Window frame materials and window size: parameters that influence energy efficiency in buildings

Ernad Ibrahimovic, Alma Hudovic Kljuno

Program of Architecture, Faculty of Engineering and Natural Sciences, International University of Sarajevo, Sarajevo, Bosnia and Herzegovina.

Abstract

When it comes to finding a suitable closing for the openings on the building envelope, the choice of proper windows and doors is crucial because it directly affects the energy gain and loss and consequently also the costs.

This paper aims to demonstrate how the window design, in terms of material and size, significantly affects the climatic conditions inside the building, such as temperature, humidity, light, and the quality of living in the space. A combination of quantitative and qualitative methods will be used to conduct the research. Data collection and analysis have been done for aluminium and PVC-U window types. To perform data analysis, the collected data were used for description and comparison. Qualitative analysis can reveal the efficient window property and demonstrate the difference using a deductive method. The heat transfer analysis will be performed using the software Winiso combined with SchuCal version 2020 R2. The test results are presented in the form of tables and diagrams, and explained additionally.

Key words: *Thermal transmittance, U-values, Aluminium windows, Vinyl (PVC-U) windows, Window frames, Window size*

1. Introduction

In the last several decades, European countries pay greater attention to energy use and sustainability in the construction industry. From 2021, new buildings must implement the nearly zero-energy standard across Europe – the EU Building Directive prescribes this. With that in mind, the importance of properly selected and designed windows in buildings is essential [1]. By the year 2050, approximately 6.5 billion of the 9.5 billion people on Earth will live in cities. Cities today already consume around three-quarters of all resources and are responsible for approximately 70% of all harmful greenhouse gas emissions [2]. The implementation of properly selected windows plays a vital role in sustainability. Sustainability features are becoming more significant in the valuation of property, too. Confirmation of this can be noticed in sustainability certificates, which are increasing in demand, particularly in the commercial sector.

It is estimated that windows alone contribute from 25% to 40% of the heat loss through a typical building assembly [3]. This research aims to investigate how aluminium and PVC-U windows perform when it comes to saving energy. For this purpose, Schueco aluminium and vinyl (PVC-U), window frames are chosen. It was decided to focus on profiles that are rated by the Passive house Institute in Germany. To achieve the Passive house requirements, the window frames need to have Uf values (window frame) so that Uw ≤ 0.80 W/m2K (window as a whole) [4]. Additional elements applied in window frames such as glass, spacers, or type of insulation that have high significance for window performance were taken into consideration as well. Note that a U-value of 0.5 W/m²K was chosen as the required performance level, simply based on the fact that the best commercial insulated glass units (IGU) on the market now have a U-value of 0.5W/m²K.

1.1 Research methodology and research approach

The research will be conducted through the combined quantitative and qualitative methodology. The outcome is based on data collection and analysis.

The window profile combinations and their Uf values were analyzed for two widely available window frame materials: PVC-U, and aluminium. Each window was designed having the same volume of a material, spacer, and glazing system; their U values and thermal performances were calculated and compared.

Two-dimensional heat transfer analysis of the frames will perform for different profile combinations and the windows' size using the software WINISO in a combination with SchuCal version 2020 R2. WINISO is software used to solve two-dimensional heat flow and steam diffusion flow, isotherms, Uf-Values, and Psi-Values. SchuCal project planning program can make preliminary calculations for windows, entrance doors, sliding doors, and curtain walling made from composite aluminium and steel profiles.

For analyzing window profile combinations, the base aluminium and PVC-U window system were chosen. Generally, window systems are divided based on the outer frame's installation depth (marked with the blue arrow in Figure 1). For this case study, the window system of 90 mm outer frame for aluminium and 82 mm for PVC-U was used with triple glass Ug 0,5W/m²K including a suitable glass spacer.

Changes in the outer frame and vent frame dimension (marked with the green arrow on Figure 1) were analyzed using heat transfer analysis software WINISO and SchuCal version 2020 R2. The collected outcome data were analyzed and presented for further discussion and conclusion.

2. Development of aluminium and PVC-U windows and material properties

Even though traditionally windows with wooden frames were used for many centuries, with industrialization and the beginning of modernist architecture, aluminium as a window frame material became more popular. Windows with aluminium frames were slimmer than those with wooden frames and gave a more elegant appearance to the window opening and the entire building. Nowadays there is a variety of materials used in the window production industry including affordable and low maintenance aluminium and PVC, both in the scope of this research, but also traditional material such as timber, and more specific and rather costly steel and fiberglass.

