Stanka Ostojić[1], Zoran Veršić[1], Iva Muraj[1]

Energy analysis and refurbishment strategy for Zagreb University buildings: former Faculty of Technology in Zagreb by Alfred Albini

[1]University of Zagreb, Faculty of Architecture, Fra Andrije Kačića Miošića 26, 10000 Zagreb, Croatia

Abstract

In the year 2012 the University of Zagreb started the process of energy audits and energy certification of all university buildings with the intent to improve their energy performance. As a property owner, the University of Zagreb encompasses approximately 130 buildings (465,000 m^2). The first phase of this research project involves the audit of 23 faculty buildings, which make up 30% of all faculty buildings area belonging to the University. One of the largest buildings audited in the first phase is the building of the former Faculty of Technology in Zagreb built from 1958 to 1964 and designed by the esteemed 20th century Croatian architect Alfred Albini. This classic work is the last of Albini's accomplishments and is a protected cultural heritage monument. Today the building belongs to the Faculty of Food Technology and Biotechnology and the Faculty of Mining, Geology and Petroleum Engineering. The paper presents results of the energy audit and energy certification of Albini's modern architecture building and determines the energy balance in contemporary usage. The paper also suggests possible energy efficient improvement measures and profitability calculations.

Keywords*: energy audit; energy refurbishment; cultural heritage; former Faculty of Technology; University of Zagreb; Alfred Albini*

Introduction

The Republic of Croatia's Ordinance on Energy Audits of Construction Works and Energy Certification of Buildings[1] prescribes the introduction of energy audits of buildings which are necessary for determining energy performance and management in buildings with energy and water consumption, measures for energy-efficient improvements and their cost – effectiveness, and energy certification of buildings [1]. The ordinance also prescribes energy certification deadlines, which was for public use buildings with a total useable floor area greater than 1.000 m^2 scheduled for 31st December 2012. The deadline for buildings with the total use of floor area more than 500 m^2 was set on 31st December 2013, whereas for building exceeding 250 m^2 was 31st December 2015. Energy performance certificates provide information on the energy features of buildings and facilitate comparative analyses of buildings on the basis of their energy features, efficiency of their energy systems and the quality and features of their exterior walls. An energy performance certificate can be obtained only after a detailed energy audit of the building which also includes gathering the information necessary for energy efficiency evaluation. A building's energy consumption report contains conclusions, a chapter which lists recommendations and the order in which economically justified measures should be adopted in order to improve energy efficiency and energy performance of the building. The energy efficiency status of the building complex of the former Faculty of Technology was calculated using a software programme (*Toplinska zaštita Novolit 2009*) in 2013 according to valid technical regulations.

[1] Ordinance on Energy Audits of Construction Works and Energy Certification of Buildings (Official Gazette 81/12, 29/13, 78/13)

1. Refurbishment Strategy for Zagreb University Buildings

Given the legal requirement of the certification process, the University of Zagreb decided to perform energy audits of its faculty buildings. Altogether 32 faculties are housed in more than 130 buildings whose gross floor area amounts to approximately 412.000 m^2, which, if the buildings housing Rector's offices are included, reaches approximately 465.000 m^2.

The project of energy audit and certification of the university's buildings has been headed by a coordination team. The assignment of auditing was, however, entrusted to individual teams from the Faculty of Architecture, Faculty of Civil Engineering, Faculty of Electrical Engineering and Computing and the Faculty of Mechanical Engineering and Naval Architecture. The five teams consisted of one expert from each of the mentioned institutions. The first round of energy audits included the buildings of the eight following faculties: Faculty of Architecture, Faculty of Geodesy and Faculty of Civil Engineering which all share the building at 26 Kačićeva Street (gross floor area ~21.300 m^2), Faculty of Humanities and Social Sciences at 3 Lučićeva Street (~23.850 m^2), Faculty of Food Technology and Biotechnology and Faculty of Mining, Geology and Petroleum Engineering at 4 and 6 Pierottijeva Street (~17.150 m^2), Faculty of Electrical Engineering and Computing at 3 Unska Street (~43.100 m^2), Faculty of Mechanical Engineering and Naval Architecture at 1 and 5 Lučićeva Street (~30.570 m^2). The buildings of all these faculties make up more than 30% of the total floor area of all Zagreb University's buildings.

