Doctoral Dissertation

REHABILITATION OF HERITAGE BUILDINGS:
Energetic Retrofit in the Historical District of the Budapest Old Jewish Quarter

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COMMONLY USED ABBREVIATIONS AND NOTATIONS

ABBREVIATION AND NOTATIONS	MEANING	MEASUREMENT UNIT
$\sum A/V$	total heated building envelope surface per volume	m^2/m^3
A	footprint of the building	m^2
A/P	ratio of footprint per perimeter	m^2/m
A_N	net heated area	m^2
APR	Annual Percentage Rate	-
CF	Cash Flow	-
CH	Condensation Heater Scenario	-
CSOK	Funding for Dwellings of Families	-
DH	District Heating Scenario	-
E_P	Total primary energy consumption	kWh/m^2a
EPBD	Energy Performance of Buildings Directive	-
ESCO	Energy Service Company	-
EU	European Union	-
GIS	Geographic Information System	-
HP	Heat Pump Scenario	-
LI	Least Invasive Scenario	-
Low-E	Low-Emission (glass)	-
NÉES	National Building Energy Strategy	-
NPV	Net Present Value	-
NZ	Nearly Zero Scenario	-
OR	Original Scenario	-
q	heat loss coefficient	W/m^3K
q_F	specific net heating energy demand	kWh/m^2a
Q_F	total net heating energy demand	kWh/a
SAI	storey area indicator	-
U	thermal transmittance	W/m^2K

MOTIVATION AND ACKNOWLEDGMENTS

Since my childhood, I have always been interested in historical buildings, which curiosity was planted in me by my parents, taking me and my brother to travel frequently. I choose to become an architect based on these experiences. During my university years, I aimed to focus on the research activity in my studies. After earning a degree at Ybl Miklós Faculty of Architecture and Civil Engineering, Szent István University, Budapest, one of my dreams came true: I received a job offer to teach at the university, which I accepted. With this decision, I was set to continue working on the academic side of the architectural profession.

The foundation of the present doctoral dissertation was a cooperation between Osaka University and my alma mater, which began in 2009. I was a Bachelor student, when I first met Professor Kita and his students who were interested in the Budapest Jewish Quarter. I instantly took the opportunity to work together with them. In 2014, I was given the chance to work on the Jewish Quarter research in the Osaka University for two months, which was another dream coming true for me. Since then, I have visited Japan multiple times.

When the time came for me to decide on my dissertation topic, I chose to work on the preservation of the above-mentioned unique area of Budapest, and the building type it contains. My studies also led me to deal with one of the most important questions of our time: sustainability and energy efficiency. The common ground between heritage preservation and sustainability resulted in the proposition of current work.

The current research and the preparation of the dissertation lasted many years to complete, during which I received enormous support and help from people, who I wish to express my gratitude to:

First and foremost, I am most deeply grateful to Professor Michihiro KITA for the continuous trust and support I received from him since 2009, which greatly affected my choices of carrier and study, as well as research. With his support, in 2018 I spent two months at the Osaka University for research, which influenced me deeply, and taught me a great deal about research and publication methodology.

I would also like to express my gratitude to my wonderful colleagues for the suggestions, support and help during the research: Prof. Rudolf KLEIN DSc, Prof. Balázs MARKÓ, Dr. Gergely NAGY PhD, Dr. Aurél BENÁRD DLA, Dr. Attila TALAMON PhD, Viktor ROZMANN, Zoltán LACZÓ and Prof. Gyula KISS. I am especially grateful to András HORKAI, who supported this research from the very beginning with his expertise. I am also deeply thankful for the extensive and selfless help of Dr. Béla NAGY, and Ms. Anna PERCZEL, who shared their outstanding knowledge about the area with me. In addition, I would like to thank the Architect Master students of Ybl Miklós Faculty of Architecture and Civil Engineering, Szent István University for their help in field survey.

Furthermore, the professional help of Dr. Szabina TÖRÖK PhD and Dr. Bálint HARTMANN PhD from the Hungarian Academy of Sciences, Centre for Energy Research was essential in completing the work.

I am deeply grateful for Miwa SUGITA and Kyoko NAKAGAWA for their support and help during my stays in Japan!

Last but not least, I would also like to thank my wonderful family: my Mother, Father and Brother. I am especially grateful for my Husband for his patience and emotional as well as professional support thorough the years.

ABSTRACT

Today several energy saving measures are taken worldwide. As a segment of these, energy efficiency of the buildings should be increased. In Hungary, the number of new buildings is very low annually, thus the rehabilitation of the existing, ineffective building stock should also be considered as an energy saving measure. Historical districts and heritage buildings constitute a special part of the above question, as several limitations increase the complexity of their retrofit. Therefore, it is highly important to establish renovation guidelines for these buildings, which provides better life quality for the residents by increasing energy efficiency, while respecting the unique, historical architectural character.

The major architectural heritage of Budapest is the *en masse* of the traditional apartment buildings built around the turn of the 19^{th} and 20^{th} century. They are the most significant part of the cityscape, with their ornamented façade and unique forming, making the area internationally recognised as historical, cultural and architectural heritage.

Currently, most of the buildings in Budapest downtown districts are in a poor condition, due to the lack of maintenance. Although their importance is not questioned, apart from some protected buildings, most of the traditional stock is not sheltered from demolitions by law. Such unprotected buildings are often destroyed to be rebuilt as contemporary apartment houses or modified to the point of losing their original values. One of the reasons for demolitions is the poor energetic state of the house and the sustainability problems. The heating energy used for the winter is particularly excessive. As these downtown districts are the most populated parts of Hungary, the problem affects numerous residents.

Planning an energetic rehabilitation for heritage buildings, however, meets several limitations, narrowing down the possible energy efficiency interventions.

The aim of the present research is to find solutions for heritage respecting energetic retrofit of the traditional apartment house type. The renovation of these historical buildings requires special methodology and technology: the conventional interventions, for example heat insulation, is seldomly applicable: the ornamented façade and custom-made fenestration cannot be insulated or replaced with regular solutions, without damaging the heritage values.

The case study area is situated in the middle of the above area in Budapest: part of the 7th district, known as Belső-Erzsébetváros, named the old Pest Jewish Quarter.

Various investigations were carried out to answer the above complex question. This survey focuses on three main aspects: Architecture, Energy and Refurbishment. To be able to give a complex answer to the heritage respecting energetic renewal, all the characteristics, limitations and opportunities covered by the three topics were investigated and combined to reach conclusions.

First, the architectural character to be conserved is described. Style, forming and structure typologies were defined to be able to assess the full building stock.

As a second part, the energetic characteristics of the buildings are surveyed. Using bottom-up methodology, demand-side energetic values were calculated. Their connection to the geometry and architectural style were surveyed in detail. The results show that the heating energy demand can be estimated based on geometry and architectural style data.

As the third step, by investigating the limitations of heritage protection, structural and engineering upgrade scenarios were created. The effect of renovations on the buildings' energetics were surveyed. The calculation results show that reaching the nearly zero energy level prescribed by the European Union is possible using heritage respecting solutions. The traditional buildings show high energy saving potential, the heating and domestic hot water energy can be reduced by 69% with retrofit measures.

The above results help to estimate the energy saving potential of a traditional building stock on large scale and contribute to the estimation of the national energy saving potential of Hungary. The results can also be used as a benchmark for energy demand and usage assessment based on simple geometry and style data of a building. By offering multiple heritage respecting choices, the scenarios can be used as decision support for a future rehabilitation project.

Keywords:

Budapest, building rehabilitation, building typology, decision support system, energy efficiency, heritage protection, historical building, Hungary, nearly zero energy, rehabilitation, retrofit methodology

1 INTRODUCTION

1.1 IMPORTANCE OF THE TOPIC

Climate change is one of today's most crucial topics, which is on several points linked to the built environment. The construction sector is one of the most influential energy consumers in Europe, and the energy utilization of buildings has been constantly increasing in the last 20 years. In most European Union countries, the buildings are responsible for more than 40% of the total primary energy consumption (European Parliament and Council, 2010).

Although the newly designed buildings must comply to strict energy efficiency measures, their ratio is insignificant compared to the vast number of ineffective houses. In Hungary, the phasing out of the buildings (including demolitions and new constructions) is only 1,7% annually (Hungarian Central Statistical Office, 2019). This means that the present building stock plays and will play a significant role in the energy usage of the country for a long time – which should be considered when planning energy saving measures at country level.

The energy efficiency of the existing buildings is a complex question, and their renovation is even more difficult when they have historical and cityscape values, limiting the possible technical solutions.

The traditional multi-storey apartment houses of Budapest, dating from the turn of the 19th and 20th century is considered such heritage building type. They were usually built in an unbroken row, with enclosed courtyards, ornamented façades and other characteristic architectural elements. All the buildings are unique in detail, but together they create a unified cityscape. This building type of Hungary can mainly be found in Budapest downtown (88% of the total, national stock of the type (ÉMI Építésügyi Minőségellenőrző Innovációs Nonprofit Kft., 2015)).

Literature deals with the history and architecture of the traditional apartment buildings of Budapest in detail, but their present problems and future are rarely mentioned. Their rehabilitation is, however, unavoidable, due to their averagely bad condition. In the last few years, the demolitions increased in number, and multiple irreplaceable buildings were destroyed under the pretence of modernization. One of the reasonings to destroy a building is the insufficient energetic state.

Therefore, surveying the energetic characteristics of the historical buildings and offering guidelines for heritage respecting renovations might help saving more and more historical buildings, and maintain the unique, historical cityscape of Budapest downtown.

The chosen case study area is situated in Budapest, referred as Old Pest Jewish Quarter, which is in some ways more unique than most of the downtown districts. The forming of the houses is diverse, opening the opportunity to survey multiple variations of the historical apartment houses in focus, helping the future adaptation to other districts. Also, this choice of area aims to highlight the fast demolitions and the thus endangered Jewish memories. The above problem is topped by the averagely bad condition of the buildings (Nagy, 2008) and the large number of inhabitants (Szabó, 2012), which is why the problems affects numerous people.

1.2 AIM OF RESEARCH

The aim of this study is to find heritage respecting energetic retrofit solutions for the traditional apartment houses of Budapest. By creating renovation guidelines, the decay and demolitions of this important building stock might be stopped.

As the problem of the heritage respecting rehabilitation is multi-sided, the research contains architectural, energetic and refurbishment topics. To find the consensus between energy efficiency and heritage protection, a complex methodology was used to combine the aspects. The methodology contains a wide range architectural analysis covering geometry, structural and style data, expanded by energetic surveys, such as calculating energy demand and energy usage. The above were combined in refurbishment guidelines, built on the analysis of boundaries and possibilities. The guidelines are detailed in structural and engineering system scenarios, their energy saving potential is compared to find the optimal solutions.

The conclusions can be used as decision support for planning heritage respecting rehabilitations in the future. Also, the estimation of energy demand, usage and energy saving potential of the stock is also possible based on the results. Currently in Hungary, there is no available energy density information system or energy saving potential map, which would make the necessary improvements foreseeable and plannable. The present study also wishes to contribute to solve the hiatus.