2.1 Aluminium windows and material properties

Aluminium as a construction material was introduced already at the beginning of the 20th century but due to the high production cost, it was not widely applicable. Just in the 1920s after certain innovations in the production process were applied and aluminum became more affordable for investors it began to be used for many purposes in the construction industry [5]. The first aluminium windows began to be produced in the 1930s. Their great advantage was their lightweight and slim appearance. However, aluminium as a metal

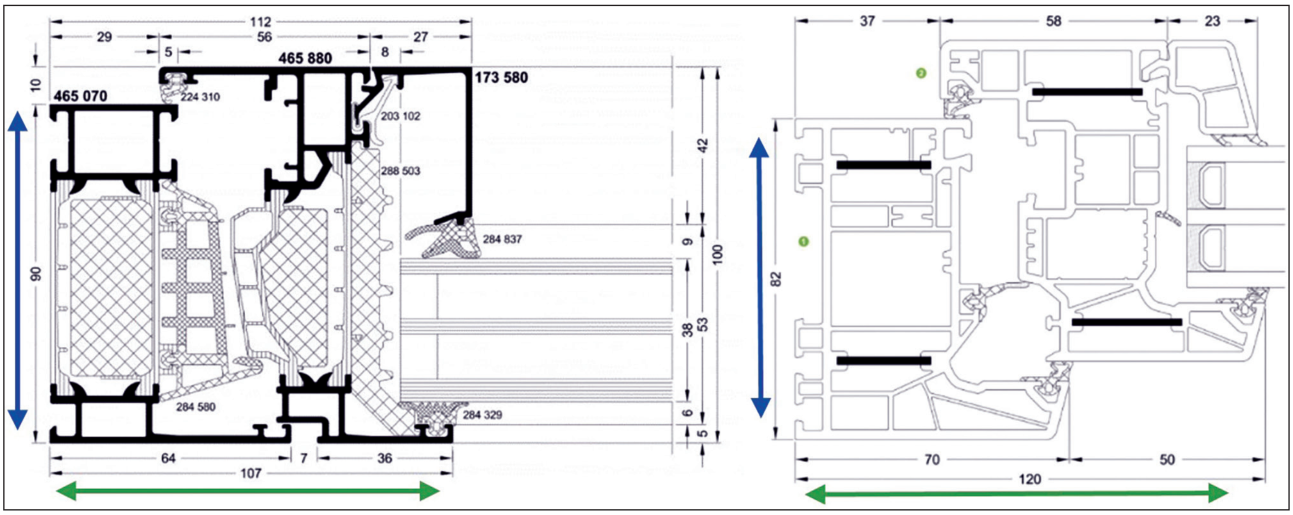

Figure 1. On the left side cross-section of aluminium window and on the right side cross-section of PVC-U window (Schuco, 2020)

is an excellent conductor of heat. Due to this feature, aluminium windows were very uneconomical, and the areas they closed did not provide the desired internal comfort in the building.

The most important reason for the use and production of aluminium windows was their lightweight. At the same time, aluminium is a material that does not corrode and has relatively high strength, so it is also suitable for larger window surfaces. For a long time, aluminium windows were "reserved" for office and retail buildings due to the elegant and severe appearance, which architects streamed to achieve in these building typologies. Over time, aluminium windows were improved. Double-glazing was introduced in 1980 [6]. Nowadays, aluminium windows answer to the low energy requirements thanks to advanced insulation technology and the extreme durability of the material itself. Another good characteristic of this material is that it can be remelted and reused again without losing its quality which is very important considering the fact that the construction industry is one of the main environmental polluters [5].

Aluminium is durable, light and relatively easy to handle, produced from ore, bauxite. Aluminium windows are corrosion-resistant and require little maintenance. It is generally known that aluminium production requires a large amount of energy, and it produces environmentally hazardous pollutants. The construction and utilization of buildings are also the leading cause of greenhouse gas emissions. The building sector offers twice as much potential for cutting CO2 emissions. Governments are responding with stricter regulations for the building sector [7]. Aluminium can be recycled an unlimited number of times without changing quality. Recycling requires just around 7% of the energy needed compared to production from its ore. Windows made from aluminium are light and long-lasting. To improve the characteristics of aluminium frames so that they can be resistant to seawater, acids, or corrosion, different alloys are added such as magnesium, copper, zinc, silicon, manganese, etc. Additionally, the frames are coated using two different coating techniques: powder coating and anodizing. The coating serves to protect the material and alloys and also to change the color of the frames.

