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ENERGY EFFICIENCY UPGRADES: RESIDENTIAL BUILDINGS FROM THE PERIOD UP TO 1940 IN ZAGREB

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ABSTRACT

The refurbishment, conversion or upgrading of existing buildings always involves energy-efficiency issues. Upgrading a building to improve its energy efficiency requires careful consideration if works are to be effective, economical and avoid damaging the historic character of the building. The selection in applying measures result from the level of building conservation and the building condition. The basic subject of this research is the existing housing stock presented through residential buildings in the central part of Zagreb from the period prior to 1940. The year of construction of buildings (1870-1940) provide a general idea about the method of construction and the materials that were used, and these are the factors influencing the building's energy performance. They are two and three-story buildings of massive brick walls without thermal insulation and single-glazed double windows, with unheated basements and attics, with vaulted and wooden ceilings and with gable roofs. The street facades are rendered with ornamentation. The research will analyze energy performance of buildings of this period and demonstrate energy-efficiency upgrade measures in terms of their constructional details and energy performance benefits. This paper will show the importance for integrated approach balancing between energy efficiency and protection requirements. The concepts range from a simple energy-efficiency improvement for a building envelope to more complex and expensive methods such as extensions and even demolition work. Possible constructional measures include improving the thermal insulation, renewing the windows, eliminating thermal bridges or decreasing the solar heat gains by providing sunshades. For buildings protected by

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conservation orders, it is clear that non-intrusive upgrading can ensure that a traditional building has the potential to the long-term viability.

Key words: Residential Building, Building Envelope, Energy-Efficiency Upgrades, 18701940, Zagreb

Introduction

Standards of quality and complexity of buildings are constantly arising. Subjects such as energy saving methods of building, ecology, sustainability or revitalization dominate last years in contemporary architecture. The refurbishment, conversion or upgrading of existing buildings always involves energy-efficiency issues. Upgrading a building to improve its energy efficiency requires careful consideration if works are to be effective, economical and avoid damaging the historic character of the building. The selection in applying measures result from the level of building conservation and the building condition.

Residential Construction in Croatia

Housing, like no other segment of construction, documents the state of society and the social framework influencing architects in their design. A chronological consideration of residential building construction over the last 140 years shows that structure, ground plans and building materials are logically interrelated. Five characteristic periods of Zagreb residential construction defined by social and political relationships and their respective housing models could be singled out [1]:

- The period up to 1940: buildings with mostly massive construction consisting, without thermal insulation on external building elements.
- The 1940-1970 period: buildings with massive structure of (mostly) thin reinforced concrete; no requirement for thermal insulation materials.
- The 1970-1987 period: buildings with massive or skeleton structure of (mostly) thin reinforced concrete; marginal use of thermal insulation materials.
- The 1987-2006 period: buildings with mostly thin insulation that meets the criteria for energy savings and thermal protection under technical regulations at the time.
- The period after 2006: buildings have been built in accordance with the technical regulations.

The basic subject of this research is the existing housing stock presented through residential buildings in the central part of Zagreb from the period up to 1940.

Residential Buildings from The Period Up to 1940

It is important to understand and evaluate the way in which existing buildings were created towards the end of the 19th and beginning of the 20th century. The process of town rapid expansion, organized urban planning practice, population growth and traffic, marked the development of majority of European cities. Two characteristic periods of Zagreb residential construction up to 1940 defined by social and political relationship and their respective housing models could be singled out: the second half of the 19th and at the beginning of the 20th century (1862-1914) and the period between World War 1 and World War 2 (19181940). The construction of residential buildings in Zagreb depended on general economic conditions at that time and could be subdivided into the following periods: the pre-industrial town (1862-1892), early stage of industrialization (1893-1908) and the industrial town (19091913). Historical development of the Zagreb Lower Town area became the largest residential zone of the town by 1914. [2] The following periods are: the period of WW1 (1914-1918), the period of stagnation following WW1 (1919-1926), the flourishing period (1927-1931), the crisis (1932-1935), the period of standardization (1936-1940) when investments set a standard of financing the construction and the period of World War II (1941-1945). [3] The 1918-1940 period, besides being marked by great political and economic changes, both in the world and in Croatia, brought about significant changes in the understanding of the functioning of towns in general and the related dwelling problems in the cities. The types of residential buildings from that period were: the built-in house, the corner house, the semi-built-in house, the backyard house, the complex of houses and the villa.