The buildings audited in the first phase are either located in the protected historical centre of the City of Zagreb or they are protected as individual immovable cultural properties. The first phase of the project of energy audit and certification began at the end of 2012.

2. Former Faculty of Technology in Zagreb

The former Faculty of Technology in Zagreb and the present Faculty of Food Technology and Biotechnology and the Faculty of Mining, Geology and Petroleum Engineering comprise two buildings: the building at 4 Pierottijeva Street and the building in 6 Pierottijeva Street that was constructed at a later date (Fig. 1, 2).

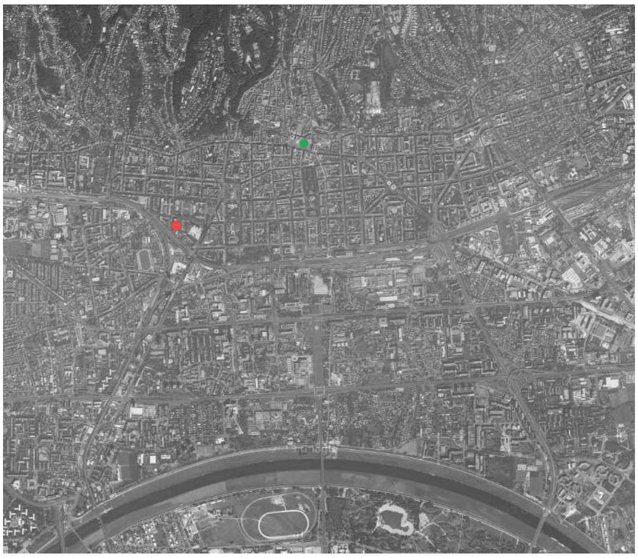

Fig. 1. Position of the former Faculty of Technology in Zagreb (red dot) and main city square of Ban Josip Jelačić (green dot). Source: Google Maps (https://maps.google.com/)

The older building at 4 Pierottijeva Street, which used to house the Society of Engineers and Technicians, was built in 1937 (architects M. Haberle and H. Bauer). Its L-shaped plan comprising ~1,138 m^2 gross floor area is divided into a south and north wing. The building has a ground floor, mezzanine and three storeys housing lecture halls and offices of the Faculty of Mining, Geology and Petroleum Engineering. All the building's architectural parts show the formal features typical for the period in which it was built: reinforced concrete skeleton and brick infill walls, plaster applied to internal and external walls with openings, multi-ribbed reinforced concrete floors and flat roofs. The southern and western gable walls are attached to the subsequently built structure designed by Alfred Albini[2].

[2]Alfred Albini was a Croatian architect (Graz, 1896 – Zagreb, 1978). He studied at Vienna's University of Technology (former Technishe Hochschule) in 1919, and graduated from the Polytechnic of Zagreb in 1923. From 1923 to 1962, he worked at the Faculty of Architecture in Zagreb, first as teaching assistant to Viktor Kovačić and later as professor. In the period from 1928 to 1964, Albini designed and completed several residential and commercial buildings: the Žerjavić Fundation House (Zagreb, 1928-1930/32), the building of the Town Savings Bank (Osijek, 1930), Meixner House (Zagreb, 1933), the Arko House (Zagreb, 1940), the Croatian Cultural Centre in Sušak (Rijeka, 1941), the Residential and Commercial Building in Zadar (1954) and the Faculty of Technology in Zagreb (1964). He was the laureate of the City of Zagreb Award (1962), Viktor Kovačić Award for life achievement (1966) and Vladimir Nazor Award (1968). [2] [3]

Fig. 2. Aerial view of the older building at 4 Pierottijeva Street (1) and subsequently added building at 6 Pierottijeva Street (2a – Large Building and 2b – Small Building). Source: Google Maps (https://maps.google.com/)

Albini was a prominent protagonist of Croatian modern architecture who moderately and creatively built on the tradition accepting numerous modernist impulses and integrating them in his personal architectural expression. He took special interest in the issues of urban planning and protection of cultural heritage and expressed his views in newspaper articles and theoretical papers. [4]

The building at 6 Pierottijeva Street, also a part of the former Faculty of Technology, was built in 1958-1964 according to the design by Alfred Albini. His associates on this project included A. Dragomanović, D. Ložnik, B. Krstulović, J. Meniga, and E. Erlich, the last of whom was also responsible for designing the architectural structure. Clearly demonstrating Albini's architectural signature this building, last in his career, forms part of the anthology of Croatian architecture and is today a protected cultural property.

