

PAPER • OPEN ACCESS

Comparative analysis of an existing public building made from natural building materials and reference buildings designed from common building materials

To cite this article: P Medgyasszay 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **323** 012140

View the [article online](#) for updates and enhancements.

Comparative analysis of an existing public building made from natural building materials and reference buildings designed from common building materials

Medgyasszay P

Department of Construction Materials and Technologies, Budapest University of Technology and Economics, Hungary

medgyasszay.peter@epito.bme.hu

Abstract. The paper examines a public building constructed of partially natural materials and two imagined buildings with the same geometry, using LCC and LCA methods, with self-developed software. The imagined buildings were designed using the building materials and building mechanical systems commonly used in Hungary which fulfil the relevant energetic requirements in 2010 and in 2019. As a sensitivity analysis the LCA performance of buildings was examined with residential building function. The paper introduces the environmental benefits that can be obtained with natural materials and with other tools in case of the examined building. Based on the results, design strategies can be phrase for environmentally conscious design of buildings with similar scale and function.

1. Introduction

The building industry, despite of the noteworthy increase of environment-conscious attitude, has a significant role and responsibility to handle the challenge of climate change, as one of the most important present problem of humanity. The buildings and construction are still responsible for the 36% of global final energy use and 39% of energy-related carbon dioxide emissions. According to the forecasts by 2060 230 billion m² new building floor areas will be constructed. This floor area is equivalent to the field area that in the next 40 years every single week the territory of city Paris would be rebuilt. [1]

To reduce the building industry-related energy consumption has several possibilities and strategies. Based on the publication of Global Alliance for Buildings and Constructions for 2050 the aims "*Achieving a large diffusion of net zero energy buildings*" and "*Reducing embodied energy and GHSG emissions*" have significant priority in the next 10 years. [2] The combination of these two aspects is also important because more and more building materials have to be produced in order to achieve better insulation. By using life-cycle approach analysis, like Life Cycle Assessment (LCA) with environmental focus or the Life Cycle Cost Analysis (LCC) with economic focus, we can find the optimum of the two, sometimes conflicting goals. Our previous research confirmed that natural building materials can achieve a low value in both embodied and operational energy need, because of their low primer energy content. [3] [4]

In the paper, a realized and two imaginary public buildings will be analysed with LCA and LCC methods. The imaginary buildings are the same as the realized building, but their material use and building service systems are representative for the age of the design and the present days. As a



sensitivity analysis, beside the public building function the calculations were carried out also for a residential building function. The goal of this paper is to highlight the magnitude of environmental benefits that can be gained through natural materials and other measures.

2. Methodology

2.1. Case study building: realized building.

The constructed case study building was designed in 2010 by the Belső Udvar Architect and Expert Office by Péter Medgyasszay, Ágnes Novák and Péter Büki architects. [5] The whole project was introduced in details in previous publications. [6] [7] In the following, only the examined two-building complex Demonstration Centre will be described, where a small restaurant and kitchen on one side, the reception, auditorium and other functions on the other side are located. The two buildings form an inner yard, surround an artificial lake (figure 1). One end of each building is lower by 80 cm than the other. This arrangement of curved walls results in a sense of fake perspective in the enclosed space of the two buildings. Each building is in the scale of a Hungarian country-house (approx. 8,5x28 m), but because of the non-conventional wall shape and the large roofs, the two-building complex has a unique view (figure 2 and figure 3).



Figure 1. Ground floor layout of the Demonstration Building [5]