2.2 PVC-U windows and material properties

The first PVC-U profile was made in 1954 which served to assemble the first plastic window from it. The first coextruded colored profiles appeared in 1972, and the profiles from recycled raw materials in 1988. One of the advantages of plastic profiles is the power of thermal insulation and affordable price, which has made it a customer's favorite choice. However, the ability to retain heat in the room or prevent penetration of cold air from outside has not always been a property of PVC windows. The original mass-produced frames were without chambers and were single glazed which caused high energy losses. Partitioned air circulation cavities in the profiles, which are the essential thermal insulation instrument, had become an integral part of them since 1967 when the first three-chamber window was created. Three-chamber profiles were the only available option for a long time until the issue of energy efficiency began to impose itself extensively among experts who came up with constructing a passive house that requires, among other things, appropriate facade shutters. Today, PVC windows have between five and eight chambers and multiple glass layers, while those with four chambers are almost no longer considered [8].

The material which is used to produce PVC-U windows is Polyvinyl chloride (PVC), the most widely used polymer in the world. German inventor Friedrich Klatte in 1913 was granted the first patent for the process of polymerization to produce PVC. In 1933 commercial production of PVC started. Around 20% of all plastic made worldwide refers to polyvinyl chloride, second only to polyethylene. The essential raw elements for PVC are derived from salt and oil. The saltwater's electrolysis provides chlorine blended with ethylene (obtained from oil) to form vinyl chloride monomer (VCM). Molecules of VCM are polymerized to form PVC resin, to which suitable additives are combined to create a customized PVC mixture.

PVC uses less non-renewable fossil fuel to produce than any other plastic materials because other thermoplastics are derived from oil entirely, while PVC is produced from two materials. 57% molecular weight is derived from common salt and 43% is derived from hydrocarbon feedstock [9].

Material has to be combined with a variety of specific additives before PVC can be made into products. Mechanical properties, color, clarity, weather-fastness, and flexibility, are determined by these additives. This method is described as compounding. PVC's compatibility with various additives is one of the material's many strengths and makes it such a highly adaptable polymer. PVC is ideal for construction product because of good impact strength and weatherproof attributes. PVC has a relatively small carbon footprint compared to other materials. PVC windows help to cut energy bills and are fully recyclable. Their properties are reprocessed well and recycled into second (or third life) applications with ease.

They are also easy to maintain, are durable, and recyclable which is an important characteristic contributing to the protection of the environment. Additionally, the manufacturing process of PVC windows has low levels of pollution and consumes less energy than the production of wooden windows [10].

PVC-U windows are additionally constructed with metal reinforcements to improve the rigidity. However, that is a weak spot of a standard vinyl window frame. There are two typical methodologies to tackle this problem: either replace the reinforcement with a better insulating material with comparative strength or replace the frame material with a more robust material by which the reinforcement becomes redundant [11].

In the beginning, the PVC-U windows were available in three colors only: white, golden oak, and rosewood. Today, the color palette is rich even though white window frames are still the most popular because they are also the cheapest option on the market. The methods of PVC-U window frames surface treatment are different: PVC-foils, acryl color, painting, and aluminium cover profile. From all the above-mentioned methods, the most popular solution of frame treatment is with foils even the aluminium cover caps are desirable, too. Advantages of surface treatment of the PVC-U window frames are:

- protection of weather influence,
- increasing the attractiveness and versatility of the PVC windows,
- optical embellishment,
- increasing the value of the real estate.

However, non-white PVC profiles result in higher surface temperatures and can even reach the softening temperatures of 79-81°C. To avoid possible deformation, these frames must be ventilated.

