and give incorrect results, and some are misapplied and thus give false confidence in some measures. Traditional buildings require different assessment and practice with regard to the control of moisture in buildings, which is vital for fabric and human health.

3. Historic Building Refurbishment Specifics

Energy efficiency can be greatly improved without touching the building construction – through optimization of the performance of the building envelope and intelligent operation and management of HVAC (Heating, Ventilation and Air Conditioning) system [21–23], changing the doors and windows, improving building air tightness, etc. High energy performance buildings feature airtight building envelopes with high levels of thermal resistance and have control over the flows of heat, air, and moisture into and out of the building. Historic buildings built before current building codes in most cases have high levels of air leakage and inadequate insulation. Both issues increase heating and cooling losses and demands on heating, ventilation, and air-conditioning systems and decrease occupant comfort and indoor air quality. Houses built before 1980 often have little or no wall insulation. Given that walls can represent most of the building envelope area, ensuring that walls have proper levels of insulation is an essential part of any historic building energy retrofit [24]. Post-insulation of outer walls is the most challenging and most energy effective measure for historic building. The retrofit of interior insulation is commonly implemented to improve energy performance of these buildings, while maintaining their often historic exterior appearance [25].

Historic buildings usually have listed valuable properties which must be preserved when refurbishing the building. The building facades are the most common thing that has cultural value and therefore very often when refurbishing historical building there is only one option to achieve better heat transfer coefficient – to insulate from the inside.

Insulation from the inside is quite a problematic issue itself. There are many risks and disadvantages while doing this kind of refurbishment including:

- The risk of the outer walls becoming too cold and not being able to evaporate accumulated moisture.
- Risk of closing the pores of wall material (bricks, etc.) and preventing moisture from coming out.
- Moist walls in few freezing cycles can become damaged, especially ceramic brick walls.
- Disadvantage of losing inner space when adding the layer of insulation and covering the insulation with some appropriate finish material.
- The disadvantage of not seeing the original materials from the inside.
- Complexity of the installation.

However this is the only method which highly increases the energy efficiency of the building. This refurbishment method is allowed in many cases when refurbishing historic buildings. There are some commercial products developed with special application technologies and the price and complexity of work shows how much effort is needed to overcome the moisture problem in the walls, especially in colder climate countries.

Modern materials usually help to eliminate the problem of losing much space, but these materials have to be examined in practice to see how they work concerning moisture regime.

4. The Most Energy Effective Retrofit Measures for Historic Buildings

In refurbishment process of historic buildings the compromise between payback period, level of comfort, and preservation of historic authenticity of the building must be found.

The energy consumption for heating and cooling the inside takes around 45% of the energy consumed in buildings. Other great energy loses happen in heating the water, lights and electronics.

Energy efficiency can be greatly improved without touching the building construction – through optimization of the performance of the building envelope and intelligent operation and management of HVAC (Heating, Ventilation and Air Conditioning) system [21–23], changing the doors and windows, improving building air tightness, etc.

International experts from project "Co$_2$olBricks", which was partially financed by EU and took part in period of 2010–2013 have created the list of the most effective measures in energetic refurbishment of historic brick buildings, to which authors of this article have added the additional criteria on cost and complexity of installation (Table 1).

Table 1. The most effective measures for energetic refurbishment of historic brick buildings

Energy saving measure	Number	Possible energy Savings, % from total energy use in building	Cost of installation (5-high, 3-medium, 1-low)	Complexity of installation (5-high, 3-medium, 1-low)
Improving heat production/boiler	1	17	4	2
Heat pumps	2	15	3	3
Post-insulation of roof and sloped ceilings	3	15	4	
Post-insulation of exterior wall (from inside)	4	14	5	5
New windows or energy efficient secondary glazing on windows, shading the windows	5	11	2	1
Increasing building airtightness	6	8	1	1
Regulated ventilation system	7	Increase of comfort, installed together with increased airtightness	4	4
Energy effective modern lighting system	8	7	1	1
Post-insulation of cellar ceiling, cellar walls	9	3	4	4
Home automation and smart applications	10	2	3	2
Infrared heating	11	up to 30 in spaces of great volume (churches, etc.)	4	3

The most effective energy effectiveness measures for historic buildings can be grouped in three categories:

1. Improving energy use for heating devices:

- Improving heat production/boiler – most historic buildings have old heating production infrastructure and boilers. Installing modern heating system can increase heat production effectiveness and decrease energy consumption for heating by 40%.
- Installing heat pumps – in historic buildings heat pump is widely used to save energy for heating; it uses environment heat for heating and water heating, providing a stable, well-adjustable and automatically controllable heating system that works all year round. It can save up to 30% of heating energy, or up to 10% of overall energy use in historic building.
- Infrared heating – radiant heating can be used in huge spaces, where great energy savings can be achieved because of local heat spot.