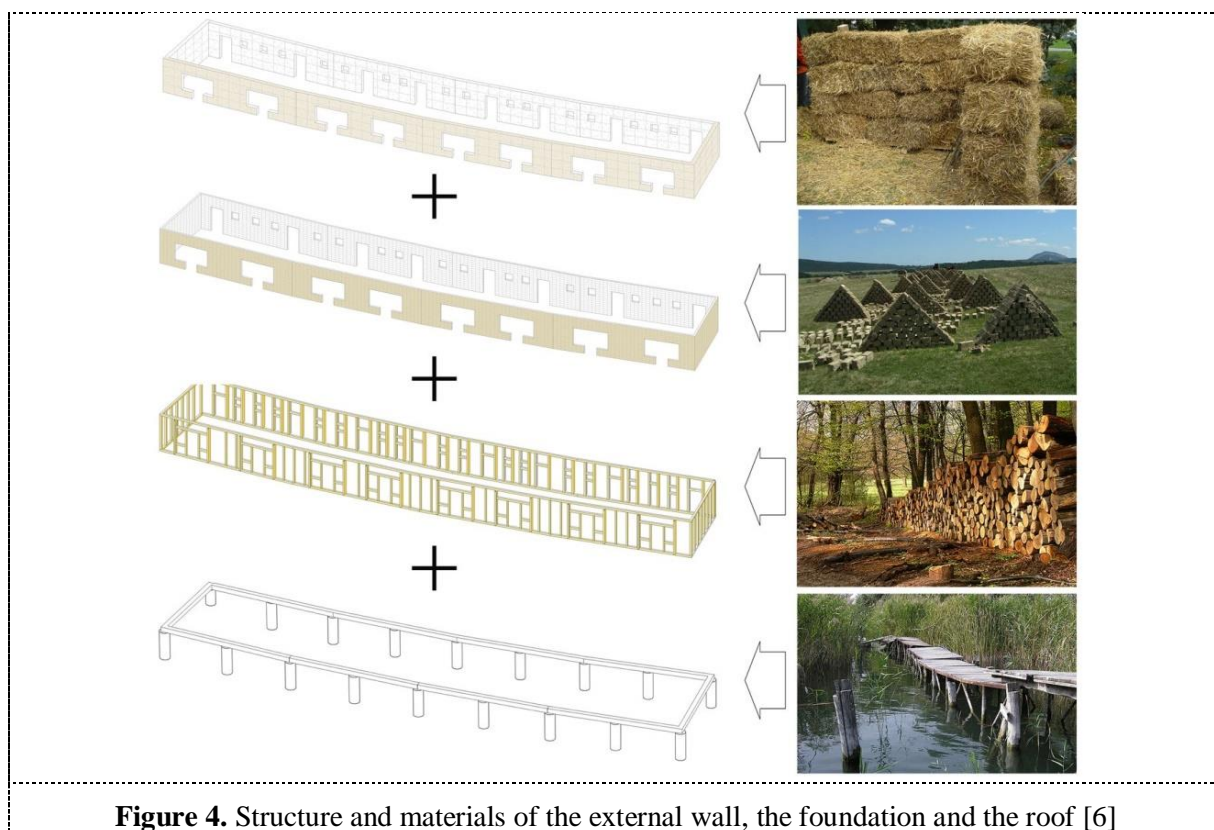


Figure 2. View of the Demonstration Centre from the parking. [Medgyasszay]



Figure 3. View from the terrace with the inner yard and the artificial lake [Medgyasszay]

The Demonstration Centre, also to demonstrate the environmental goals of the whole project, was built partially from natural building materials. Due to the deep loadbearing soil level and the considerable movement of the underground water, it was necessary to use pile foundation and beam grid under the walls. The beam grid structure was highly insulated due to low energy demand of the building. The external wall structure is constructed from a wooden post and beam structure. The wooden "ladder" frame consists of 10/15 cm pillars at the inner side and 5/10 cm pillars at the outer side at an average of 90 cm distance. The 15 cm thick adobe wall was positioned between the wooden loadbearing columns. The adobe hand-made bricks were produced in 20 km distance from the building site. The outer side of the walls are insulated with 35 cm thick straw bales harvested and collected from the nearby fields. The wall was plastered on both sides with adobe-plaster and painted with limewash. The roof was covered with tiles. The doors and the windows were made from wood with triple glazing. The floors were covered with ceramic floor tiles, brick and wood (figure 4).



As heating system a wood chip boiler was installed with low temperature floor heating. A ventilation system was installed only in the kitchen area. Because of the good heat storage and heat insulation capacity of the constructions, no air-conditioning system was designed. The hot water need of the building was also covered by the wood chip boiler.