It consists of two separate structures (Large and Small Building) elongated in the north – south direction and connected with two glazed volumes (Fig. 3). The two-storey Small Building comprises a gross floor area of ~2.994 m^2 and it has a basement, mezzanine and one storey. Large Building has a gross floor area of ~12,736 m^2 and, in addition to a basement and mezzanine, has six storeys and a machinery room on the flat roof. The ground floor of Small Building contains an entrance volume, library, student cafeteria with accompanying facilities while the first floor contains a large amphitheatre (lecture hall). Large Building consists of a central corridor and rooms facing west and east (seminar rooms, small lecture rooms, labs and offices), two staircases and lifts. The plan, which is based on a modular grid of 1.75 m, provides a functional spatial organisation and adaptability of the space on all floors (Fig. 4).

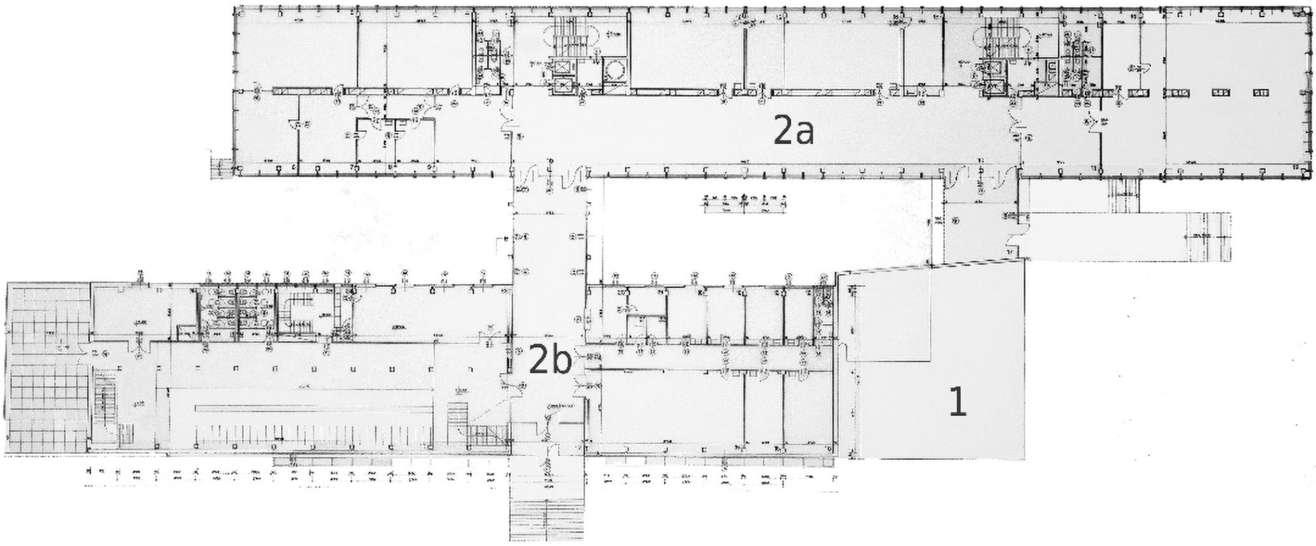

Fig. 3. Present situation of the former Faculty of Technology – Large and Small building (south-eastern façade)

Fig. 4. Ground floor plan of the former Society of Engineers and Technicians (1) and the former Faculty of Technology (2a – Large building, 2b – Small building). Source: Faculty of Food Technology and Biotechnology, University of Zagreb