1.3 LIMITATIONS OF RESEARCH

As the aim of the research is to create systematic rehabilitation guidelines based on complex architectural, energetic and retrofit surveys, the research contains technological and architectural engineering aspects. Social-demographic effects of a possible retrofit are not addressed here, the study only aims to find optimal technical solutions between the contrast of energy efficiency and heritage protection.

In the present study only, the residential buildings were surveyed. This function is the most common one in the stock of all buildings, and also if only traditional buildings are regarded (see in Section 2.5.2 in detail). Focusing on one type of function offers a better comparison of the energetic characteristics.

Given that the dominant form of energy usage in the Hungarian residential buildings is winter heating and domestic hot water production, the study focuses on these aspects (see Section 3.1 for further details).

1.4 FRAMEWORK OF STUDY, STRUCTURE OF DISSERTATION

Due to the complexity of the scope above, the dissertation is built on three connected parts: Architecture, Energy and Refurbishment, providing input data for each other. The structure is illustrated in Figure 1.

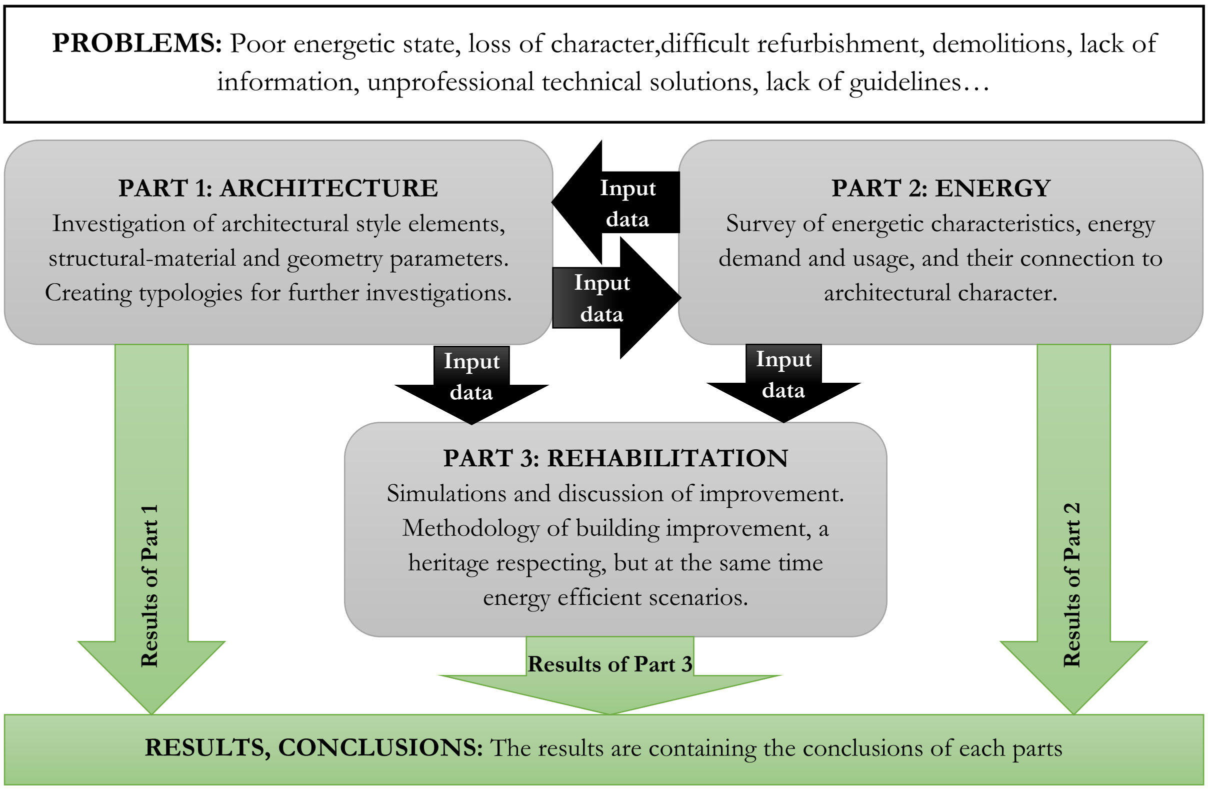


Figure 1: Structure of the Dissertation (source: Authors' own figure)

2 PART 1: ARCHITECTURE

- **Aim of Part 1**

The aim of this part is to understand the architectural characteristics of the buildings in the case study area, and to create typologies to support the latter steps.

- **Methodology of Part 1**

First, literature research was carried out, previous studies were collected and analysed (Section 2.1).

Parallel to the above, a field study began in the case study area. It included physical measurement of dimensions and documentation of each building. During the field research, every building was photo documented (APPENDIX A), the main geometrical data (footprint, perimeter, height, size of arcade, type of roof…) were recorded. In the case of inaccessible areas, like: roof geometry or enclosed spaces, Google maps (2019) and Apple map (2019) applications were used to collect data. The above recorded data also contained the information required for later energy calculation (Part 2).

A detailed database was created on the chosen case study area. Table 1 summarizes the type and source of the main data. The table was created in Microsoft Excel format (APPENDIX B), extended with QGIS software (2019), which helped to visualize the data on maps based on identification codes assigned to each building (APPENDIX B).

As the next step, statistical analysis was carried out. The ratio and distribution of different functions and construction years were surveyed (Section 2.5).

The case study area contains almost 500 buildings; thus typologies were created to support latter calculations and refurbishment (Section 2.6). A survey of architectural styles was carried out based on literary sources combined with data of the Jewish Quarter to define the 'Style typology'. The layout (footprint) of each building was assessed and sorted into groups based on its main form, to define a 'Geometry typology'. 'Structural-material typology' was created based on characteristic utilized structures of construction each year. Using the typology, 'Packages' which summarize data of all enveloping structures were added to each building.

To clarify the special characteristics of the Jewish Quarter, the relationship among main data, architectural style, geometry, and package were assessed.

See the methodology of Part 1 visualized in Figure 2. See results of Part 1 in Section 2.8.

Table 1: Type, source and period of main architectural data in the database

Data type	Source	Period of investigation
Year of construction	Budapest City Archives (Budapest City Archives Database, 2019), literature research*)	2009–2015
History of modification	Budapest City Archives, literature research *), interview to owner/residents	
Geometry (size of footprint, height…)	Budapest City Archives, satellite images, physical measurement**)	2016–2017
Current function	Field study, observation	
Drawings (plan, section, elevation)	Budapest City Archives, literature research *), photo documentation**) (façade)	
Structure and material	Budapest City Archives literature research *), photo documentation, observation**)	2017

***) See Section 2.1**
****) If there were no data available in archives or books, new data is created by measurement, observation, and photo documentation**

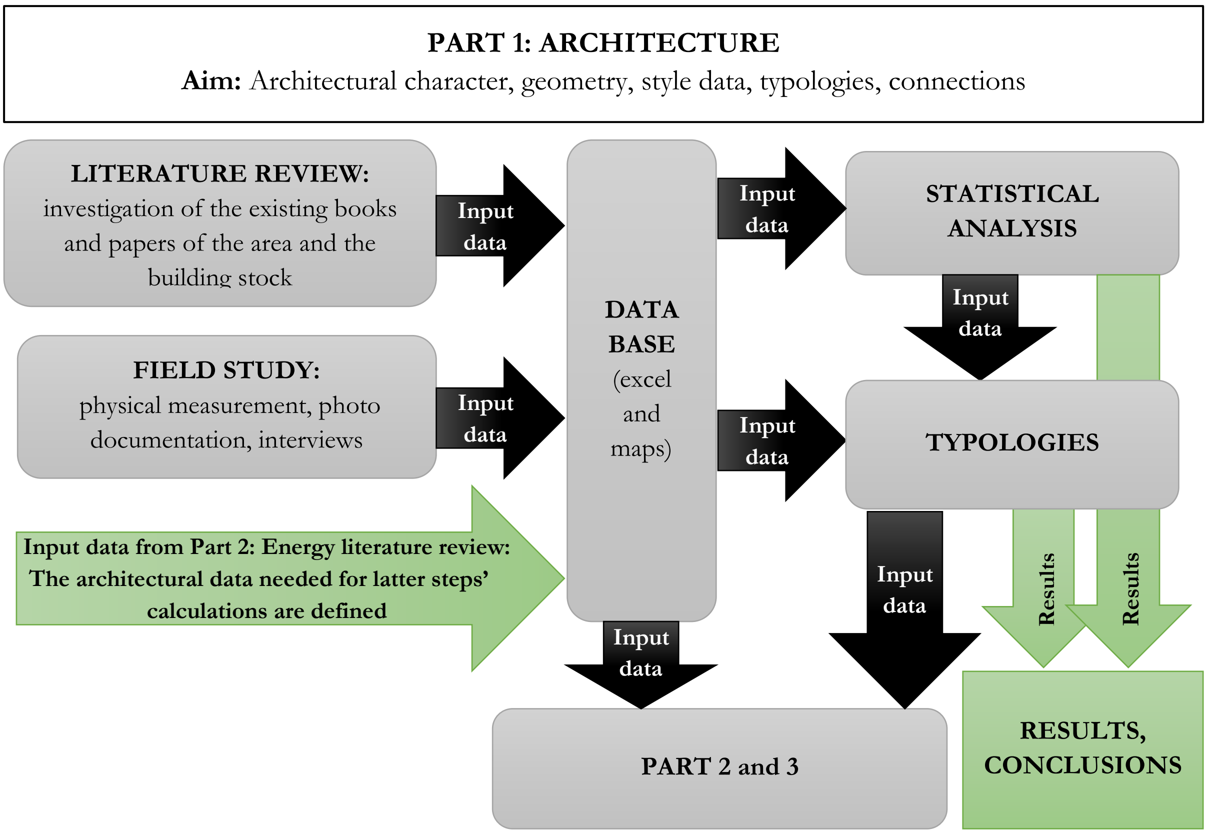


Figure 2: Methodology of Part 1 (source: Authors' own figure)

2.1 LITERATURE REVIEW, PREVIOUS STUDIES

Several studies analyse the inner districts of Budapest focusing on historical and architectural questions. Concerning architectural styles of the surveyed time range, the books of Sisa (2015), Sisa and Wiebenson (1998), Ritoók (2003), Prakvalvi, et al. (2004), Rados (1961), and Kalmár (2016) should be mentioned.

Dealing with the most characteristic building type of the area, the traditional apartment houses, Körner (2010) summarizes the most important data on investors, space relations etc. Also surveying the traditional apartment houses, Ritoók's two books (1991) and (2003) were used, which details the usual structures and layouts of the type.

Pattantyús (2013) surveys extensively the building structures and materials used in the characteristic residential houses of Pest. Edvi (2005) book also offers information about the mandatory building structures and materials of the 19th century.