The Built-In Apartment House in Zagreb Lower Town

Architectural elements of built-in houses and their possible energy-efficiency upgrades are the topic of this article. The built-in apartment house can be defined as a two-story or multistory building with a front and a backyard façade and its sidewalls leaned on the walls of adjacent buildings. Units within the blocks were created as representative higher citizen housing.

The Lower Town (Donji grad) is bordered by Ilica (the main street) in the north and the railway tracks in the south. The town-planning regulations dating from 1865 (the first Regulation plan) and 1887 (the new Regulation plan) prescribed future development of the town, giving it a morphological structure. An orthogonal street pattern (N-S and E-W street direction with 5° deviation) characterized by squared and elongated town blocks. [4] Most of its streets, parks and urban blocks in the center designed with the regular orthogonal street network were planned and constructed in that period. (Fig. 1.)

The Lower Town is a relatively modern area of Zagreb with mostly the 19th century historic architecture. In 1930 a new type of flat surfaces fronts in line with modern architectural tendencies appeared. Although there were a lot of alterations, additions

and interventions into existing urban structure during last 70 years, Zagreb's town blocks have succeeded to keep high level of style consolidation.

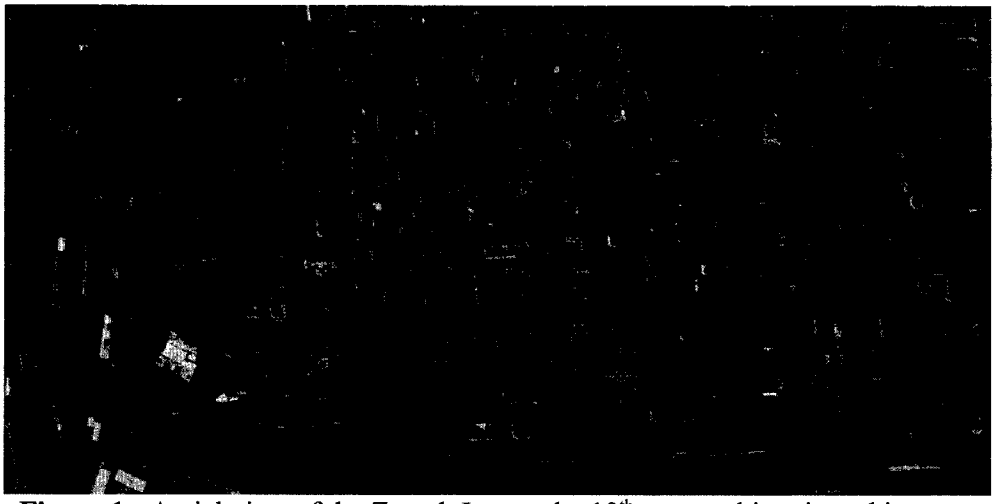


Figure 1 : Aerial view of the Zagreb Lower the 19th century historic architecture. source: Google Maps (https://maps.google.com/)

Cities are facing great pressures resulting from the needs of mobility, economy, housing and other development, so preservation of architectural heritage is very important. The Municipal Institute for Protection of Cultural and Natural Monuments is protecting and preserving

Zagreb's architectural heritage. Today, the Lower Town is a protected historic ensemble. Some buildings have also been protected as individual immovable cultural properties and are listed on the National Register of Cultural Monuments at the Ministry of Culture.