3. Simulation methods

An examination of the properties of a series of window frames currently available on the market resulted in two different frame materials: aluminium and vinyl. All test models were created in collaboration with the building industry. For the aluminium frames, the current standard reference is a three-chamber profile with a thermal break in glass fiber reinforced polyamide (Figure 1). The system is made airtight and watertight using a central gasket, typically combined with an interior gasket. Similarly, common vinyl window frames are composed of five or seven chambers, and a steel profile is inserted to ensure adequate strength and stiffness. Two gaskets, one at the interior plane and one at the exterior plane, ensure weather tightness. For this examination, seven chamber profiles are going to be used. Besides chambers, window systems are divided based on the outer frame's installation depth (marked with the blue arrow in Figure 1). For this purpose, Schueco window system of 90 mm outer frame for aluminium and 82 mm for PVC-U will be used with triple glass Ug 0,5W/m²K with a suitable glass spacer. Various profiles with different dimensions of the outer frame and the vent frame will be combined and tested. It was decided to focus on profiles that are rated by the Passive house Institute in Germany. To achieve the Passive house requirements, the window frames need to have Uf values (window frame) so that Uw ≤ 0.80 W/m2K (window as a whole). The European standard EN ISO 10077-2 provides a numerical calculation method to calculate the frame's U-value (Uf). Which is typically done by using 2D heat transfer programs. For this analysis, the software WINISO with a combination with SchuCal version 2020 R2 will be used. WINISO is software used to solve two-dimensional heat flow and steam diffusion flow, isotherms, Uf-Values, and Psi-Values. SchuCal project planning program can be used to make preliminary calculations of U values for windows, entrance doors, sliding doors, and curtain walling made from composite aluminium and steel profiles.

3.1 Window frame thermal transmittance

Based on the criteria defined for window frames, the following part refers to the profile combination testing for aluminium and vinyl (PVC-U) windows. All acquired data is analyzed with Minitab statical software.

3.1.1. Aluminium

Various profiles have been selected for testing with a basic installation depth of 90 mm. Profile combinations refer to the dimensions of the outer frame and vent frame. Five outer frames have been chosen with face widths 64, 84, 104, 155, and 205 mm. This is shown in Table 1. Four vent frames with face widths 36, 46, 56, and 61 mm are shown in Table 1. A total of twenty combinations was made and tested with SchuCal version 2020 R2 heat transfer program following the European standard EN ISO 10077-2. All possible combinations tested are shown in the Table 1.

Table 1. Profile combination for aluminium frames

ALU	Outer Frame (face width outside mm)	Vent Frame (face width outside mm)
1	64	36
2	64	46
3	64	56
4	64	61
5	84	36
6	84	46
7	84	56
8	84	61
9	104	36
10	104	46
11	104	56
12	104	61
13	155	36
14	155	46
15	155	56
16	155	61
17	205	36
18	205	46
19	205	56
20	205	61

3.1.2. Vinyl (PVC-U)

Unlike aluminium profiles, vinyl profiles have fewer choices for outer frame and vent frame. The basic installation depth of 82 mm, chosen outer frame face widths 70, 80, 90, and 100 mm and vent frame face widths 73, 83, and 110 mm, is shown in Table 2. A total of twelve combinations was made and tested with the software PlanSoft 4 heat transfer program following the European standard EN ISO 10077-2. All possible combinations tested are shown in Table 2.

Table 2. Profile combination for vinyl frames

PVC-u	Outer Frame (face width outside mm)	Vent Frame (face width outside mm)
1	70	73
2	70	83
3	70	110
4	80	73
5	80	83
6	80	110
7	90	73
8	90	83
9	90	110
10	100	73
11	100	83
12	100	110

3.2 Window size and thermal transmittance

To assess the impact of window size on building energy load, different window sizes for aluminium and PVC-U have been tested. Calculation of Uw values was performed with software Schuco PlanSoft version 4.5 for PVC-U windows and Schuecal 2020 R2 for aluminium windows following the DIN EN 10077-1. In general, The Schüco PlanSoft software offers all kinds of calculation and representation options for planning plastic windows and doors. On the other hand, Schuecal 2020 R2 is used for aluminium windows, doors, sliding doors, facades. The aluminium window size is changed in 13 scenarios. All combinations tested are shown in Table 3. The same three-layer glass was used for the calculation of isotherms with an Ug value of 0.5 w/m2K and a super spacer with a PSI value of 0.038 W/mK, with an outer frame of 104 mm and a vent frame of 56 mm.