2.2. Case study building: imaginary building 2010

The design principle of the "imaginary case study building 2010" was to define an average Hungarian building from the year of the design what fulfil the actual energetic requirements with the same geometry as the constructed one. The external load-bearing wall was designed from brick (Porotherm 38 N+F), and in the slab on the ground construction 6 cm expanded polystyrene insulation (EPS) was planned. In the roof construction 15 cm rockwool was planned and the openings were assumed as wood construction with double glazing. The rest of the building was conceived with the same structures as the built building.

The heating system was imagined, as a common Hungarian system, with low temperature gas-boiler and radiator units. Like the realized building, the ventilation system was designed only for the kitchen, and no air-conditioning unit was applied. [8] [9]

2.3. Case study building: imaginary building 2019

The design principle of the "imaginary case study building 2019" was to define an average Hungarian building from the year 2019 what fulfils the present energetic requirements with the same geometry as the constructed one. The external load-bearing wall was designed from brick (Porotherm 30 N+F) with 10 cm EPS, and in the slab on the ground construction 12 cm EPS was planned. In the roof construction 25 cm rockwool was planned and the openings were imagined as wood construction with triple glazing. The rest of the building was conceived with the same structures as the realized building.

The heating system was imagined, as a common Hungarian system, with condensing gas boiler and radiator units. Like the realized building, the ventilation system was designed only for the kitchen, and no air-conditioning unit was planned. The following table introduces the differences of three building (table 1).

Table 1. Comparison of the structures, building services and energy demands of the realized and imagined buildings

	Realized building	Imagined building 2010	Imagined building 2019
Foundation	pile foundation	pile foundation	pile foundation
External wall	wood frame, adobe brick and straw bale insulation $U=0,15 \text{ W/m}^2\text{K}$	brick wall $U=0,45 \text{ W/m}^2\text{K}$	brick wall with 10 cm EPS $U=0,22 \text{ W/m}^2\text{K}$
Roof and attic floor	wood frame, 25 cm rock wool insulation $U=0,15 \text{ W/m}^2\text{K}$	wood frame, 15 cm rock wool insulation $U=0,24 \text{ W/m}^2\text{K}$	wood frame, 25 cm rock wool insulation $U=0,15 \text{ W/m}^2\text{K}$
Slab on the floor	flooring, concrete, 5 cm EPS, 5 cm XPS insulation $U=0,33 \text{ W/m}^2\text{K}$	flooring, concrete, 6 cm EPS, insulation $U=0,49 \text{ W/m}^2\text{K}$	flooring, concrete, 12 cm EPS, insulation $U=0,3 \text{ W/m}^2\text{K}$
Openings	wood frame, triple glazing $U=0,8 \text{ W/m}^2\text{K}$	wood frame, double glazing $U=1,4 \text{ W/m}^2\text{K}$	wood frame, triple glazing $U=0,8 \text{ W/m}^2\text{K}$
Heating, HWS	wood chip boiler	gas boiler	condensing gas boiler
Air conditioning	no	no	no
Ventilation	only in the kitchen	only in the kitchen	only in the kitchen
Primary energy demand of heating (kWh/m²a)	9 as public building, 41 as residential building	25 as public building, 86 as residential building	12 as public building, 54 as residential building
Primary energy demand of hot water (kWh/m²a)	5 as public building, 16 as residential building	15 as public building, 38 as residential building	15 as public building, 37 as residential building
Primary energy demand of ventilation (kWh/m²a)	16 as public building, 0 as residential building	18 as public building, 0 as residential building	18 as public building, 0 as residential building
Primary energy demand of lighting (kWh/m²a)	9 as public building, 0 as residential building	9 as public building, 0 as residential building	9 as public building, 0 as residential building

2.4. Calculation method: energy demand and vapour calculation

All calculations performed for the case study were made with the Belső Udvar E-P-LCC-LCA software. [10] The software development started in 2006 according to the methodology described in the Hungarian Government Decree on the Energy Performance of Buildings. [11] In addition to the initial, simplified energy calculation method, the software used a detailed method from 2010 onwards. The so called "detailed method" with the calculation of the solar gain depending on the orientation of the glazed surfaces and the length of the heating season enabled the software to calculate the energy demand of low-energy buildings with a good approximation. The building, as a specific public building, has different user behaviour profile from a common house. The spaces are not heated in the whole heating season, but in the kitchen area intensive ventilation (8 l/h) is necessary. As basic energy data the following parameters were taken into account:

- average air-change rate: 1,16 l/h,
- internal heat gain: 7 W/m²,
- correction factor because of intermittent use: 0,4,
- net specific energy demand of lighting: 6 kWh/m²yr,
- reducing factor of lighting: 0,6,
- nett specific energy demand of hot water supply: 7 kWh/m²yr.