Energy-efficiency upgrades concept ranges from a simple energy-efficiency improvement for a building envelope to more complex and expensive methods such as extensions and alterations and even demolition work. Contemporary examples were created in the Zagreb's Lower Town designed by well-known architects. Office and residential buildings were built after winning 1st prizes on architectural competitions. New architecture was incorporated in unfinished town-blocks. Some of the newest examples of present day urban structures are: Hoto center at the Flower Square, designed by B. Podrecca 2006-2012, Ban Centre at the corner of Cesarceva and Kurelceva Street, designed by O. Baric, S. Dombi and S. Andrijevic 2007-2013 or residential building in Meduliceva Street, designed by Dj. Drazic that is currently under construction. To integrate a new architecture into historic urban structure is not an easy task. It always comes down to the competence of an architect.

Architectural Elements of the Built-in Apartment House

Architectural elements of the built-in apartment house from the period up to 1940 and their context within the Lower Town of Zagreb are being analyzed through following criteria - spatial environment, functional organization, structure and technology of the building prior to creation of the referential housing model.

Today, the Lower Town is highly sought-after. The planning evaluation shows a lot of advantages. The location within the city center with wide streets, some lined with trees, in a dense urban setting, makes them attractive. The inner-city location in the vicinity of the main city squares, makes them desirable residential area. All the major public and cultural buildings are located nearby. Attractiveness also plays a role. This is area with public transport (trams). Disadvantages that can be singled out are exposure to the main street – noise. There are also evident lacks in green areas, but nearby parks and an indoor block green areas make up for it.

Living spaces are large apartments with large rooms (5-6 x 3-6 m) and high ceilings (3,5-4 m) that are often superior to those of a new building. From a typological point of view, it is not exclusively-functional ground plan design, but almost any use is conceivable: an apartment for a large family or it can be transformed into the office. Main living rooms are placed near the front facade. Each room has one or two windows facing the street. Rooms near the backyard facade are smaller and narrower.

Plan types of the Zagreb-style built-in apartment houses that were standardized included: the standard plan, the plan with a mid-backyard wing, the plan with backyard extensions and the plan with lateral light wells. (Table 1.)

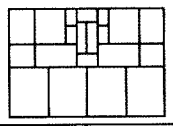
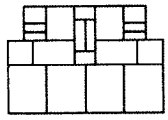
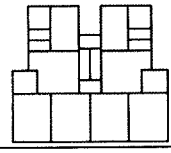
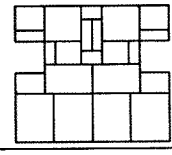
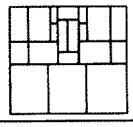
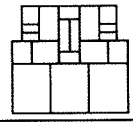
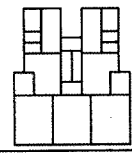
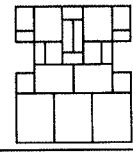
The apartment houses characterized by a plan type with a central backyard extension or two separate backyard extensions make up two thirds of all buildings. [3] Other plans are combinations of these four types depending on the complexity of plans or irregularities of the lot. Two and three-story apartment houses above the ground-floor level make up four fifths of all buildings in the Lower Town. Residential apartment houses with commercial premises on the ground floor make up one third of all buildings.

Almost all built-in apartment houses in this period had axially symmetrical front surface at the level of residential stories whereas more than half of the fronts were strictly axially symmetrical.

If we look at the economic evaluation of the Lower Town area, it is probably the most expensive part of the city and the apartments have the status of luxury living. A standard type of plan organization consists of two apartments to the staircase. Today, the buildings are deteriorating because of the long lack of maintenance (deteriorating facades and old installations). There are lack of garages and parking areas. It depends

on location, but when buildings are too close to each other, some of them have not enough sun/light and ventilation.

Table 1 : Plan types of the built-in apartment houses in Zagreb Lower Town. source: D. Kahle [3]

STANDARD PLAN	PLAN WITH A MID BACKYARD WING	PLAN WITH A BACK-YARD EXTENSION	PLAN WITH LATERAL LIGHT WELLS
			
			

Structure and Technology

The year of construction of a building (1870-1940) provides a general idea about the method of construction and the materials that were used, and these are the factors influencing the building's energy performance. Built-in apartment houses were financed by private capital investments. Licensed builders and construction companies executed more than three fifths of these buildings. The average construction time took up less than a year for more than three fourths of the buildings. The built-in apartment houses were conditioned by Building regulations and the Regulation plan in force and carefully supervised by building inspectors.