Fig. 6. View of Large Building's north-western façade (present situation)

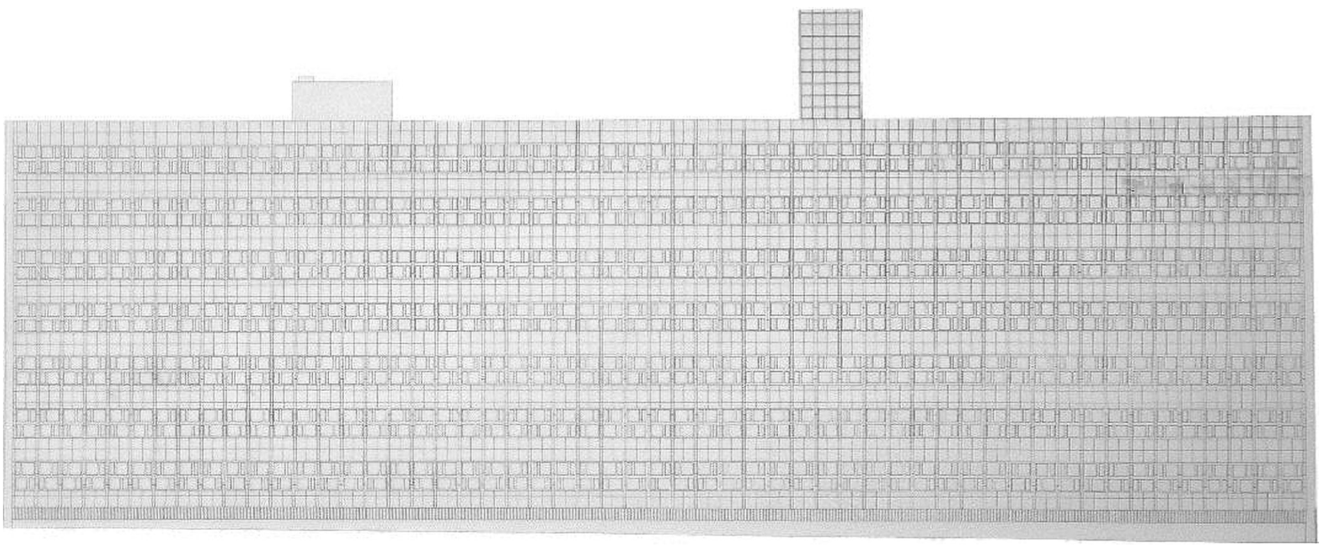

Fig. 5. Western façade of Large Building at 6 Pierottijeva Street (original Albini's drawing). Source: Faculty of Food Technology and Biotechnology, University of Zagreb

The wall bearing structure is a reinforced concrete skeleton composed of columns and transverse beams. The ceiling is constructed as a multi-ribbed reinforced concrete slab. The modular grid concept is adjusted to the façades and windows. The exterior walls of Large Building are coated with stone slabs placed at a distance from the main load bearing structure and supported by reinforced concrete elements. The façade pattern created by continuous alteration of windows and stone slabs, corners with contrastingly dark edges and window panes represent the main elements of the building's visual expression (Fig. 5, 6). [5] The facades of Small Building are all plastered except for the east façade which is coated with stone slabs rising up to the walls bellow mezzanine windows.

The process of determining architectural elements of the buildings included the use of original design plans created in 1958 by architect Albini as well as sketches and information collected during the energy audit of the buildings. [6]

Material components of architectural elements and their U-values[3] were presumed according to the construction date of audited buildings, which was the period 1958-1964.[4] [7]

3. Refurbishments Over the Years

The flat roof of Large Building was partially refurbished in the 1980s. However, since no surviving documents about the refurbishment could be found, it was impossible to determine which parts of the roof were repaired. The refurbishment included thermal insulation with 5 cm thick plates of mineral wool and covering of the substructure with corrugated sheet-metal. According to the building manager the roof leaked at places even after it had been refurbished. In the last several years, the leaks have been periodically repaired (in segments of about 50 m^2 depending on financial circumstances). These newly refurbished roof sections have not been thermally insulated but only covered with corrugated sheet-metal (ventilated covering).