During the energy calculations the avoidance of interstitial condensation in external constructions was also checked. A vapour module was developed in 2008, which allows steady-state investigation of water vapour adsorption in structures according to the Hungarian calculation method [12].

2.5. Calculation method: Life Cycle Cost Analysis

The LCC module of the software was developed in 2011 in the framework of research financed by the JRC. [13] The global costs were calculated according to the European Directive 244/2012/EU and its guideline. [14] [15] To the investment costs were added the sum of annual costs for every year (energy costs, maintenance, replacements, etc.) and was reduced with the residual value, all expressed as Net Present Value referring to the starting year. It is important to emphasize that if the investment has shorter lifetime than the calculation period (e.g. mechanical equipment) additional investment (replacement cost) was calculated. [15] The lifetime of mechanical equipment was calculated according to the EN 15459. [16] The lifetime of each layer of building constructions was calculated according to the recommendation of Bundesministerium für Verkehr, Bau und Stadtentwicklung. [17] As economical basic data the following parameters were taken into account:

- calculation period: 30 years,
- discount rate, excluding inflation 4%,
- long-term energy price escalation: 2% for electricity and wood and 2.8% for natural gas.

The investment cost of building materials and mechanical systems materials, including the price of material and labour, were taken from cost databases [18], manufacturer data and quotes. The cost of heating and domestic hot water production was 50 HUF/kWh for electricity, 8,3 HUF/ kWh for wood chips and 16 HUF/kWh for natural gas.

2.6. Calculation method: Life Cycle Assessment

The LCA module of the Belső Udvar E-P-LCC-LCA software was developed in 2012 based on previous research. [19] [20] For the calculation of the environmental impacts, the method of life cycle assessment (LCA) was applied, following the norms ISO 14040 and ISO 14044. The functional unit was one building per one year. The environmental data of building materials and mechanical systems were divided by their life time, as the environmental data of operation was calculated according to the energy calculation. Environmental data from the Swiss ecoinvent 2.0 database were used, with certain

modifications to account for the Hungarian circumstances where necessary. [19] Due to the typical environmental impact caused by the construction industry, only three impact categories were considered: [21]

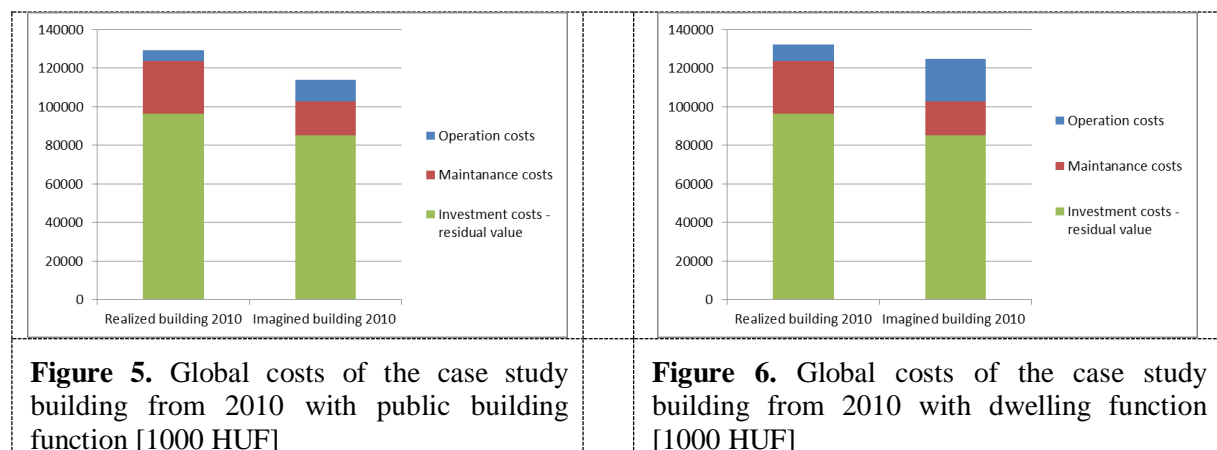
- non-renewable cumulative energy demand (CED, n.r.) [MJ]
- global warming potential (GWP100a, CML 2001) [kg CO₂-eq]
- acidification potential (AP, CML 2001) [kg SO₂-eq]