The technical solutions used at the time were the best that could be afforded. Architects from that period used four basic materials: bricks, wood, lime and iron. Buildings have massive walls in full brick, thick from 25 to 80 cm (in some cases even more), without thermal insulation. The outer walls alone bear the load. They are correspondingly thick and solid on the lower floors. On the top floor, they are at least 25 cm thick Their ability to store heat is very good. Together with the solid middle wall and the large amount of space, apartments from this period have a very well balanced indoor climate.

Most frequently, they are two and three-story buildings with unheated basements and attics and with gable roofs. There are a relatively large percentage of apartment houses with basement apartments and attics converted into apartments. (Fig. 2.)

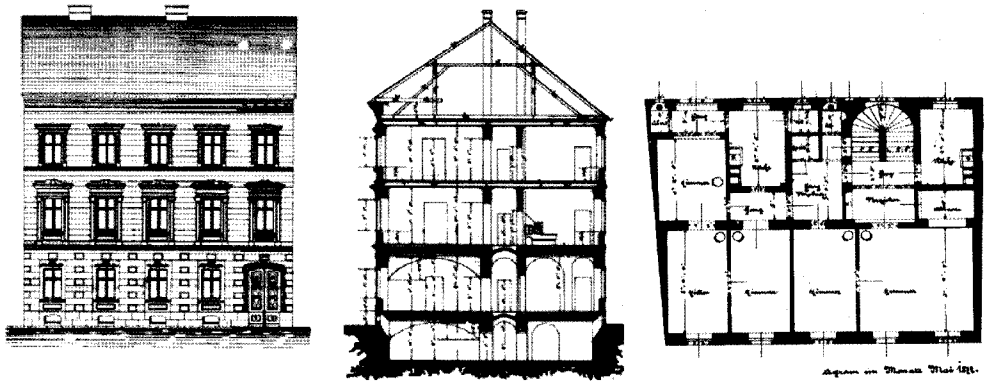


Figure 2 : Typical built-in apartment house from period up to 1940: street façade, section and 1st floor plan.

Buildings have wooden-beam ceilings, with the exception of basement and ground-floor structures that were frequently built as massive arched constructions. The most widespread type of roof was a single-pitch roof to the street with a flat roof to the backyard. The openings are generously sized. The street facades are rendered with ornamentation, fitted out with a richly adorned front, a spacious stairwell and oriels or balconies. (Fig. 3.)

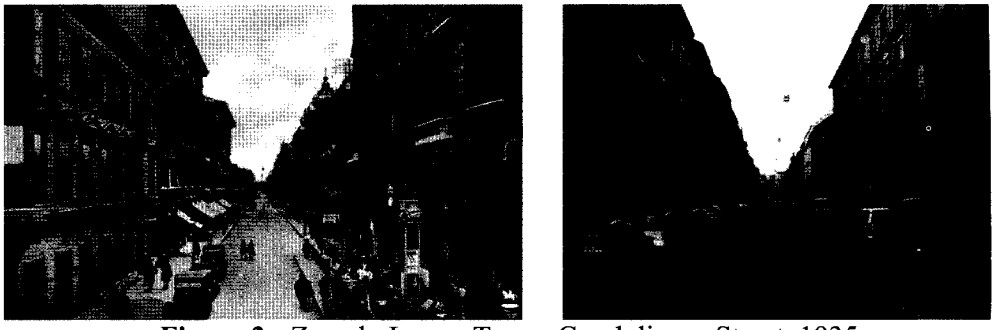


Figure 3 : Zagreb, Lower Town, Gunduliceva Street: 1935 (source:www.skyscrapercity.com) and today.