2. Increasing energy effectiveness of building envelope:

- Post-insulation of roof and sloped ceilings – up to 42% of heat is being transferred throw the roof of the building, therefore roof post-insulation is essential step in increasing energy effectiveness of existing building.
- Inside post-insulation of exterior wall – houses built before 1980 often have little or no wall insulation. Given that walls can represent most of the building envelope area, ensuring that walls have proper levels of insulation is an essential part of any historic building energy retrofit. Post-insulation of outer walls is the most challenging energy effective measure for historic building. The retrofit of interior insulation is commonly implemented to improve energy performance of these buildings, while maintaining their historic exterior appearance. When insulating walls from inside it is important to understand how this will affect the existing wall.
- Post-insulation of cellar ceiling, cellar walls – the temperature difference between indoor and the first or basement floor is considerably lower than the temperature differences in external walls of buildings. Studies have shown that floor insulation provides a very small part of the total heat gains in comparison with roof and exterior wall insulation. However, if floor modification or reconstruction is planned the opportunity to improve the efficiency of it should be used.
- New windows or secondary glazing on windows, shading the windows – windows are often rated as the cultural and historical heritage, and complete their replacement with modern, energy-efficient windows is not possible, but the use of individual methods or their combinations is possible in agreement with the competent authorities: window sealing; installation of secondary glazing; replacement of old glass with the glass of low iron content and a low degree of blackness, leaving the old frames; installation of light reflection system between the glazing; shutters, curtain installation (night-time option); complete replacement of the window with the highest possible energy efficiency class; replacement of window boxes; solar screening.
- Increasing building airtightness and installing regulated ventilation system – air tightness is the fundamental building property that impacts infiltration. Due to poor air tightness in historic buildings heat loss increases up to 40%. various studies have shown that in the case of historic buildings, the main energy saving potential lies in the air-tightness of the building. However, reducing the fresh air inflow leads to the necessity of ensuring a comfortable indoor climate for the users of a building and for the preservation of the building. In order to ensure the comfortable indoor climate, the recommended air change per hour (ACH) should be 0.5 l/h.

3. Other technical measures:

- Heat recovery systems – the thermal efficiency of systems with heat recovery is between 50…90% and annual efficiency between 60…95%.
- Energy effective modern lighting system – lights use around 11% of energy in historic building and it can be greatly reduced by using modern light bulbs and LED. LED light bulbs last up to 10 times as long as compact fluorescents, and far longer than incandesced light bulbs.
- Central control of electrical components – electronic devices consume around 7% and lighting up to 11% of energy used in houses and it can be greatly reduced by automation systems.

5. A Method of Refurbisment Raudonė and Panemunė Castles

In this section we present a method of refurbishment of Raudonė and Panemunė Castles.

5.1. Raudonė Castle and Panemunė Castle

Raudonė Castle[1] is in Raudonė, Lithuania. Castle construction works started in late 16th century. A new renaissance castle was built on the ruins of the old one by the German knight, Hieronymus Krispin-Kirschenstein. Since then, the castle has been rebuilt many times. The 18th century Polish owners of the Raudonė estate commissioned a renovation of the castle. The next owner, the Russian Prince Platon Zubov, acquired the estate in the first half of the 19th century and his family transformed the castle yet again. Their architect was Cesare Anichini. Today the building is an example of 19th

[1] https://en.wikipedia.org/wiki/Raudon%C4%97_Castle

century neo-gothic architecture. Its' last private owners were Sophia Waxell (a Zubov) and her Portuguese husband from Madeira, José Carlos de Faria e Castro. Now the building is used as Jurbarko r. Raudonės main school (see Fig. 2).

Fig. 2. Jurbarko r. Raudonės main school

Panemunė castle[2] was built as his luxurious residence in 1610. Since the then until 1925 the castle was a private property. Owners of the castle changed many times as well as its appearance was reconstructed according to wishes and tastes of its` new owners. 1995 – 1997 the castle was partially reconstructed.

Nowadays, 2 corpuses of Panemunė castle has remained – the western with 2 towers, and the southern. It belongs to Vilnius Art Academy which takes care about the restoration (2009–2012) of the castle and fitting it to science, education and tourism purposes. Panemunė castle before (Fig. 3a) and after (Fig. 3b) refurbishment is presented as follows.

(a) (b)

Fig. 3. Panemunė castle (a) before and (b) after refurbishment

5.2. Method of restoration Raudonė and Panemunė castles

In this section we present method of refurbishment of two castles. The preparation and documentation phases were performed according to Lithuanian laws. Here we present only the process of restoring Raudonė and Panemunė castles below. It is:

1. *Plan of refurbishment* is designed.
2. *Preparation works* are performed according to the plan. They include temporary protection of historic resources, like parts of walls, mosaic, etc.
3. *Ensuring safety of works* according to Lithuanian law of workers safety and health [28].
4. *Perform refurbishment of a roof:*
   a. Dismantled the old bearing structures, like beams and rafters.
   b. Restored bearing structures, like beams and rafters.
   c. Insulation of roof.