Specializing in the Old Jewish Quarter of Pest, Anna Perczel's (2007) outstanding research study focuses on the unique, Jewish related buildings of the area, and was one of the first architectural books to draw attention to the endangered buildings of the area.

In his collective study, Attila Déry (2006) summarizes the construction data of the buildings in the district. Béla Nagy's survey for preparing the regulation plan on the area contains investigation of the building stock (Nagy, 2008). Rudolf Klein introduced a matrix typology of synagogues, containing the Jewish Quarter examples (Klein, 2011). Nagai et al. (永井裕太, 2009) revealed the process of transformation in urban fabric by analysing the memories of the Jewish community.

Although it is not closely related to architecture, an important study Frojimovis, et al. (1999) examine the history of the Jewish Quarters, describing important events, and the Jewish lifestyle, assisting the understanding of Jewish influence on the architecture of the area.

About the past rehabilitation attempts, information can be found in the author's previously published paper (Sugár, et al., 2017).

Based on the previous studies, it can be concluded, that several investigations have been carried out in the Old Jewish Quarter. However, the typology and possibility of renovation of the full existing building stock has not yet been examined.

Information of each building, such as the year of construction, history of modification, geometry, drawings, structure, and material, was investigated based on data of the Budapest City Archives Database (2019), and the above literary sources. Around 80% of the required data of buildings is incomplete in the archives, or in historical books. In consequence, interviews, physical measurements, and photo documentation were utilized to complete the data of such buildings.

2.2 SHORT HISTORY OF BUDAPEST

Budapest is the capital and largest city of Hungary, divided by the River Danube (Figure 3), which was created by merging the adjacent towns Buda, Pest and Óbuda (old-Buda) in 1873. Although it was not always the capital of the country, the settlement has always been an important centrum. Its history goes back thousands of years.

The earliest written records started with the establishment of Aquincum by the Roman Empire around AD 89. During the Roman occupation, the River Danube and the fortress system alongside it served as border protection. The Hungarian conquest of the Carpathian Basin happened in AD 896, when the Budapest area became a tribe fortress of Arpad, whose dynasty ruled Hungary for centuries. During the Middle Ages, multiple wars destroyed the towns Pest, Buda and Óbuda, which were eventually rebuilt. (Even the UNESCO world heritage lists the constant renewal of Budapest as one of the unique values: ”Budapest is an outstanding example of urban development in Central Europe, characterised by periods of devastation and revitalisation” (UNESCO World Hetitage site, 2002)).

The major development of the city started in the ‘Reform Era’, during the 19th century, when Pest-Buda evolved to a real metropolis of the time: The merging of Buda, Pest and Óbuda was carried out. Large expansion and development started around the downtown of the Middle Ages with new cultural and political institutions and a road system. Today’s Budapest was mainly built in this prosperous time of Hungary.

In the 20th century, the major historical disaster was the Second World War, when a significant part of the city was destroyed by bombing. The war caused the death of countless residents. The darkest episode was the ‘Holocaust’, the rounding up, deportation and genocide of the Jews. The Budapest Jews were collected to ghettos, one of which was in the case study area, the Old Jewish Quarter of Pest.

After the War, yet another rebuilding of the city started. In 1950, the surrounding smaller villages and towns were merged into Budapest, expanding its area and population. Soviet influence and occupation began in 1945, which ended in the revolution of 1989, where the “System-change” occurred, and Hungary was declared a republic.

Budapest is now divided into 23 districts with autonomous local governments under the umbrella of the Mayor of Budapest, head of the General Assembly (Bácskai, et al., 2000) (Preisich, 2004).

The major architectural heritage of Budapest is the *en masse* of the traditional apartment buildings built during the prosperous 19th century, and on the turn of the 19th and 20th century. These became the most significant parts of the cityscape, with their ornamented façades, which create a unique sight spreading out on 13 km^2 (Figure 4), making the area internationally recognised as historical, cultural and cityscape heritage.

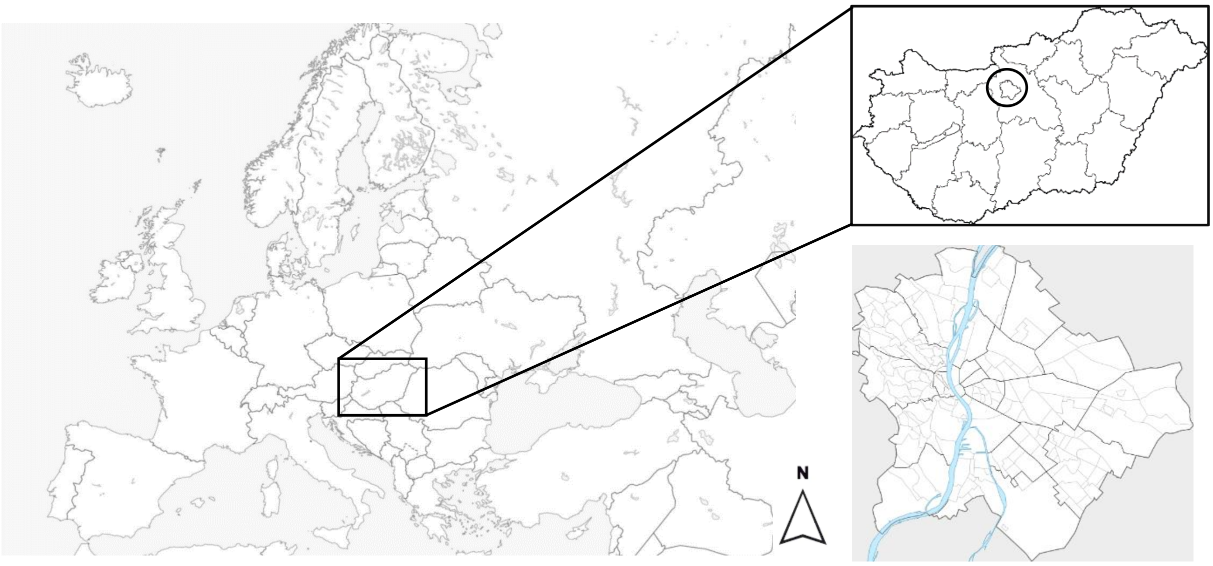


Figure 3: Hungary is situated in Central Europe, its capital is Budapest (source: Authors' own figure).

Figure 4: Left: Aerial photo of Budapest divided by River Danube. Right: Typical part of the cityscape and urban fabric. Source of the photos (Flickr, 2019) (Szeretlek Magyarország, 2019)

2.3 THE TRADITIONAL APARTMENT HOUSE TYPE IN GENERAL

As mentioned above, the 19th century was an outstanding period in the history of Budapest causing fast expansion of the city. The quick urbanisation and the demand for housing gave birth to the traditional apartment house type, called 'bérház', or house for rent in Hungarian.

The older Baroque style buildings of the 17–18th century gradually disappeared by the end of the 19th century, especially on the Pest side of the Danube. The Great Flood of Danube in 1838 destroyed the majority of the existing buildings, which quickened this change.

During this era, the population of Pest had grown rapidly, bringing an unprecedented wave of constructions. The evolution of the aforementioned characteristic apartment building type is closely linked to this population growth, which resulted a dire need of mass construction. As the newly settling population was of less wealthy social state, individual constructions were not an option. The few wealthy citizens thus built larger apartment buildings for rent (Ritoók, 2003). The so emerging new buildings were larger, with unique façades, but complying to strict construction regulations, thanks to which the streetscapes remained unified (Figure 5).

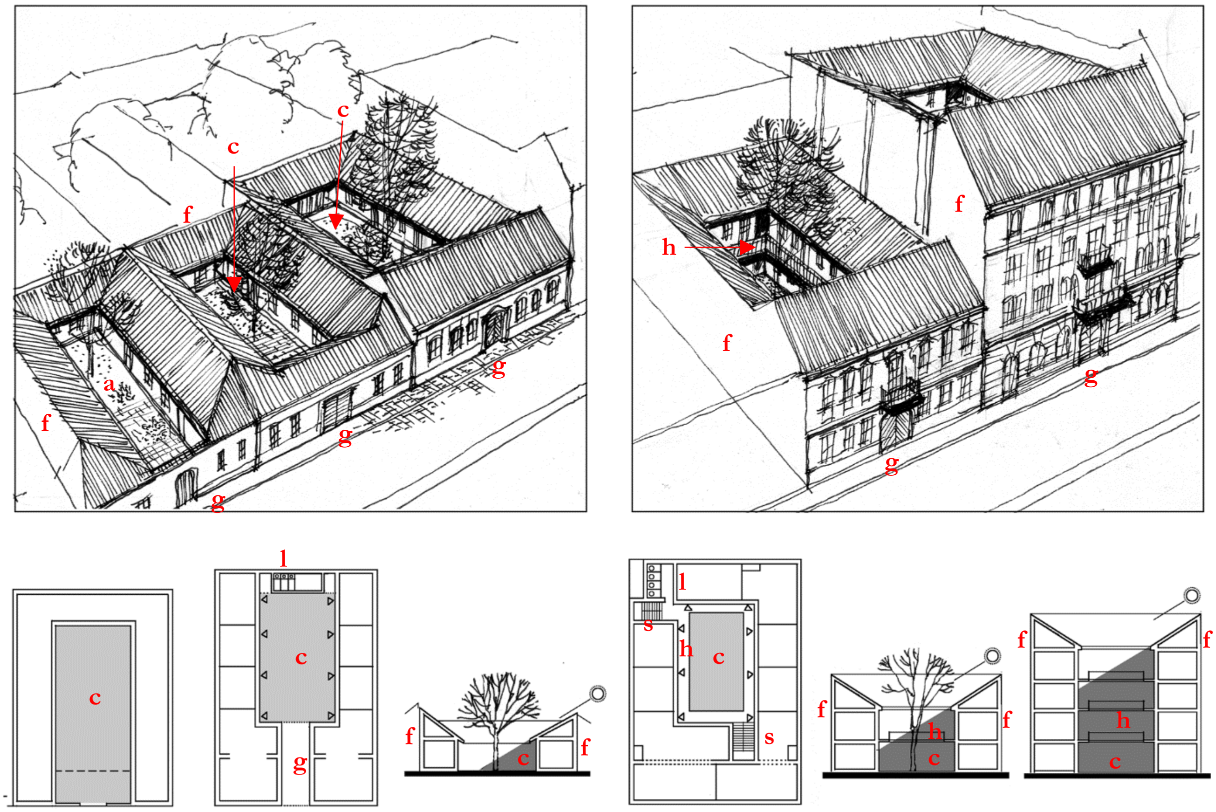


Figure 5: Left: The forerunner of the traditional apartment houses in the 17th–18th century with an enclosed courtyard, but one or maximum two storeys. Right: Typical traditional apartment houses from the 19th century, built in a row with an enclosed courtyard. Nearing the turn of the century, they became higher with darker courtyards (Bitó, 2003).
c = courtyard; l = common lavatory; h = hanging corridors; g = gate; f = firewall; s = staircase

As mentioned above, this type functioned as a condominium with different size and variously equipped flats. The buildings are mostly built around a courtyard. The street front wing is more decorated, containing larger flats. Traditionally, the owner or a rich renter occupied these. The courtyard wings contain simpler flats, often only with a kitchen and a room. Older examples of the type have common lavatories at the end of the corridors, as a conventional solution of hygiene in the 19th century. The courtyard can be accessed by using the gate on the street front. Near the gate there is the main staircase. The flats on the upper stories can be entered from the hanging corridors running parallel the walls. This type of building is mostly built in an unbroken row along the narrow streets of the 19th century Pest, connecting to each other with firewalls on three sides (Körner, 2010).