The elegantly designed front houses contrast with the buildings, which were set back from the street. Doors and single-glazed windows were most often with wooden frames and with distance between two window sashes wider than 10 cm. This kind of a window solution results in considerable heat losses, due to both transmission and air infiltration through poor sealing joints.

From a historic distance, an ecology evaluation of the quality of housing architecture shows a good building quality. Natural materials were used in construction. Buildings are still in pretty good shape. Good thermal insulation is a result of wall dimension

(tick and solid walls). Insulation is questionable due to the dense building. Trees inside and around some block are used as plant protection from sun radiation.

Models

On the basis of division of residential buildings by period and technology of construction, models were created and heat loss estimates made for these buildings. The analysis covered models of multi-apartment buildings for the period of construction up to 1940. The process included definition of their simplified models and specification of their geometrical characteristics and their components that make the building envelope between the heated and unheated environment. (Fig. 4.) An analysis of models eventually showed the influence of orientation to be under 10 %, so this factor was not considered in the analysis of final results. [1] [5]

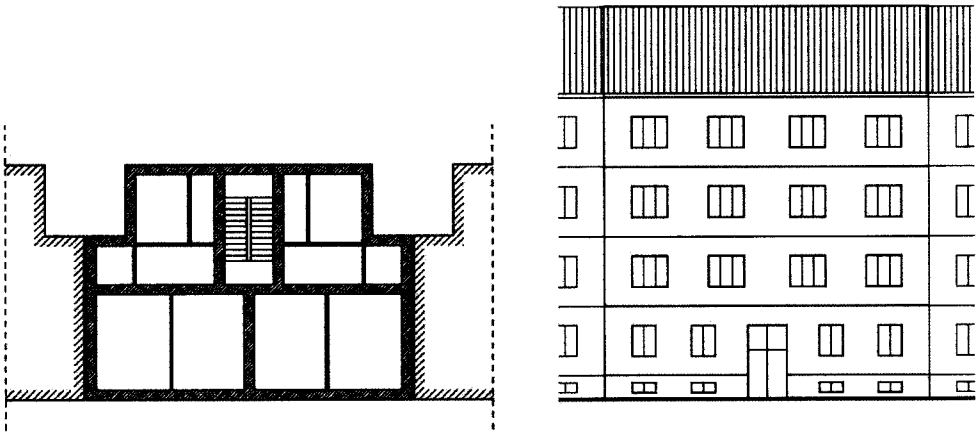


Figure 4 : The model of a built-in apartment house from period up to 1940: characteristic floor plan and street façade. [5]

Models were defined for built-in apartment houses i.e. buildings that are part of a "block" and for those that are free-standing. The plan type of the building is characterized by a central backyard extension. The calculation of energy each of these buildings uses for heating was done according to the current algorithm for calculating energy required to heat/cool the inside of a building (HRN EN ISO 13790). For the purpose of this calculation, the heating temperature was taken to be 20 □C/24 hours/7 days. The change of air which depends on the air-tightness of rooms makes a significant impact on energy loss in houses from this period, particularly in the case of airflow due to inadequately sealed joints around windows and the exterior doors. For this reason, we factored in the air change of 1.0 h-1. Heat losses in buildings are significantly high. (Table 2.)

Energy Efficiency Upgrades

The renovation of historical buildings is frequently faced with the challenge of how to improve the thermal insulation levels of old structures effectively and simply. Till today there has been no method available which offers a technically satisfactory solution to this problem without noticeably changing the outward appearance of the building. There are a number of simple measures that can serve to improve the energy efficiency of existing buildings. Architectural and engineering interventions are suggested which can improve thermal insulation of the building envelope and the elements incorporated in it (openings).

Improving Thermal Performance of Basements, Floors and Roofs

The heat requirement can be reduced by insulating the unheated attic ceiling. If the basement is used, the thermal performance of floors and walls contribute reducing heat loss. In order to attain a satisfactory heat loss limitation level thermal insulation should be also applied in the unheated basement ceiling. Thermal insulation should be also applied in the roof construction (in flat and in pitched roofs). From the outside these renovation measures are not visible and can be applied independently from other measures. Through complete conversion of the attic floor and through insulation of basement, the heat requirement can be reduced by almost 50% but these measures of renovation are not sufficient.