The flat roof above the library in Small Building was refurbished in 2000 and in this case as well, the lack of documentation of this refurbishment made it difficult to precisely determine roof layers during the energy audit. For the purposes of calculation, the layers were presumed just as in the case of the roof on Large Building. The flat roof covering of the lecture hall was repaired in 2009. It was refurbished with a vapour barrier, a 10 cm polystyrene insulation layer and a synthetic waterproofing membrane.

Old deteriorated windows and doors were replaced with new double glazed aluminium or 5-chamber PVC windows and doors (1999-2009). Characteristics of PVC windows are: Uframe – value = 1.10 W/m^2K, Uglass – value = 1.40 W/m^2K with overall Uwindows – value = 1.31 W/m^2K.[5] Some openings have not yet been replaced and still have old wooden, aluminium or steel frames with extremely poor thermal characteristics.

Continued use of certain decayed openings and a periodical replacement of windows and doors resulted in the installation of various types of sun shading systems. The majority of openings have the interior sun protection mechanisms (venetian blinds) combined with heat reflective glazing. The exceptions are stairwells, sanitary facilities and spaces in the basement on the north, west and south facades of Large Building which do not have any sun protection systems. The openings on the south volume connecting Small and Large Building have also been left unprotected. The openings on the north volume – which connects the building at 4 Pierottijeva Street with Large Building – are protected from the sun with venetian blinds in the interior and fixed horizontal aluminium brise-soleils on the exterior. The calculation included the additional shading of individual openings with the neighbouring higher building or eaves.

The last reconstruction of Small Building in 2008 involved the removal of the door that served as wind protection (Fig. 7). Improper installation of some windows and the removal of the door resulted in increased air leakage at the building envelope which, consequently, led to greater energy consumption for heating and affected the feeling of comfort due to draught.

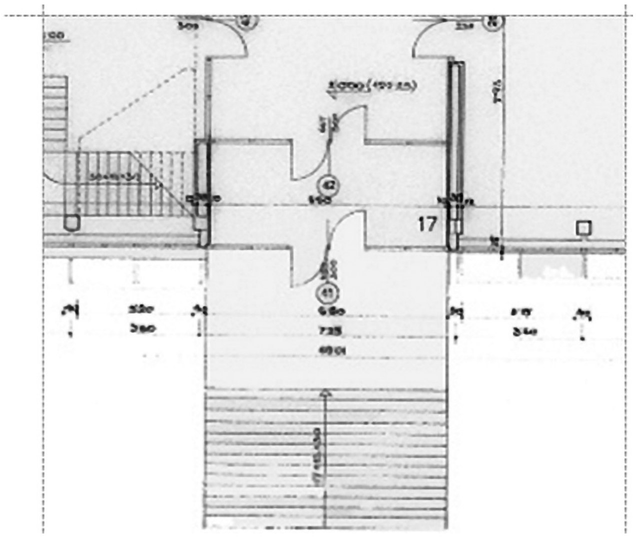

Fig. 7. Original Albini's ground floor plan of Small Building. The drawing shows the position of the wind-protection door which was removed in the 2008 reconstruction of the building. Source: Faculty of Food Technology and Biotechnology, University of Zagreb

[3] U-value is the coefficient of heat transmission or thermal transmittance [W/(m^2K)].

[4] *** (2012a): 68-73

[5] According to Technical Regulation on Rational Use of Energy and Heat Retention in Buildings (OG 110/08, 89/09, 79/13, 90/13) the biggest permitted U-value for translucent façade elements on buildings heated at +18°C or more is 1.80 W/(m^2K). [8]

4. Calculation of the Building's Energy Performance

Regardless of specific purposes of each of the described buildings, they are considered as a whole when speaking about thermal protection and energy savings. The amount of thermal energy required for heating of the building has been calculated according to the currently valid Croatian norms.