The proportions of the buildings (height, ratio of the courtyard), structures and materials were strictly regulated at the time (Edvi, 2005), resulting in a unified streetscape, but due to the diverse architectural forming and ornaments each and every building is unique. The general type of building itself with some differences is widespread in Middle-Europe, in the towns of the former Austro-Hungarian Monarchy.

After the Second World War, the larger flats were divided up and used as co-lease to cope with the housing shortage. Private lavatories were built in the flats during the 1960–70s. For decades, these houses have faced with constant neglect based on political and financial reasons, resulting in today's obsolete state (Nagy, 2005).

Presently, around 10 000 buildings of this type exist in Hungary, with more than 242 000 flats, adding up to a total 14 million m^2 footprint. 88% of the buildings is found in Budapest (ÉMI Építésügyi Minőségellenőrző Innovációs Nonprofit Kft., 2015).

The above facts underline the importance of a heritage respecting modernization, to be able to protect the values and character of the buildings, but at the same time increasing the living standard of the residents.

The case study area is situated in the middle of the above area in Budapest: it is a part of the 7th district, known as Belső-Erzsébetváros (Eng.: Inner-Elizabethtown), or the former Jewish Quarter of Pest.

2.4 CASE STUDY AREA

2.4.1 Main data

The chosen case study area is situated in the statistical boundaries of Budapest 7th District, bordered by Király Street, Erzsébet Boulevard, Rákóczi Street and Károly Boulevard, which runs parallel to the past Medieval city walls (Figure 6). The area includes the so-called Old Jewish Quarter of Pest.

This part of the downtown area, named Belső-Erzsébetváros (Inner-Elizabethtown), was mainly an agricultural area until the 18th century with rural fabric. Today, 477 plots and 441 buildings are situated on 0,6 km^2. The most characteristic building type of the area is the above mentioned traditional multi-storey apartment house with a courtyard. They were mostly built around the turn of the 19th and 20th century, but younger buildings can also be found scattered in-between. The oldest of the stock was built in 1811, the newest in 2016. 86% of the buildings were built before the end of the Second World War, which the author considers traditional.

Compared to its size, the population is high, its density is almost 25 000 person/km^2 (Hungarian Central Statistical Office, 2015) making it the most densely populated district of Budapest and Hungary.

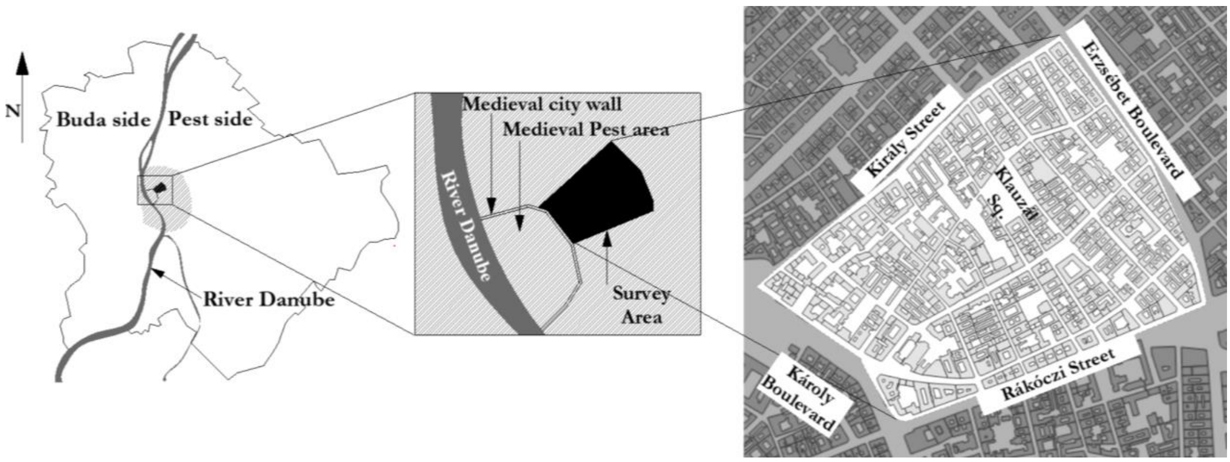


Figure 6: The case study area is situated in the middle of Budapest, next to the past Medieval city wall (middle). The slashed area on the left represents the area in the city built with traditional apartment houses (source: Authors' own figure).

2.4.2 History

The case study area was considered an outside area next to the city wall with village houses and fruit farms until the 18th century. The narrow, rectilinear streets of today can be originated from the agricultural past. Even today, the blocks bordered by these streets are unusually deep, resulting in interesting plot and layout forms. This organic fabric was preserved because the development of the area predated the major city regulation plans. The real urbanization of Inner-Elizabethtown started in the 19th century. After the destruction of the Great Flood of the Danube in 1838 (Figure

7), the rural houses mostly disappeared, yielding their place to the newly forming traditional apartment houses (Figure 8) (Perczel, 2007).

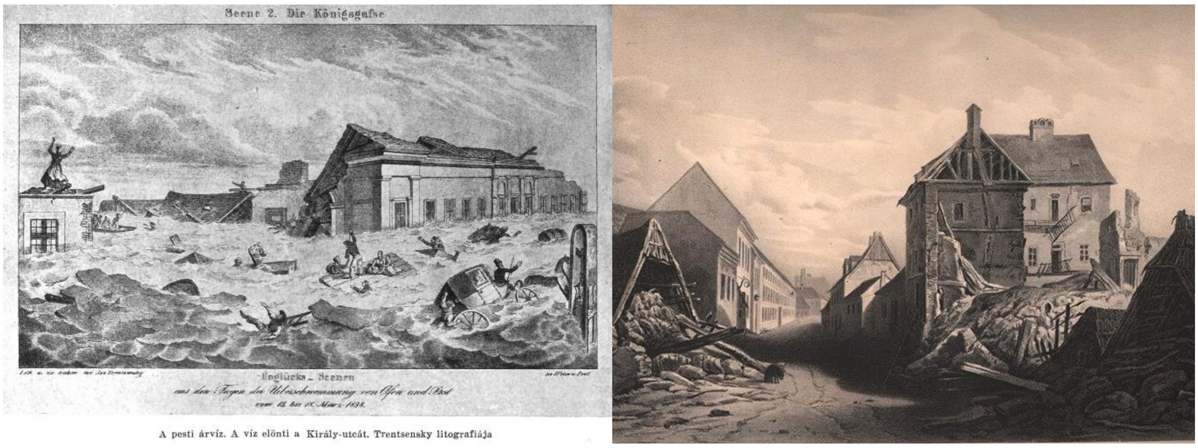


Figure 7: Király street during and after the Flood of 1838. All the rural adobe houses were destroyed. Source of picture: left (Pásztor, 1938) right (Kaján & Piros, 1988)

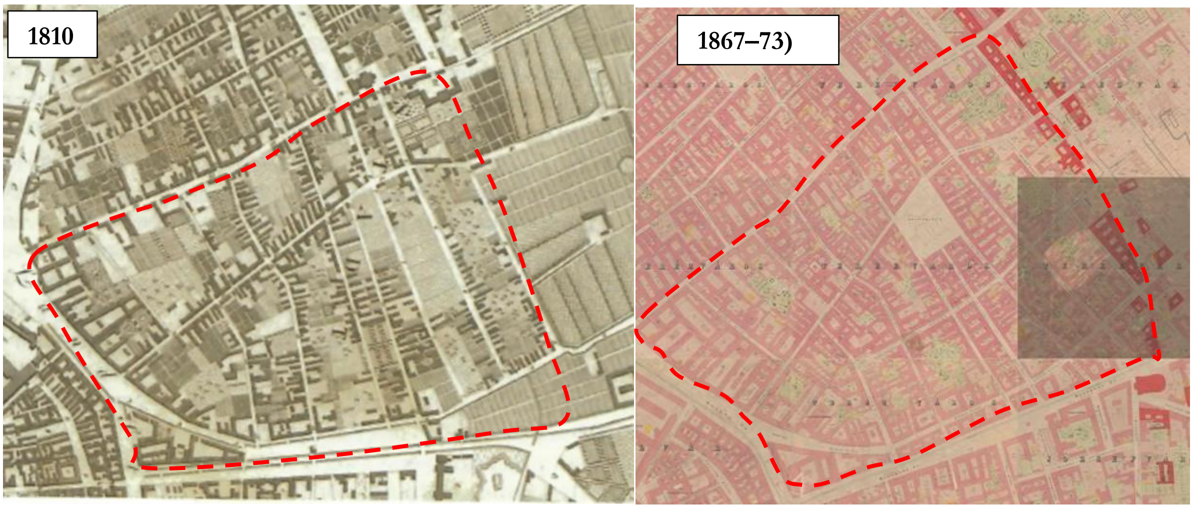


Figure 8: The urbanisation of the area occurred during the 19th century. At the beginning of the century, the area was rural, agricultural (Source (Perczel, 2007)). Until the end of the century dense urban fabric of today emerged (Source (Mapire, 2019))

Figure 9: Left: Market day in the Klauzál square. Middle: Trade-signs and shoppers on Király Street. Right: Streetscape around the turn of the century. Source of the pictures: (Fortepan, 2019)

The district underwent fast development, functioning as a residential and commercial area (Figure 9). The peak of this evolution was around the turn of the 19th and 20th century, when the area was operated mainly by the Jewish residents.

The Jewish occupancy in the area was a consequence of the restrictions on certain minorities. Until Joseph II's Patent of Toleration in 1783, Jews were prohibited to enter the walled city of Pest. The development of their commercial district started here, adjacent to the long-existing Jewish Market, right next to the city wall of Pest. Only a law of 1840 permitted them to own real estate, until then, the daily practice of religion was carried out in praying rooms of rented apartment buildings (Figure 10) (Frojimovics, et al., 1999).

Figure 10: The since demolished Orczy House, which was the largest house of the area, providing rental apartments, synagogue, kosher butchery and many other functions for the Jewish renters. Right: indoor synagogue; Left: street front façade; Pictures from around 1880. Source (Egykor, 2019)

There is a certain uniqueness of the area provided by the Jewish residency. The majority of the buildings in the area could be typical in other parts of the city too, but the older, 19th century houses of Pest can be found in exceptionally large numbers here. Decorative Jewish symbols can be observed on buildings together with Hungarian and Oriental motifs, which is considered rare (Perczel, 2007). The Jewish presence also can be perceived in the relatively large number of passage houses, synagogues and small factories. The passage houses enabled access through the deep block without using the streets. These expanded commercial life, at the same time supported the faster, smoother, hidden way to reach the synagogues (Frojimovics, et al., 1999). The vast majority of today's buildings was built around the turn of the century.