Improving Walls Insulation (Internally)

Outer changes are not allowed because of historical value of the building. The facade is the face of a building. The proposed thermal insulation can be added on inner surfaces of external structures. There are often prejudices against insulation from the inside because of the bad reputation of the systems that were previously used. Today technically sophisticated systems are available for examle breathable interior insulation systems (iQ-Therm). Additional insulation of the inner surfaces of exterior walls can save almost 50% of the heat requirement. However, if insulation is applied to the inside of the outer walls so as not to cover the stucco facade, the advantages of heat storage are lost. The thermal bridges, in contrast, can be ignored due to the wooden ceilings. The thermal comfort inside the building could be crucially increased by additional insulation on the roof, the external walls and the floor slab.

Improving Window Insulation

Openings should adapt to the style in shape and detail. Energy efficiency upgrade consider improvement of the existing window frames or the installation of new windows of identical material and appearance, but with the old glass replaced by insulated glazing (low-E glass with inert gas in the airspace). With double windows, the external panes are the ones most frequently retrofitted or replaced as the single

pane, while the internal panes are replaced by new glazing which is more energy efficient. When this is the case, measures to prevent condensation on the external-pane glazing need to be undertaken. Reducing natural air ventilation to the minimum change of air (0.5 h-1) is another energy-saving measure. Depending on the planned measures and their combination, it is possible to achieve savings, which will result in a significant reduction of the loss of energy needed for heating.

Results

Architectural and engineering upgrades suggested additional layers of thermal insulation and quality frames and glazing of windows and doors. This project proposed thermal insulation of building envelope introducing minimal insulation of building construction parts - for outer walls (EPS: 12 cm), walls towards staircases (MW: 8 cm), floors above unheated basement (EPS: 12 cm), roofs/attics (EPS: 12 cm) and windows Uw=1,3 W/m^{2}K.

Table 2 : Data on energy consumption for existing and renovated multi-apartment buildings up to 1940.

Energy consumption for residential buildings up to 1940	Continental Croatia: Zagreb, Maksimir Weather Station	
	$Q''_{H,nd}$ [kWh/m^2]	
Building type	Current state	Energy efficiency upgrades
Linked (part of a block)	227	65
Detached (free-standing)	277	70

The average amount of heat loss in buildings is between 220 and 280 kWh/m^2 annually. Analyses further show that, by improving thermal insulation of the building envelope, this amount is reduced to 60-70 kWh/m^2 annually, which means thermal energy consumption decreases by around 70%. [6] (Table 2.)

After the implementation of architectural and engineering measures aimed at improving the energy efficiency of buildings, data on their energy consumption show a cumulative result of all the interventions made on the building shell (walls, roofs, floors and windows), and a decrease in ventilation heat loss. Architectural and engineering interventions are necessary, but not the only ones that can be made to reduce the consumption of energy for heating, cooling, ventilation, lighting and domestic hot water preparation without reducing the living comfort.

Conclusion

Traditionally build structures require a medium level of refurbishment every 50-60 years and a major refurbishment every 100-120 years. The Lower Town residential houses built 100150 years ago need renovation and energy efficient upgrades.

The primary goal of this research was the preservation of historic building substance and its adjustment to the new requirements and today's needs. Energy-efficiency upgrade project has to be designed respecting various regulations and guidelines that insure the best building construction in terms of form, construction, building physics and economizing. By giving some of the basic principles of historical buildings techniques and specific technical measures, cause of further building decadence can be prevented and solved.

At the end, the main conclusions could be drawn from the work described:

- Modifications = energy-efficiency upgrades are necessary,
- Simple and non-intrusive architectural and engineering upgrades are possible,
- Measurable factors such, as energy efficiency, have to be taken into consideration as well as factors that can be assessed qualitatively such as health and comfort,
- The built-in apartment houses from the period up to 1940 have great potential in terms of energy savings.

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