Table 3. The aluminium window size

	Width of the window (mm)	Height of the window (mm)
1	600	600
2	650	800
3	700	1000
4	750	1200
5	800	1400
6	850	1600
7	900	1800
8	950	2000
9	1000	2200
10	1050	2400
11	1100	2600
12	1150	2800
13	1200	3000

The initial dimension of the window is 600x600 mm because it is not possible to make a smaller window due to technical reasons. The largest window dimension is 1200x3000mm. The dimensions of the windows have an increase of 50 mm in width and 200mm in height. The PVC-U window size is changed in 13 scenarios. All combinations tested are shown in Table 4, with a slight difference in dimensions due to technical limitations. The glass and the spacer characteristics are the same as on the aluminium window, with an outer frame of 90 mm and a vent frame of 83 mm. The initial dimension of the window is 600x600 mm, and the largest window dimension is 1200x2600mm. The windows' dimensions have an increase of 50 mm in width and 150-200mm in height.

Table 4. The PVC-U window size

	Width of the window (mm)	Height of the window (mm)
1	600	600
2	650	750
3	700	900
4	750	1050
5	800	1200
6	850	1400
7	900	1550
8	950	1700
9	1000	1850
10	1050	2000
11	1100	2200
12	1150	2400
13	1200	2600

4. Results

4.1 Profile combinations

Based on the analysis of case studies, the profile combination of window frames simulation results shows that window frame thermal transmittance Uf can be improved up to 30% with the right profile combination in aluminium window construction. The test results for all aluminium profile combinations are given in Diagram 1. Test recorded the highest Uf value of 1.1 W/m²K in the narrowest face width profile combination, the outer frame of 64 mm, and the vent frame of 36 mm.

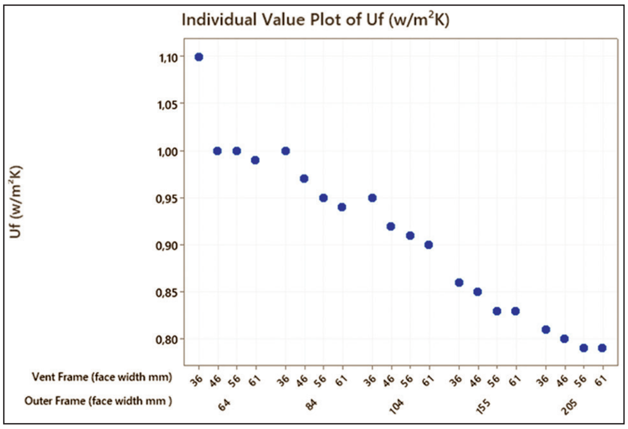

Diagram 1. Profile combination for aluminium frames results of testing

The best value is in the largest face width profile combination. The outer frame of 205 mm and the vent frame of 56 and 61 mm with a value of Uf 0,79 W/m²K. On the other hand, simulation results for profile combinations of vinyl profiles in each combination have the same thermal transmittance result Uf of 1.0 W/m²K. The test results for all vinyl profile combinations are given in Diagram 2. All acquired data is analyzed with Minitab statical software.

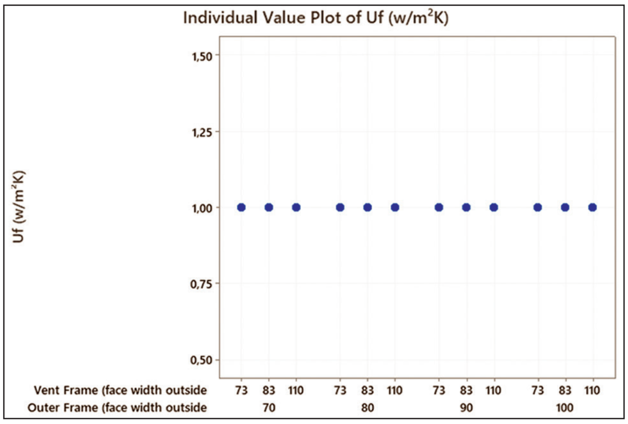

Diagram 2. Profile combination for vinyl frames results of testing

4.2 Window size and thermal transmittance

Based on the analysis, the impact of window size on thermal transmittance is evident. Window size simulation results show that aluminium window thermal transmittance Uw can be improved up to 23% with the proper window dimension. The test results for different aluminium windows sizes are given in Diagram 3. For the initial dimension of the aluminium window, 600×600 mm listed the highest thermal transmittance of Uw 0,95 W/m²K, and the largest window tested 1200×3000 mm records the best value of 0,73 W/m²K.