During the 20th century, only smaller interventions occurred, of which the project of Madách Sugárút (Madách Boulevard) was the most grandiose plan to change the mainly organic structure. The concept was to open a main road to rival the nearby Andrássy Boulevard, which is ever since its opening has been the most important avenue of the area. For the project, the largest and most important tenement house of the Jewish Quarter, the Orczy House (Figure 10) was demolished with many others. Several new plans were created, and in the 1930's, the complex of 11 interlocking buildings were built with a great gate motif to open up the densely built in inner part (Figure 11).

The project, however, halted here, and only the beginning of the boulevard was built (Sárkány, 1993).

Critics pointed out that the project demolished significant early buildings and monuments and brought a different scale of road and building stock to the area – disregarding the current structure of the city. If the project had been finished, the oldest part of the district would have been demolished. The Madách Promenade remained on topic ever since. The latest plans suggested the evolution of the boulevard to a promenade, then a passage (Nagy, 2008). This is a more delicate intervention compared to its predecessors, and the latest constructions have been created in this regard. This latest investment undoubtedly increased the tourism and average condition of the surrounding buildings; however, it still got criticism for disregarding historical aspects.

Figure 11: The Madách Houses, and the original plan to drastically change the urban fabric. Only the area marked with a red circle was rebuilt with the new houses and the huge gate motif. Source of the pictures: Photo is courtesy of Prof. Rudolf KLEIN. Right map is from (Siklóssy, 1985). Left is Authors' own figure.

Figure 12: Left: Budapest after the bombings during the Second World War; Middle: Dob Street of the Jewish Quarter with war damage 1945; Right: The Dohány Street Synagogue courtyard in the case study area with graves in 1945 (Fortepan, 2019)

Near the end of the Second World War, in December of 1944, the Jewish Quarter of Pest became a ghetto, causing devastating losses and destruction to the area and its residents (Figure 12). After this tragic time, a significant part of the surviving population emigrated (Perczel, 2007). Although, after the war, only a few of the deported residents came back, even today, a significant proportion of the Hungarian Jews live here (Ladányi, 2002).

During the post-war renovations, some the buildings hit by bombs were demolished, leaving behind empty plots as scars on the urban fabric. A restricted number of new constructions were carried out in the following years due to the financial and post-war crisis.

At the beginning of the 1980s, a short development started: rehabilitation, the renovation of historical district houses begun here, first in the capital city. In 1988, however, the program was halted after renewal of only three blocks (Perczel, 2007) (see more details in Section 4.1.2).

2.4.3 Present state

The constant – mostly political and financial-driven – ignorance of the 20th century towards the traditional apartment houses of Budapest caused significant damage. Currently, most of the buildings are in a poor condition. Their physical characteristics do not comply with today's health, economic or ecological requirements. Their poor energetic state also decreases their value. Although their importance is not questioned, apart from some protected ones, most of the traditional stock is not sheltered from demolitions by law. Such unprotected buildings are often destroyed to be rebuilt as contemporary apartment houses or modified to the point of losing their original values.

In the case study area, presently only 19% of the buildings are in acceptable condition, while the remaining 81% require renovation (Nagy, 2008). The above problem is topped by an intensive functional transformation. In the last few years, the area became the "party district" of Budapest, with its internationally famous ruin pubs. Although this function was historically part of the area and resulted in minor renewal recently (mainly on public places), the process accelerates demolitions (Figure 13).

Figure 13: Left: Renovated public place in front of the Madách House gate. Middle: Courtyard in poor condition. Right: Façade of a ruin pub, residing in one of the oldest buildings in the area. (source: Authors' own figure)

2.5 QUANTITATIVE ANALYSIS OF THE STOCK

As mentioned above, presently 441 buildings are situated in the 0,6 km^2 of the case study area on 477 plots. The population density is almost 25 000 person/km^2. The analysis started with the survey of construction time and function of the current stock.

2.5.1 Construction time range

The sources of data for the year of construction are (Déry, 2006) and (Budapest City Archives Database, 2019). The oldest building in the area was built in 1811, the youngest in the year of investigation in 2016. The buildings under construction in 2016, or the newer ones are not considered in the current survey (their number is low, under 10 until 2019).

The number of constructions of the area was not constant during the surveyed period (between the 1811 and 2016). Based on the number of buildings constructed in each year for the current stock of buildings, there were years with multiple construction activity, and years with significantly less or no activity. These periods can be paralleled with the historical events of Hungary.

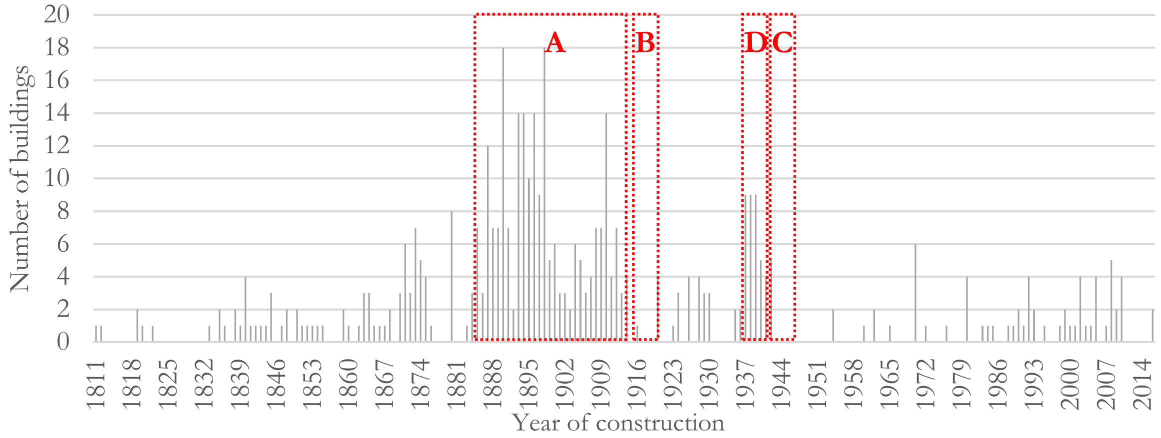


Figure 14: Number of buildings built in each year in the surveyed period, considering the construction year of the current buildings.

Figure 14 shows the number of buildings built in each year on the survey area (on current stock, not considering the demolitions and rebuilding). The peak of the construction activities of the area was between 1885 and 1915 (A). The figure also shows clearly the less active construction periods, for example during the First (B) and Second World War (C) and the following financial crisis, when a low number of new buildings can be observed. The peak around 1938 shows the project of Madách Houses (D), where a significant part of the old fabric was replaced. The average age of the buildings is 115 years.

2.5.2 Utilization of the stock – proportion of functions

The current function of the buildings was observed during a field study in 2016–2017. The predominant main function of the buildings is residential (81%, 386 buildings). The second most frequent main function is office (5%) (Figure 15). A significant part of the plots is empty, used as parking space or garden with service (7%)

Nearly all the buildings have at least one secondary function besides the main function, which is positioned on the ground floor or basement, on the street façade. The most common secondary function is commercial and service (87%). Concerning the secondary function of the predominant residential buildings, nearly all the buildings have restaurants, shops or other catering services in their ground floor (Figure 16).

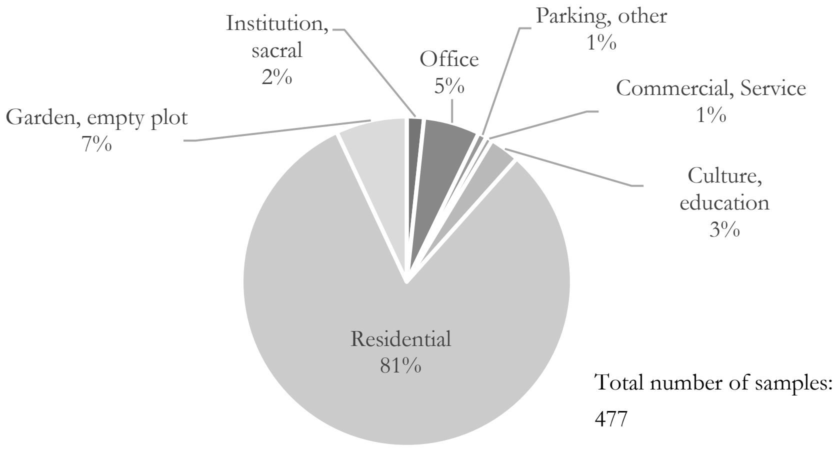


Figure 15: The ratio of the main function of the buildings

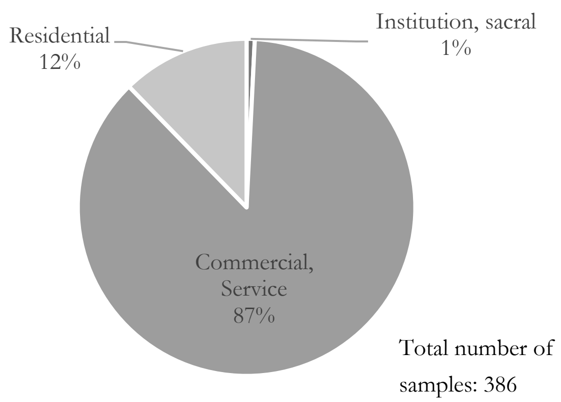


Figure 16: The ratio of secondary functions of residential buildings

Based on the predominance of the residential function (81%, counting only the buildings without the empty plots, 88%), hereinafter, the survey is focusing on the characteristics of the apartment buildings.

2.6 QUALITATIVE ANALYSIS OF STOCK: TYPOLOGIES

2.6.1 Architectural style typology of the apartment buildings

In European and thus Hungarian history of architecture, architectural styles are often used as basic terminology, a tool of classification. Although, the styles between 10th–18th century can be mostly differentiated from each other, it is difficult to draw a line or define an exact year as the beginning and the end of the style.

According to Szentkirályi and Détshy (2007), to be able to decide what the architectural style of a given building is, five characteristics should be observed:

- Forming of space,
- Forming of body,
- Building materials,
- Structures,
- Morphology.

In the case of 10th–18th century (Figure 17) buildings, the classification is mostly simple, even without considering all the five characteristics at the same time. The classification itself was developed for these styles exactly around the turn of the century, when the arts and architecture – again – looked back and started to use the past elements.

From the 19th century, multiple parallel styles were applied, the style elements started to appear mixed on a building, which makes the classification more difficult. Figure 17 shows the main architectural styles, with their respective time period. Our periods of investigation are the Historicism and Modern periods.