2.7. Sensitivity analysis

In addition to the results calculated for the special public building, LCA tests were carried out for a more general function, examining the function-sensitivity of the findings. The building was also examined as a residential building according to the user behaviour profile described in TNM 7/2006. [11]

3. Results

During the LCC investigations, the problem appeared that due to the economic crisis of 2012 and the change of the Hungarian energy price support policy, the buildings from 2010 and 2019 are not comparable from economic point of view. Because of this reason, for the LCC result only the value of the Realized building and of Imagined building 2010 are introduced, both as public building and as residential building. (figure 5-6)



The global cost of the Realized building, with higher energy quality and using natural materials, is higher than the global cost of the Imagined building. The higher global cost is caused by the higher cost of investment and maintenance, which was not compensated by the lower operating costs. It is important to emphasize that the higher installation costs (difference of 11,5 mFt) were only partly caused by the additional cost of the wall structure based on natural building materials (1 mFt). The other extra cost (10,5 mFt) was the difference in the cost of the higher energy-quality slabs, roofs and doors, as well as the higher cost of the mechanical equipment. If the building is used more intensively as a residential building, with the higher operating costs the global cost difference decreases (from 16,3 mFt to 7,3 mFt), but in the case study examined, the building with lower investment cost still has a lower global cost.

Figure 7-12 show the LCA results of three buildings as a public building and as a dwelling. In the realized building, the use of natural materials was primarily realized in the construction of the wall structure. Therefore, in the diagrams describing the results, the environmental loads associated with the construction of the wall structures are separately identified. It is also possible to identify separately the environmental load associated with the installation and the operation, the sum of which gives the whole lifetime value.

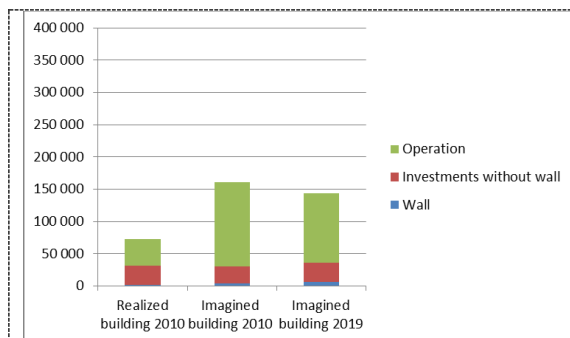


Figure 7. Cumulative energy demand of case study buildings with public building function [MJ/yr]

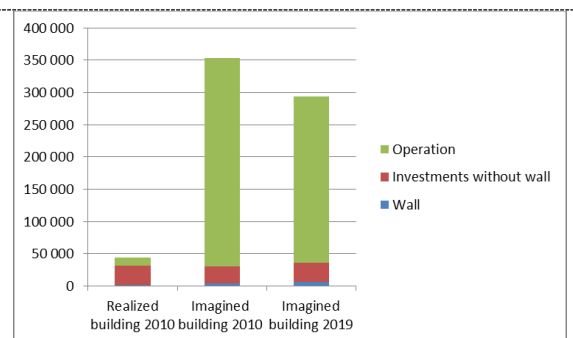


Figure 8. Cumulative energy demand of case study buildings with dwelling function [MJ/yr]

Figures 7-8 show that building structures made of natural materials are significantly more advantageous in terms of cumulative energy demand than conventional structures (1394: 4090: 5766 MJ/yr). However, the significant difference is due to the biomass-based heating system in the examined case studies. The greater is the importance of operation phase, the greater are the savings.