The energy efficiency status of the building complex of the former Faculty of Technology was calculated using a software programme (*Toplinska zaštita Novolit 2009, version.1.06*). The required amount of thermal energy for heating was calculated according to the HRN EN ISO 13790 standard[6]. The calculation included the climate data provided by the Zagreb Maksimir Weather Station, and the average climate data for continental Croatia[7]. [9] [10]

All the rooms except for certain labs and chemical storage rooms were defined as heated spaces. In order to simplify the procedure the calculation of ventilation losses included an assumed natural ventilation of all spaces although some lecture rooms have been ventilated through mechanical systems enabling thereby waste heat recovery. Thermal bridges were also taken into consideration and the calculation of linear heat losses included defined types of thermal bridges and a selection of suitable details from a catalogue of thermal bridges[8].

The defined heat losses comprised the losses through exterior walls, walls adjacent to unheated spaces, openings, flat roofs, portions of ceilings that are cantilevered beyond the exterior wall, ceilings over unheated spaces, floors on the ground and foundation walls above the ground level. The total amount of energy required for heating was calculated on the basis of the following entry data: heating regime of 10 hours per day, 7 days a week with the estimated average indoor temperature of 20°C.

According to the calculation of the overall thermal energy necessary for heating, which amounts to 30.8 kWh/m^{3}a, the building belongs to the E energy efficiency class[9].

[6] Technical Regulation on Rational Use of Energy and Heat Retention in Buildings (OG 110/08, 89/09, 79/13, 90/13) determines that the level of heat protection and energy saving is calculated by the annual thermal energy required for heating buildings whereas the energy spent on cooling, lighting etc. is disregarded.

[7] The building's energy consumption is (for the purposes of energy certification) calculated on the basis of climate data for specific weather station and reference climate data for a certain region.

[8] The catalogue contains illustrations of successfully reduced or eliminated thermal bridges and is an integral part of the new Technical Regulation on Rational Use of Energy and Heat Retention in Buildings (OG 97/14). [11]

[9] The maximum permitted amount of energy used for heating buildings is 17.2 kWh/m^{3}a.

5. Architectural Measures for Energy-efficient Improvements

The results obtained through the calculation of energy required for heating and the recognized energy saving potential formed the foundation of the proposal of architectural measures for energy-efficient improvements. Each measure, and the way it contributes to energy efficiency, corresponds to the specific calculation of the amount of energy required for heating. The results have been compared to the existing conditions and the return on investment periods have been estimated for each of the proposed measures (Table 1). [6] In addition to the proposed architectural measures, energy-efficient improvements are possible to achieve with the measures that are related to mechanical and electric installation equipment.

The calculated savings of the required heating energy, reduction of carbon emission and the return on investment period lead to the conclusion that the most suitable energy-efficient improvement measure for the buildings is M7. It comprises the M1, M3 and M5 measures: thermal insulation of walls and roofs, replacement of old windows and doors and installation of a door for wind protection (Table 2).

Exterior walls make a considerable part of the building envelope[10] and a lack of thermal insulation of the walls presents the problem of a great heat loss. Since the building complex of the former Faculty of Technology is an immovable cultural property, refurbishment of the existing exterior walls from the outside was not an option. An additional reason for proposing refurbishment of the exterior walls from the inside may be the fact that the infill walls are recessed in relation to the load-bearing reinforced concrete structure of Large Building and as such they form niches in the interior spaces which contain radiators. A great number of radiators were made from cast iron with no thermostatic valves which prevents the regulation of heat in individual spaces.[11] Installation of thermal insulation on the Large Building's infill walls from the inside would not present a barrier in the interior. The installation can therefore be done simultaneously with the replacement of the old and outdated radiators.

This measure also includes thermal insulation of infill walls in Large Building with 15 cm thick plates of mineral wool which could improve thermal characteristics of the walls and reduce the U-value from 4.00 W/(m^{2}K) to 0.22 W/(m^{2}K). (Fig. 8) The building could thereby meet the standard set by the Technical Regulation on Rational Use of Energy and Heat Retention in Buildings for the highest permitted value of the U-value for exterior walls is $U \leq 0.45$ W/(m^{2}K).

[10] The surface of infill walls between the load-bearing reinforced concrete parts in the exterior walls (columns and beams) of Large Building is 2.606 m^2. The overall surface of the exterior envelope of Large Building is 7.160 m^2.