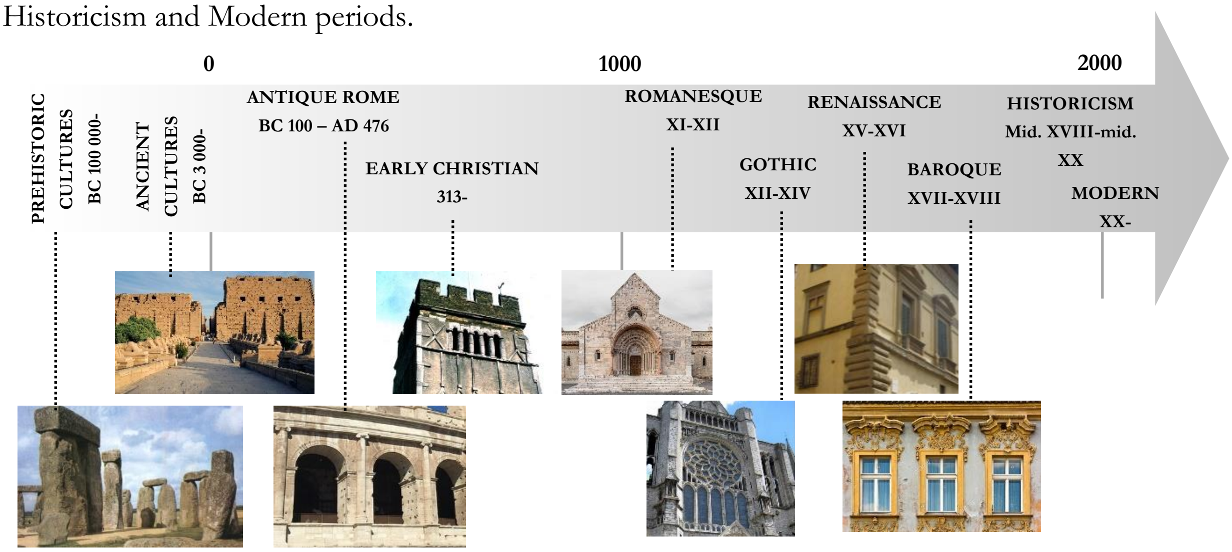


Figure 17: Classic architectural styles, which are easy to identify: Romanesque, Gothic, Renaissance and Baroque. Our period of investigation has multiple parallel styles, mainly referred as Historicism and Modernism. (source: Authors' own figure)

The 19th century itself was a flourishing period of Hungarian art and architecture, characterized by the unfolding bourgeoise, unmatched evolution of Budapest, the arts, architecture and technology catching up with the ever forerun Western-Europe. This period cannot be described by one ruling, clear architectural style, rather built up from multiple renewed style elements (Neo-Renaissance, Neo-Baroque, Neo-Gothic….). They were often used in a parallel manner, so several historical references and style elements can be perceived on a building (Sisa, 2015).

The above leads to the discordance in the Hungarian sources. By analysing the recognised and most commonly used books in education, it can be concluded that most of the studies dealing with the periods' architecture are contradicting each other in style terminology and their time range.

Figure 18 shows 6 important books, which identify the architectural styles.

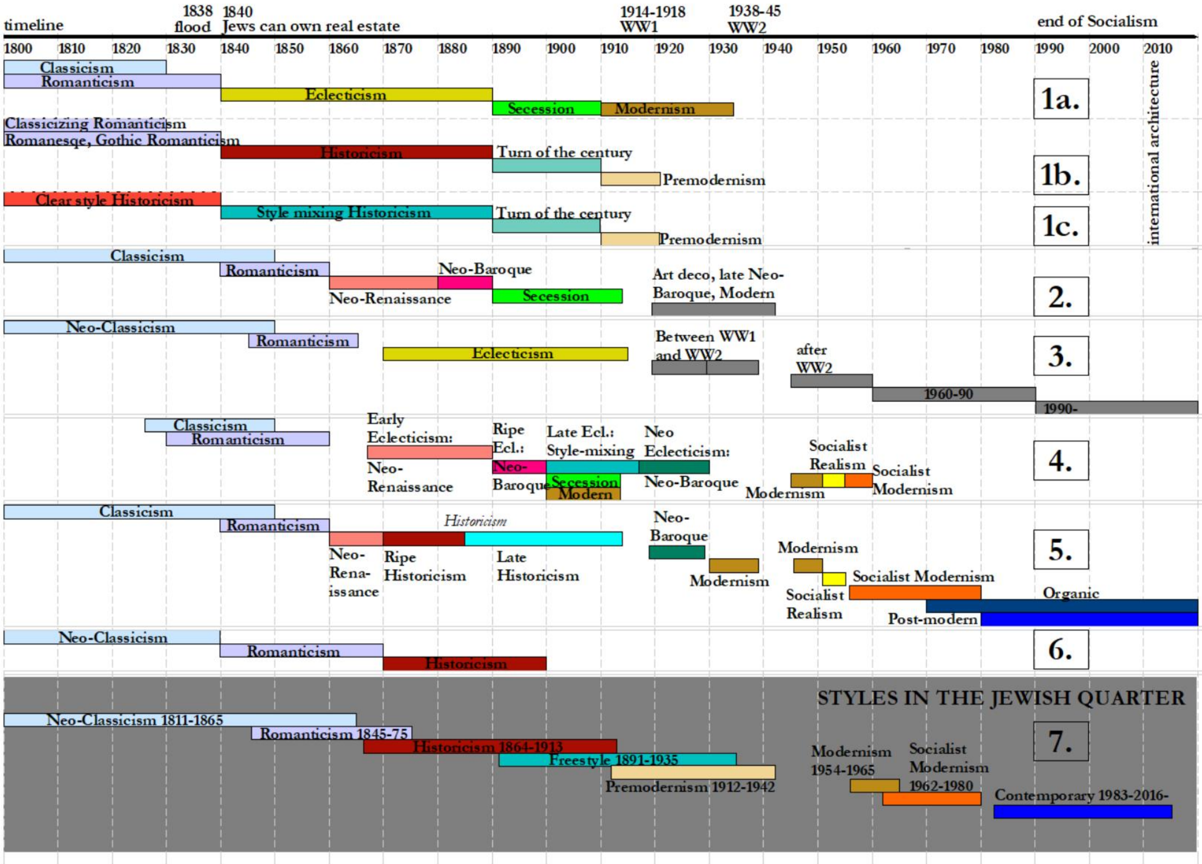


Figure 18: The main Hungarian sources about styles are visualized on a timeline. Neither the terms, nor the time ranges are decisive. At the bottom of the timeline, the suggested style terms and their time range in the Jewish Quarter are shown. Nr 1. (Kalmár, 2016), Nr 2. (Ritoók, 2003) (Prakfalvi, et al., 2004), Nr. 3 (Pattantyús, 2013), Nr. 4 (Rados, 1961), Nr 5. (Sisa & Wiebenson, 1998), Nr. 6 (Sisa, 2015), Nr. 7 Author's suggestion for the Jewish Quarter. (source: Authors' own figure)

On Figure 18 the style terminology and time range is visualized on a timeline for each surveyed source. The similar style names have the same colour code. Source Nr 1. (Kalmár, 2016) has three variations. Source Nr. 2 is a summarized timeline of (Prakfalvi, et al., 2004) and (Ritoók, 2003), as they are two consecutive books of a series concerning the history of Architecture in Hungary. Nr. 3 (Pattantyús, 2013) is a book concerning of the structural problems of the building types in the period. Nr. 4 (Rados, 1961) and Nr. 5 (Sisa & Wiebenson, 1998) can be considered the most encompassing sources. Nr. 6 (Sisa, 2015) is focusing on the 19th century in detail. Nr. 7 is the suggested terminology and periodization of current study, applied to the Jewish Quarter.

Most of the above sources discuss a limited period or some functions in detail (Nr. 1, 2, 8, 6), while Nr. 3, 4 and 5 analysed architecture in a longer period, with more general information. By observing Figure 18, it can be concluded that nearly all the sources agree in the term and period of (Neo-) Classicism and Romanticism. The largest mix-up in terminology belongs to the Historicism-Eclecticism.

Historicism is used in various contexts. In some cases, the expression is used as an umbrella-term to collect all the style names that are reusing past styles, summing Classicism, Romanticism, Eclecticism and so on. In this case, however, *Historicism* is mostly used referring to the buildings containing both Neo-Renaissance and -Baroque elements. In the case of Nr. 2, 4, 5. of Figure 18 this period is even divided into clear-style sub-groups of for example Neo-Renaissance, Neo-Baroque, etc.

The styles using Neo-Renaissance and -Baroque decorating elements together with floral, geometrical and oriental ornaments are named Eclecticism, Turn of the Century, Late Historicism, Late Eclecticism, Style-mixing Eclecticism in different books. The word *Eclecticism* itself implies mixed style elements, thus in source Nr. 4. the term is slightly confusing, equating the Early-Eclecticism with clear Neo-Renaissance for example. On the other hand, in Nr 5, Late-Historicism refers to the style mixing variant. Curiously, mainly because of the 20th centuries' political views, the expression 'Eclectic' gained a slightly negative, sarcastic undertone.

In Nr. 1a., 2., 4. the term *Secession* is used. The style is similar to Art Nouveau, using floral and folk-art elements, a very popular and highly regarded style of Hungary. In our surveyed building stock, however, the style elements of Secession are subtle and, in most cases, mixed with Neo-Baroque and Art Deco style elements. The Art Deco style uses the architectural antitypes and formal solutions of Modernism alike. The is influenced also by the ancient Egyptian, Mesopotamian and American art. Similarly, to Secession, these motifs can also be observed as only simplified decoration on mixed-style façades.

The term *Premodernism* is also a collective name, referring to buildings using Modernist forms and solutions, but still rooted in the design attitude of the previous periods. The "classic" Modernism of the international definition is rarely found in this part of Budapest.

Sources Nr. 4 and 5 mention Socialist Realism and Socialist Modernism. As their name suggest, these are the styles under the influence of the Soviet Union. The former is an interesting mix of Modernism and Classicism, rarely found in the surveyed area. The latter is a distinctive style, contrasting the previous solutions, showing signs of Structuralism and Brutalism by using mostly prefabricated elements and concrete.

Most of the sources do not discuss the end of the 20^{th} century, if they do, no encompassing term is defined for the period, rather architectural waves and schools are introduced.

One of the reasons why the above definitions and terminology have contradictions is that they are used for a wider range of reference (various functions). To be able to use the architectural style for classification in the surveyed building stock, terminology and time ranges need to be cleared and specified for the traditional apartment houses of the Jewish Quarter.