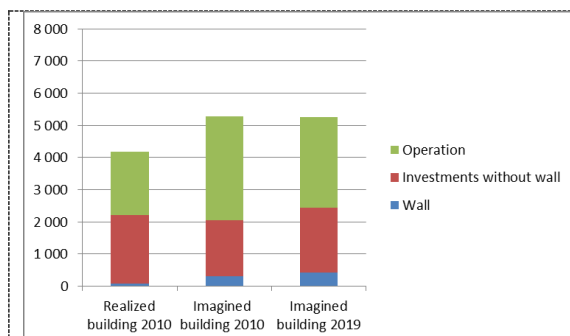


Figure 9. Global warming potential of case study buildings with public building function [kg CO₂-eq/yr]

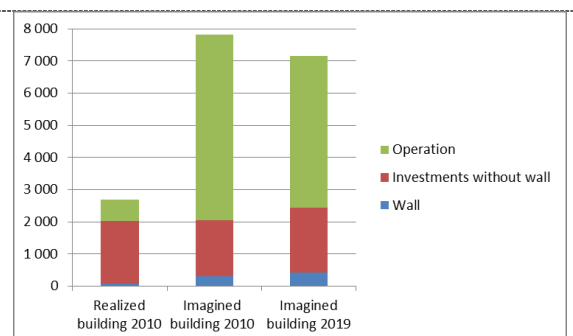


Figure 10. Global warming potential of case study buildings with dwelling function [kg CO₂-eq/yr]

Figures 8-9 show similar lessons to Figures 6-7, but the construction phase has a greater role than the operation phase. Savings in global warming potential by natural building materials are more significant than the savings in cumulative energy demand.

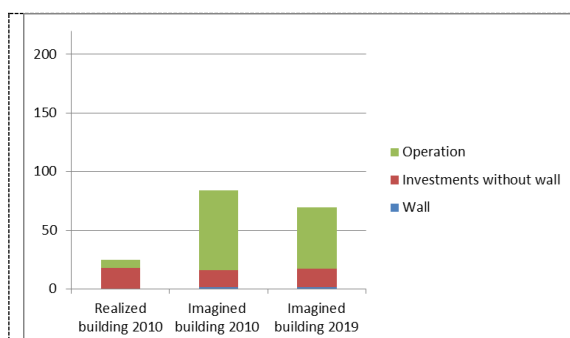


Figure 11. Acidification potential of case study buildings with public building function [kg SO₂-eq/yr]

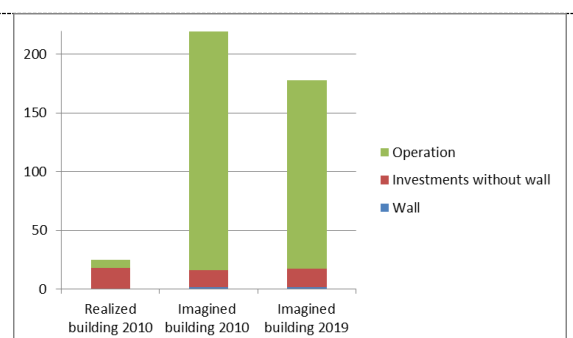


Figure 12. Acidification potential of case study buildings with dwelling function [kg SO₂-eq/yr]

4. Conclusions

The case study in this paper proved that natural materials can be used to achieve environmental savings. The wall structure made of natural materials is significantly more favourable in all calculated environmental parameters than commonly used wall structures (e. g. 66-76% saving in CED content). It is important to note that the wall structure of the "Imagined 2019" building results higher environmental impact than the "Imagined 2010" building due to higher energy requirements. It means that the environmental benefits of using natural materials will become more and more important in the construction of increasingly energy-intensive buildings.

However, the use of natural materials has in many cases technical limits, and in several constructions it is not appropriate to achieve the desired construction quality. In the examined case studies, the environmental savings associated with natural materials are not significant compared to the environmental impact of the whole building. In the case study, the greatest environmental benefit is not connected to the construction phase but to the operation phase. The mechanical system based on non-fossil energy has always resulted significant savings. These benefits are even more significant in the case of a function requiring higher operating energy (residential building) than in the case of the examined public building function.