[11] One of the proposed engineering measures is the replacement of old and outdated radiators.

Table 1: Architectural measures and achieved savings

Architectural Measure	Measure Description	$Q'_{H,nd}$ [b] [kWh/m³a]	Energy Efficiency Class [-]	Carbon Dioxide Emission [kgCO_2/a]	Return on Investment Period [years]
Existing Condition	/	30.8	E	404.360	/
M1	Thermal insulation of walls[a]	20.4	D	267.840	3.0
M2	Replacement of decayed windows and doors	28.5	E	372.935	7.3
M3	Thermal insulation of roofs	29.8	E	390.445	38.8
M4	M1 + M2 + M3	17.0	C	223.410	6.5
M5	Replacement of decayed windows and doors and installation of door for wind protection	26.8	E	351.750	8.4
M6	M1 + M3	19.4	D	253.890	6.3
M7	M1 + M3 + M5	15.5	C	202.915	6.0
M8	M1 + M2	18.1	D	237.135	3.8

[a] Measure M1 proposes thermal insulation of the inner side of the exterior walls of Large Building in order to avoid changes in the original appearance of the facades.
[b] Specific annual requirement of heating energy; maximum allowed = 17.2 [kWh/m³a]

Table 2: Calculated U-values of envelope structures and elements

Type of Envelope Structures and Elements		U-value [W/(m²K)]	U-value[a] [W/(m²K)]	U_{max}-value[b] [W/(m²K)]
VZ1	load-bearing parts in exterior wall (columns and beams)	2.75	–	0.45
VZ2	infill walls	4.00	0.22	0.45
VZ3	building plinth	3.15	–	0.45
VZ4	stone coated wall (Small Building)	4.35	–	0.45
VZ5	infill wall (Small Building)	1.55	–	0.45
VZ6	exterior wall or wall adjacent to unheated space	3.10	–	0.45
VZ7	partition wall adjacent to unheated space	2.60	–	0.45
K1	refurbished flat roof – corrugated sheet-metal covering	0.55	0.25	0.30
K2	refurbished flat roof – membrane covering	0.30	0.30	0.30
K3	flat roof (building at 4 Pierottijeva Street)	1.95	0.25	0.30
K4	flat roof – terrace	1.70	–	0.30
S1	ceiling above unheated space	1.20	–	0.30
S2	ceiling above open space	1.20	–	0.30
S3	ceiling adjacent to unheated space	1.45	–	0.50
P1	ground floor	2.55	–	0.50
VR1	aluminium exterior door or door adjacent to unheated space	2.00	–	2.90
VR2	wooden door adjacent to unheated space	2.00	–	2.90
VR3	PVC exterior door or door adjacent to unheated space	2.00	–	2.90
PR1	new windows (aluminium frame)	1.60	–	1.80
PR2	new windows (PVC frames)	1.30	–	1.80
PR3	old windows (aluminium frame)	2.90	1.30 (PVC frames)	1.80
PR4	old windows (steel frame)	5.90	1.61 (aluminium frames)	1.80
PR5	old windows (wooden frame)	3.40	1.30 (PVC frames)	1.80

[a] U-values calculated after implementing M7 architectural measure
[b] According to Technical Regulation on Rational Use of Energy and Heat Retention in Buildings (OG 110/08, 89/09, 79/13, 90/13)

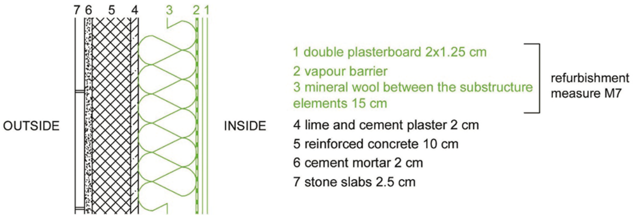

Fig. 8. Refurbishment of the infill walls in Large Building proposed by M7 measure (green colour marks the layers added in the course of refurbishment).