To clarify terminology, first, the five style characteristics are investigated of the traditional apartment houses:

- **Forming of space:** This characteristic is closely related to the forming of the body. Subtle differences in space forming can be spotted through the surveyed period. The layout of the buildings changed slightly as well as the layout of the apartments. The older examples have a two-bay streetfront part and a one-bay courtyard wing, but latter examples expand to a three-bay streetfront wing. The older layout system included a common toilet at the end of the hanging corridors, while the later types show individual toilets in each apartment. The ratio of the courtyard compared to the building decreases. The horizontal and vertical system of access (corridors, staircases) also change through time. The later flats are not designed around a hanging corridor, only opening from the closed staircases. The earlier footprints are U or F formed, later buildings have L or Strip layout. See more details in Section 2.6.2 below.
- **Forming of body:** Due to the strict regulations and space limitations, the forming of body is less elaborate but more practical compared to, for example, an ecclesiastic building. The body of the building is mostly squeezed into the plot. Also, the aim of the investors to create the most lettable flats led to maximum utilization of the plot. The earlier examples are less densely built compared to the latter ones. The plane of the façade also changes. The previously even surface starts to wave, forming more dynamic façades.
- **Building materials:** This character is closely linked to the structures below. Various materials were used during the surveyed time, but the great impacts were the appearance of the two-layered joint window, the steel and the reinforced concrete that eventually liberated the forming of the façade. See more details in Section 2.6.3 below.
- **Structures:** The evolution of technology can be spotted on the building structures. In the earlier examples, the architectural style elements (ornaments, openings on façade) were closely linked with the confined possibilities of load bearing structure underneath. In time,

decoration and the structures behind became separated, the ornaments were used as an outer shell, a changeable robe, only depending on the taste of the investor.

- **Morphology:** The decorative elements on the buildings are decisively shaping its looks. Neo-Baroque, -Renaissance, -Gothic and Romanesque motifs can mostly be observed, but Oriental, Secession and Art Deco ornaments can also be found. In most cases, the unique ornaments of classic architectural styles are mixed on one façade.

As nearly all the sources agree in the term and period of (Neo-) Classicism and Romanticism, they are also used in the current study without modifications.

In the surveyed building stock, it is rare to find clear Neo-style buildings, rather the mixture of the Renaissance and Baroque elements prevails. To clarify the meaning of the otherwise used *Historicism*, the Author decided to narrow down the term. The present study proposes that in case of multi-apartment residential buildings, the name *Historicism* should be used only to describe buildings using mainly Neo-Renaissance-Baroque elements of decoration with a simple body geometry design.

A new term 'Freestyle' is adapted to describe the buildings not decisively belonging to one style but mixing the decorative elements of Secession, Art Deco, Neo-Renaissance and Baroque architecture as well. This is very common in the case study area. The mostly similar definition of the above is 'Eclecticism', 'Late-eclecticism' and 'Style-mixing historicism' and 'Turn of the century' mentioned in above sources. The existing expressions do not exactly fit for apartment houses. 'Eclecticism' is used often as a pejorative term, undermining the real values of the buildings. The term 'Turn of the century' would be misleading, because this style expands well into the first third of the 20th century. 'Style-mixing historicism' would be the closest term, but 'Historicism' is used otherwise, thus, to avoid confusion, the term *Freestyle* is used hereinafter.

Premodern and Socialist Modern are used as their original definition.

For the newest buildings, as mentioned above, no commonly agreed, exact terms are used yet. As these buildings are not typical in the case study area, the term *Contemporary* is used.

The styles introduced below are focused on the apartment house type. The time range was defined specifically for the Jewish Quarter, by observing the construction period of all the buildings classified in each style.

The buildings in the area were classified into the style groups. The period of each style was determined by the construction time of the buildings considered. Thus, the years in brackets below, in Figure 18 indicate the marginal construction years of the buildings in the group. Some periods are overlapping, with styles running parallel, being an emblematic feature of the time. The hiatus indicates that there were no constructions during the missing years.

While creating the database and defining the styles as mentioned above, for composite buildings with different construction periods (additions and major renovations) two major methods were used:

In the case of clearly separable building parts of different styles, the parts are marked as different buildings in the database (for example the courtyard wings are Contemporary, the street front façade is Neo-Classicistic).

In the case of non-separable building parts, for example the ground floor is built earlier, then later new stories were added, the more significant style was chosen to describe the building, i.e. the style that is most closely describing the building.

The time range of the styles in the Jewish Quarter (shown on Figure 18 and below) shows that if compared with the previous long period studies, certain differences can be spotted. On the Jewish Quarter timeline Neo-Classicism lasts longer, and all the other styles averagely began later and finished later than in the sources. As for Premodernism, however, the period fits the sources which can be justified by the following. The Premodern style buildings of the area were mainly built by using district and city level, centralized master plans and prescriptions. The older styles, however, show the more conservative taste of the individual investors.

Based on the above, the author of the present dissertation proposes the below style terminology and their definition for the surveyed case study area.

The below introductions are based on the introduced sources, mainly Ritoók (1991) and (2003), Prakfalvi, et al. (2004). The structure data is based on Pattantyús's work (2013).

- ## Neo-Classicism (1811–1865)

Following the elaborately ornamented Baroque style, the simpler Neo-Classicism ruled architecture at the beginning of the 19th century, then continuously disappearing and resigning to Romanticism. Figure 19 shows examples of the Neo-Classicistic apartment house.

The street front of the houses is usually two-story with a pitched roof, the courtyard wings are lower, half-pitched roofs. On the first story of the street front the largest and wealthiest flat was built, often occupied by the owner's family. The ground floor was used for smaller flats, shops or warehouses. The courtyard wings were occupied by smaller flats, a kitchen, staff rooms, restrooms, in the earlier examples, stalls and carriage stables. The flats characteristically opened from the hanging corridors of the courtyards. The gate–lobby–staircase spatial chain is a heritage of the Baroque time, and it is usually the most ornamented part of the building. The gates of this style were usually large, arched, thus carriages could enter. It was not uncommon to have a well in the courtyard.

Concerning decoration, the clear, calm design, the elementary geometric bodies, the aim for balance and symmetry are characteristics of the style, as well as using a Greek-Roman classic order of ornaments.

The ground floor façade was usually decorated with arcature. The first floor had straight or triangular ledges over the windows. The second floor (if existent) had simple framing.

The façade ornaments included stone ledges dividing the stories, as well as crowning the façade on the top. Their function together with the window frames was besides decoration to protect the façade from rainfall. The two-layered, wooden frame windows required this protection, as in this period the outer wings were placed on the outer surface of the wall, some opening to outside.

Figure 19: Left: Example of a Neo-Classicistic building. Façade, layout, section and detail of a building. Middle and right: Another example façade and courtyard from the case study area. (c = courtyard, g = gate, h = hanging corridor, s = staircase, l = common lavatory) (source: Authors' own figure)

• Romanticism (1845–1875)

In this time period Hungary went through a revolution, fast urbanization with strengthening citizenship. Jewish residents were finally permitted to own a real estate, which also boosted synagogue constructions.

The style differs from Classicism mainly in the theme of decoration. While Classicism focused on Antique heritage, Romanticism uses Romanesque, Gothic, Byzantine or Oriental style elements. Contrary to the clear symmetry, the asymmetry and mysterious medieval mood was recalled. The openings are sometimes semi-circular and Islamic hoof shaped.

On an average apartment house often only, a few decorations can be observed. The main difference from Classicism is that the classic order of ornaments were exchanged to medieval, and the side bays of façade are emphasized rather than the centre. The apartment house layout has not changed significantly (Figure 20).

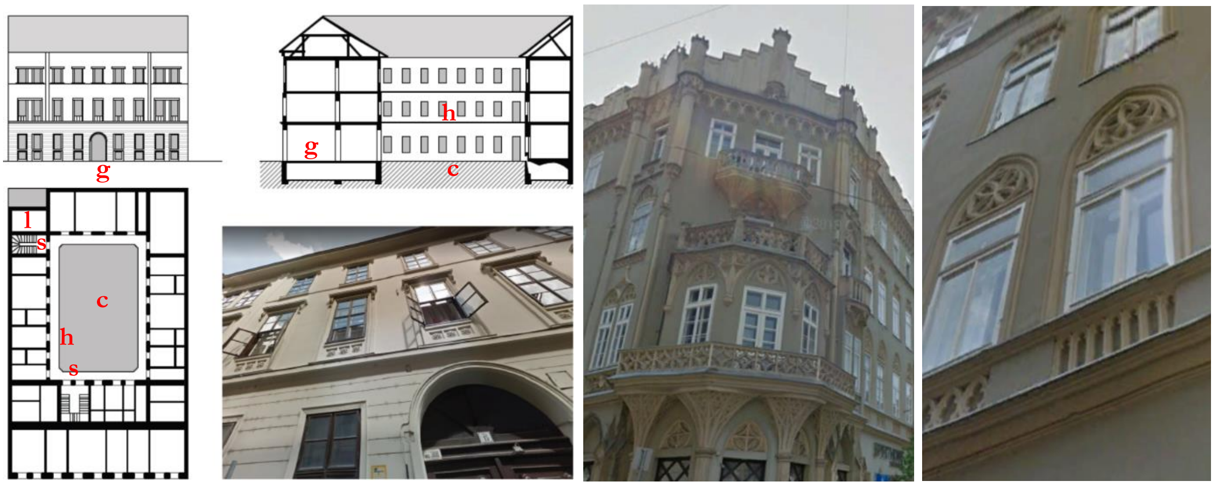


Figure 20: Figure: Left: Example of a Romanticism building. Façade, layout, section and detail of a building. Middle and right: Other example façades from the case study area. (c = courtyard, g = gate, h = hanging corridor, s = staircase, l = common lavatory) (source: Authors' own figure)

• Historicism (1864–1913)

During this period, the Austro-Hungarian Monarchy had been established, bringing peaceful, blooming years for the country. A significant part of the surveyed building stock was built in this era. It was also the time of the city regulations: new avenues, boulevards were planned and built.

The newly regulated building plots were now reticulated and were of smaller size than before. The apartment houses grew higher with more stories, although their classic structure – planned around the courtyard and hanging corridor – was unchanged. The design of the façade was aiming to show aristocratic urban palace elements, as the impressive-looking apartments were worth higher wages in rent.

Mostly Neo-Renaissance and Baroque decorative elements were used, influenced by the Italian and Western European palaces designs (Figure 21).

The approach of Historicism towards the connection of style and structure changed compared to the previous styles. The structure and materials behind the style elements and decoration were now fully separated from each other. Considering the size and location of the premises, the style elements could be added at one's choice, as a changeable robe. In the case of façades, as the outer layers of windows were now opened inside, the protective function and the size of ledges decreased. The façades however, mostly remained flat, only the ledges and other decorations emerging from the plane.

Even though the water and drainage network was now available, the residents of the less wealthy apartments still drew water from the courtyard, which points out one of the most interesting features of the apartment houses: people within very different social and financial status lived together in the same building, though in quite different quality flats.

Figure 21: Left: Example of a Historicism building. Façade, layout, section and detail of a building. Right: Other example façades from the case study area. (c = courtyard, g = gate, h = hanging corridor, s = staircase, l = common lavatory) (source: Authors' own figure)

- ## Freestyle (1891–1935)

As the name shows, this period can be described as taking style elements and decoration as one's choice and mix them in one design. The style elements are from various sources: Secession and Art Deco elements can be spotted next to Neo-Renaissance and Baroque decoration (Figure 22).

Even the apartment buildings considered advanced of the time were still designed around a courtyard, using hanging corridors.