The most important practical experience of this case study is that from the point of view of LCC analyses the phase of construction, while from the point of view of LCA analysis the operation phase is dominant. This caused a major contradiction in terms of investor and environmental goals. The investor side is interested in the construction of the cheap, energetically and environmentally weaker quality buildings. In contrast to achieve the environmental goals the most energy-efficient building is needed that uses the most natural materials, but in many cases with larger investment cost.

Acknowledgements

The research reported in this paper was supported by the FIKP grant of EMMI in the frame of BME-Water sciences & Disaster Prevention (BME FIKP-VÍZ).

Project FK 128663 has been implemented with the support provided from the National Research, Development and Innovation Fund of Hungary, financed under the FK_18 funding scheme

References

- [1] International Energy Agency. (2017). Global Status Report 2017. Global Status Report 2017
- [2] GABC. (2016). Global Roadmap towards low-GHG and resilient buildings, (November), 1–36.
- [3] Medgyasszay, P. & Szalay, Z. (2014). Optimization of Building Envelope Components Based on Life Cycle Environmental Impacts and Costs. *Advanced Materials Research*, 899, 93–98.
- [4] Medgyasszay, P. (2014). Additional Insulation of Detached Dwelling Houses with Straw-Bale Elements. *Advanced Materials Research*, 1041(5), 243–246.
- [5] Medgyasszay, P. & Novák, Á. & Büki, P.: Final plans of Nagyszík Visitor Centre (2010) Belső Udvar Architect and Expert Office.
- [6] Medgyasszay, P. (2011) In dialogue with the landscape: Great-Saline Visitor Centre, Balmazújváros, Hungary. *Holcim Awards for Sustainable Constructions*
- [7] Novák, A., & Medgyasszay, P. (2014). In dialogue with the landscape. *Vernacular Architecture: Towards a Sustainable Future*, 555–560.
- [8] Énekes, M: Examination of realized building, MSc Diploma (in Hungarian) Consultants: Medgyasszay, p., Baráti, I., BME- Magasépítési Tanszék, 2013
- [9] Medgyasszay, P. (2013). Implemented public building according to the principle of "sustainable house" in Balmazújváros: Bíbic Visitor Centre (in Hungarian). *Magyar Építőipar*, 5, 198–203
- [10] Belső Udvar E-P-LCC-LCA software – Version-2012-07-31 – Belső Udvar Architect Research and Expert Office, 2012.
- [11] TNM 7/2006. (V.24.) - Hungarian Government Decree on the Energy Performance of Buildings.

- [12] MSZ-04-140-2:1991: Power Engineering Dimensioning Calculuses of Buildings and Building Envelope Structures (in Hungarian)
- [13] Medgyasszay, P. (2011) Test run of draft framework methodology for calculation of cost optimal minimum energy performance requirements, Research report to Joint Research Centre (JRC)
- [14] European Commission. (2012). Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012. supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements. Official Journal of the European Union, 18–36.
- [15] European Commission. (2012). Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council. Official Journal of the European Union, 55, 1–28.
- [16] EN 15459 Energy performance of building - Economic evaluation procedure for energy systems in building (2007)
- [17] Bundesministerium für Verkehr, Bau und Stadtentwicklung: Lifetime of building Components and component layers (in German) (2009)
- [18] Szeredi, I.: Guidleine for estimation of constuction costs (in Hungarian), 2012. Építésügyi Tájékoztatási Központ, 2012.
- [19] G. Tiderenczl, P. Medgyasszay, Zs. Szalay, Z. Zorkóczy, Building ecological and building biological evaluation system for building constructions based on national data. (in Hungarian) Independent Ecological Center. In OTKA T/F 046265 research report, 2006.
- [20] Medgyasszay, P. (2007). Possibilities of optimum usage of adobe-building in Hungary, with special attention to the aspects of building-ecology and energy-conscious planning. PhD Dissertation.
- [21] Szalay, Z. (2007). Life cycle environmental impacts of residential buildings. PhD Dissertation.