Heat losses through the uninsulated flat roof cause a great problem in the overall energy balance of the buildings belonging to the former Faculty of Technology. An additional reason for the roof refurbishment can be found in frequent problems with rainwater leakage in Large Building. The M7 measure therefore proposes refurbishments of the flat roofs: replacement of the existing waterproof membrane with a new one (Fig. 9). The waterproof layer would be topped by 12 cm thick plates of mineral wool between the metal substructure elements. It is necessary to protect the mineral wool from the ventilated air layer with a rain barrier and to reinstall the existing corrugated sheet-metal roof. Since the decayed openings (wooden windows, steel doors and windows and aluminium windows) on façades of the former Faculty of Technology cause increased heat losses, the problem can be solved by the application of the M7 measure. It proposes the replacement of old and worn out elements and the installation of PVC double glazed windows and doors with Low-E coating whose U-value equals 1.31 W/(m^{2}K). (Fig. 10)

The exception is the eastern entrance into Small Building, built as a single glazed glass wall with steel frames which does not meet the present heat retention standards. The M7 measure proposes the replacement of this glass wall with a new one: double glazed, with aluminium

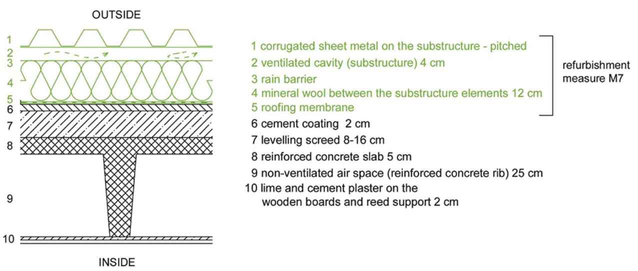

Fig. 9. Flat roof refurbishment proposed by the M7 measure (green colour marks the layers added in the course of refurbishment)

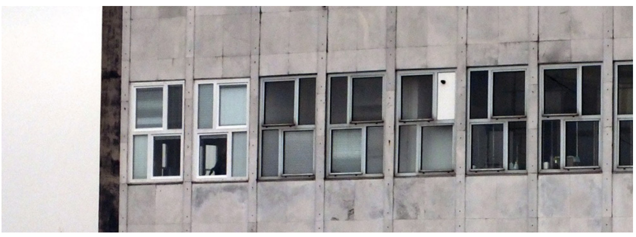

Fig. 10. A part of Large Building's northern façade (present situation)

frame, thermal break, Low-E coating and the overall U-value of 1.61 W/(m^{2}K). The measure also includes the application of sealants on each door and window if they have been warped due to long-time use and UV radiation exposure, which could help in achieving a better level of envelope air tightness.

In addition to the replacement of decayed openings the M7 measure envisages the construction of a door for wind protection or the installation of glass partition between Small and Large Building (within the south volume connecting those two buildings). This would lead to the reduction of ventilation losses which currently contribute to the considerable difference in the temperature of 4°C between the corridor, offices and classrooms. The wind-protection door would also reduce the air flow rate (and ventilation losses) in both Small and Large Building. The adoption of this measure envisages decreased air flow rate from 1.0 [h-1] to 0.60 [h-1].

Conclusion

Based on the energy audit and calculation the buildings formerly housing the Faculty of Technology (architect Albini) and the Society of Engineers and Technicians (architects Haberle and Bauer) belong to the energy efficiency class E and their values do not meet the standards proscribed by the Technical Regulation on Rational Use of Energy and Heat Retention in Buildings.

The proposed architectural measures for energy-efficient improvements have taken into consideration the fact that the building of the former Faculty of Technology is a protected cultural property. Comparative analysis has been conducted with the results of only those architectural measures whose application does not disturb the original appearance of the façade of Albini's building. The calculated savings of the required energy for heating, carbon emission reduction and the return on investment period lead to the conclusion that the most suitable energy-efficient improvement measure for the buildings is M7. It includes thermal insulation of the inner surface of Large Building's exterior walls, thermal insulation of all flat roofs, replacement of the remaining decayed windows and doors and the installation of a door for wind protection.

In addition to energy savings and decrease in maintenance costs, implementation of energy-efficient improvement measures contributes to a better quality of life and work of people and extends the lifetime of building.

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