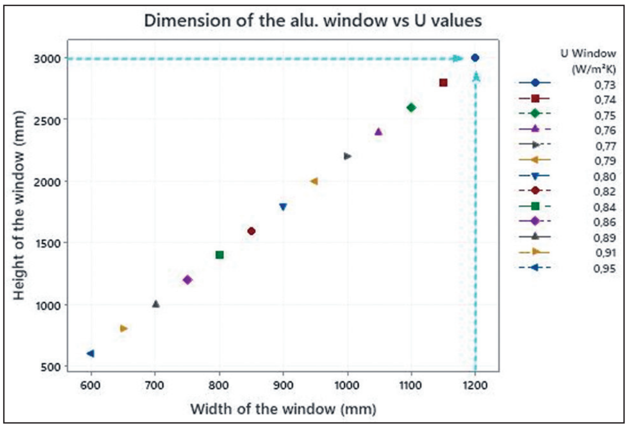

Diagram 3. Aluminium window size results of testing

On the other hand, PVC-U window thermal transmittance Uw can be improved up to 25%. The test results for different PVC-U window sizes are given in Diagram 4. For the initial dimension of the PVC-U window, 600×600 mm recorded the highest thermal transmittance of Uw 0,99 W/m²K, and the largest window tested 1200×2600 mm records the best value of 0,74 W/m²K. All acquired data is analyzed with Minitab statical software.

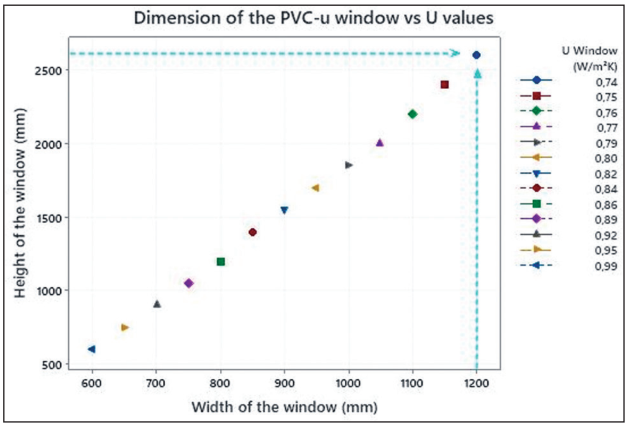

Diagram 4. PVC-U window size results of testing

5. Conclusion

The conducted test showed that the right choice of the window frame for aluminium and PVC-U windows as well as their size contribute to energy saving. In general, referring to the thermal characteristics of windows size, larger openings have better characteristics compared to smaller ones.

The results showed that the right choice of aluminium profile combination could improve thermal transmittance up to 30%, while vinyl flames have constant Uf values. Test recorded highest Uf value of 1.1 W/m²K in narrowest face width profile combination, the outer frame of 64 mm and the vent frame of 36 mm. However, the best value is in the largest face width profile combination. The outer frame of 205 mm, and the vent frame of 56 and 61 mm with a value of Uf 0,79 W/m²K. On the other hand, simulation results for profile combinations of vinyl profiles in each combination have the same thermal transmittance result Uf of 1.0 W/m²K.

It was found that aluminium window thermal transmittance Uw can be improved up to 23% with the proper window dimension. For the initial dimension of the aluminium window, 600×600 mm listed the highest thermal transmittance of Uw 0,95 W/m²K, and the largest window tested 1200×3000 mm records the best value of 0,73 W/m²K. On the other hand, PVC-U window thermal transmittance Uw can be improved up to 25%. For the initial dimension of the PVC-U window, 600×600 mm recorded the highest thermal transmittance of Uw 0,99 W/m²K, and the largest window tested 1200×2600 mm records the best value of 0,74 W/m²K.

As a result, this project can be a quick and user-friendly tool for the early design and optimization of thermally efficient aluminium and PVC-U windows.

It can be a guideline for architects and investors likewise when it comes to the choice of window material and size. With the right decision, energy costs can be decreased, and it can also influence the aesthetics of the building since each window type has its specific characteristics. This is equally important for the refurbishment projects on existing buildings as well as for new construction.

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Corresponding Author
Alma Hudovic Kljuno,
Program of Architecture,
Faculty of Engineering and Natural Sciences,
International University of Sarajevo,
Sarajevo,
Bosnia and Herzegovina,
E-mail: ahudovic@ius.edu.ba