[2] http://www.way2lithuania.com/en/travel-lithuania/panemune-castle

   d. Mounted roof.
5. *Perform external refurbishment*:
   a. Dismantled the old bearing structures, like walls.
   b. Changed windows and doors.
   c. Insulation of walls.
   d. Performed finishing of external walls.
6. *Perform internal refurbishment*:
   a. Dismantled the old bearing structures, like floor, beams, and rafters.
   b. Restored bearing structures, like floor, beams, and rafters.
   c. Mounted engineering systems (electricity, plumbing, ventilation).
   d. Restored frescoes.
   e. Performed finishing of internal walls, ceiling and floor.

Figure 4a and Figure 4b present the inside refurbishment of Panemunė castle.

(a)

(b)

Fig. 4. Inside Panemunė castle (a) before and (b) after refurbishment

6. Measuring energy efficiency of the castles before and after restoration

In this section we present measurements of energy efficiency of two castles before and after restoration.

Table 2 presents *energy consumption for heating* and *energy efficiency class of a building*. *Energy consumption for heating* and *Energy efficiency class of a building* were calculated according to the Lithuanian Construction Technical Regulation [27] using software NRG2[3]. 1st case presents energy consumption for heating of the castles before restoration. 2nd case – energy consumption for heating of the castles after restoration, when windows, roof and the floor of the first floor were restored and an electric heating equipped. And 3rd case – energy consumption for heating of the castles after restoration, when windows, roof and the floor of the first floor were restored and a geothermal heating equipped.

Table 2. Energy consumption for heating of two castles

Alternatives	Energy consumption for the heating, *Q*	Energy efficiency class of a building	Area of a building	Repairs Cost	Possible energy Savings	Cost of installation	Complexity of installation
Units	kWh/(m^2*year)		m^2	million Lt	% from total energy use in building	(5-high, 3-medium, 1-low)	(5-high, 3-medium, 1-low)
Panemunė castle							
1 case	396	E		0	0	1	1
2 case	207	D	1070,90	7.1	48	3	2
3 case	141	C		8.9	64	4	4
Panemunė castle							
1 case	389	E		0	0	1	1
2 case	195	D	2768.31	14.9	50	3	2
3 case	115	C		17.3	70	4	4

3 http://www.spsc.lt/nrg/cms/index.php?option=com_content&task=view&id=23&Itemid=1

As can be seen from the results presented in Table 2 and Figure 5, in the third case energy consumption for the heating is the least. According to the refurbishment complexity the most complex case is the third case. It equals to the fourth level of difficulty according to Table 1. In Table 2 possible energy savings are calculated according to Table 1 and the Lithuanian Construction Technical Regulation [27]. As can be seen, in the third case almost 70% of energy can be saved.

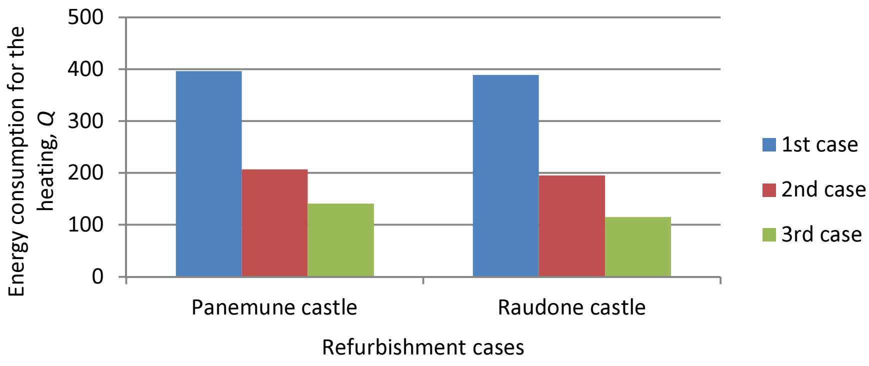

Fig. 5. Energy consumption for heating of two castles

7. Conclusions and suggestions

The analysis of the related works on refurbishment of historic buildings shows that it is not a trivial problem, it requires significant efforts and studies. There is not enough research in this area.

According to the performed research authors of this paper present method of refurbishment of historic buildings, which is based on the refurbishment of roof and internal and external envelope of the building, preserving authentic parts of the building. The emphasis was placed on energy saving also.

In the paper we propose 3 cases for the refurbishment of Panemunė and Raudonė castles. For each case of refurbishment energy consumption for the heating, energy efficiency class of a building, repairs costs, possible energy saving, and complexity of installations were calculated and it was determined that the third case of refurbishment allows to save almost 70 % of energy; however, it is the most expensive.

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