In 1894, the New Building Regulation came in effect. Depending on the height of the building, the minimum size of the courtyard was declared. The aim was to provide sufficient light and air for the flats, but a very low minimal size was prescribed. The investors and speculators, however, wished to build more and more flats, even on small and irregular plots. The buildings were designed to use the maximum permitted area, resulting in several unhealthy, small apartments with a common lavatory, earning negative opinion and criticism for the building type. Even the modern structural and engineering solutions – reinforced concrete slabs, wired water, gas and electricity, ventilation or paternoster – could not compensate for the disadvantages.

The disastrous World War 1 ended in 1918, where the country was on the losing side, suffering significant territory losses followed by a financial crisis.

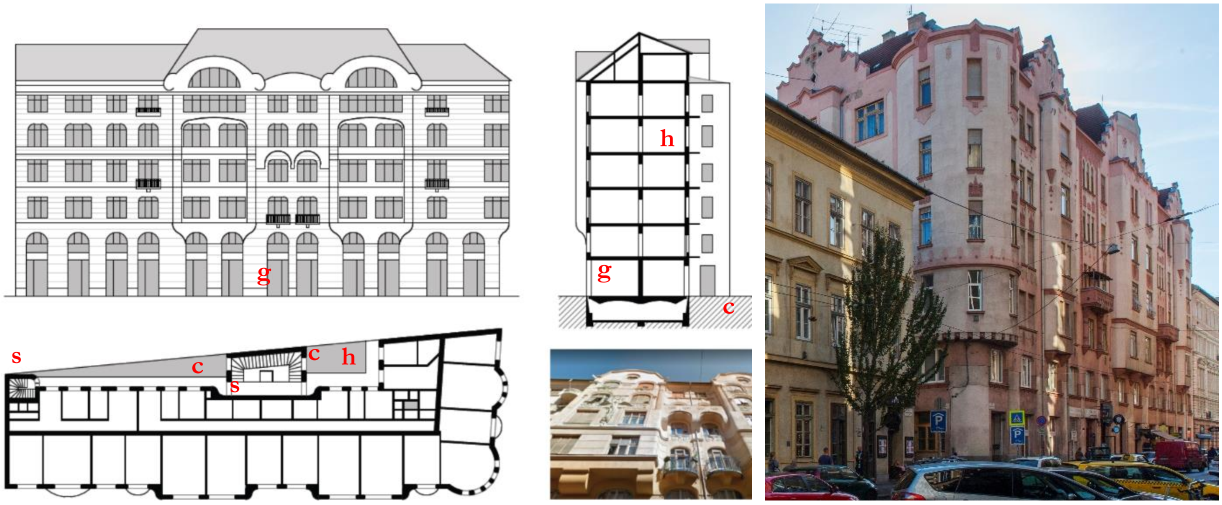


Figure 22: Left: Example of a Freestyle building. Façade, layout, section and detail of a building. Middle and right: Other example façades from the case study area. (c = courtyard, g = gate, h = hanging corridor, s = staircase) (source: Authors' own figure)

- ## Premodernism (1912–1942)

Parallel to Freestyle, the beginnings of Modernism came to the area. The façades started to simplify, the surfaces became flat, and mostly undecorated. Less and less ornamentation can be spotted.

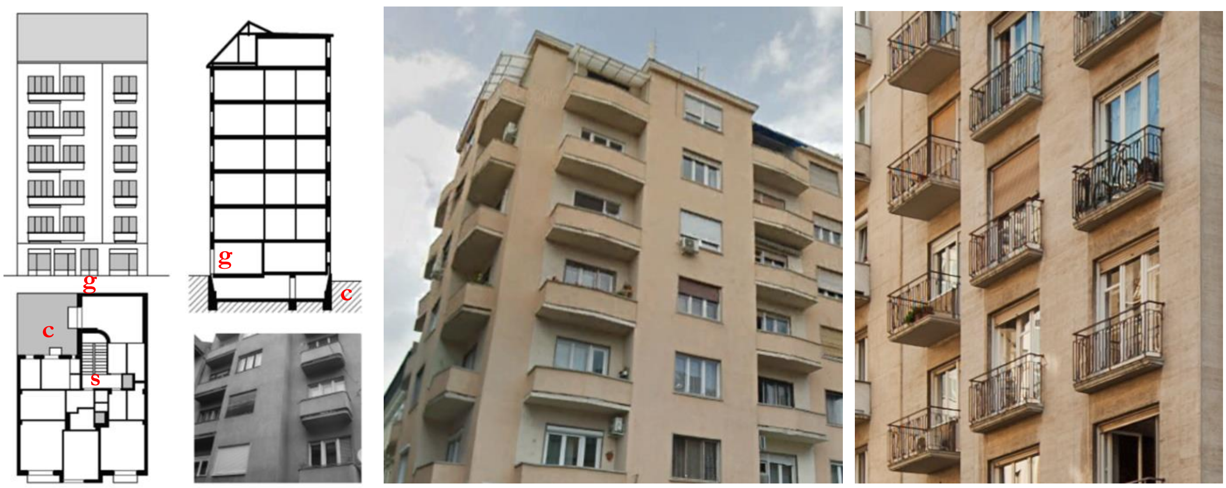


Figure 23: Left: Example of a Premodern building. Façade, layout, section and detail of a building. Middle and right: Other example façades from the case study area. (c = courtyard, backyard, g = gate, s = staircase) (source: Authors' own figure)

The layouts changed also, as new regulation came into force. The enclosed courtyards disappeared; the building layouts were designed as mostly one wing with 3 bays. The hanging corridors yielded the place to the closed staircase, from which the flats opened directly. Most of the flats got terraces, used only seldomly before (Figure 23).

Structure wise, in the first ten years after the war, during the financial crisis, the building materials were expensive compared to living labour, thus material-saving, but labour demanding structures were built, similar to the pre-war structures. After 1929, the crisis left huge poverty, and the ongoing sparing use of materials resulted in new products, for example hollow bricks, frequently used in these buildings.

During the Second World War, a significant part of the buildings were damaged by the bombings, many of them were demolished, leaving empty plots behind.

- **Modernism (1954–1965)**

Clear, classical Modernism is rare in the area.

The idea was that healthy life, cleanliness, sunshine and fresh air should be provided in the houses. The Modernist façades were simple, plastered or stone paved, the windows unframed. Typical design elements were the round windows and tube-railed balcony. The new flat roofs were designed as sun terraces, and the façades were opened with large glass surfaces to let more sunlight in. In the case of pitched roofs, the attic was also built in.

A typical apartment house contained a janitor flat, a laundry room, and storage rooms for residents. The service rooms were often in the basement or on the roof. The more luxurious houses had detailed design, expensive surfaces, and services like a gatekeeper room or a phone booth.

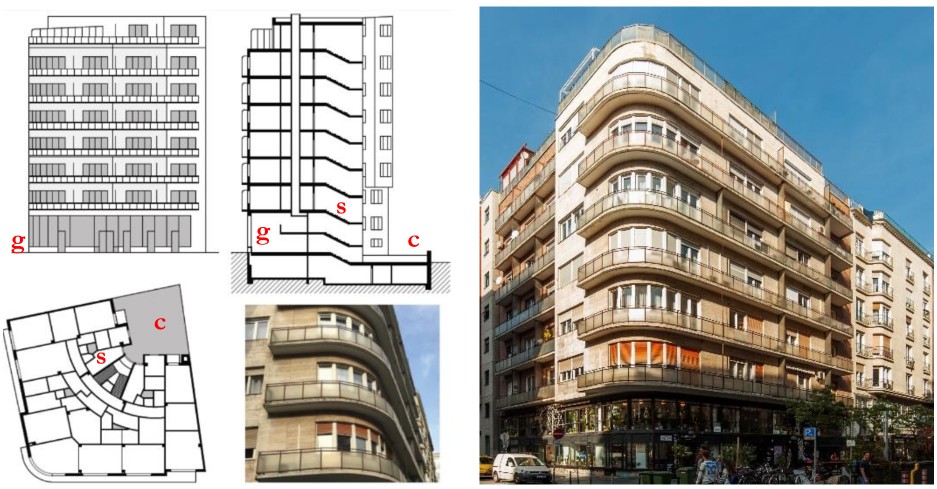


Figure 24: Example of a Modernist building. (c = courtyard, backyard, g = gate, s = staircase) (source: Authors' own figure)

Experimenting with new materials and exchanging the simple decoration of surfaces to the art of forming space itself, was also typical of the period. Using asymmetry, loosely designed layout, simple geometry and repetitive elements describe the style (Figure 24).

The new solutions contained thinner structures – reinforced concrete or steel frames and modern fenestration – which raised building physics problems seldom seen before, as well as opened the lead to the use of heat insulation materials.

- **Socialist Modernism (1962–1980)**

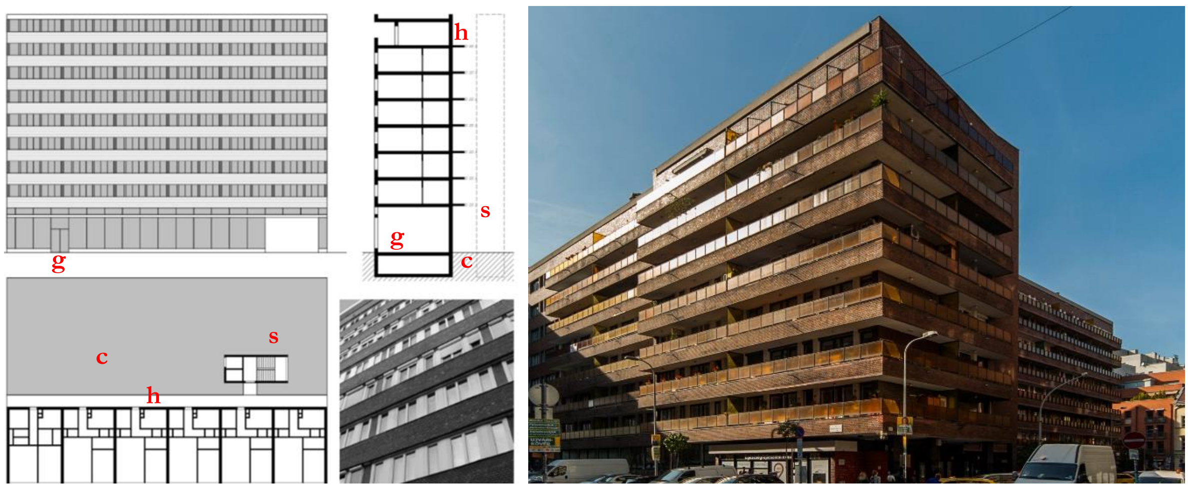


Figure 25: Left: Example of a Socialist Modernist building. Façade, layout, section and detail of a building. Right: Another example façade from the case study area. (c = courtyard, backyard, g = gate, s = staircase, h = hanging corridor) (source: Authors' own figure)

During the 1960's, the ever-growing housing shortage caused major problems. After the World War, the problem was temporarily quenched by dividing the past luxurious, large flats of the traditional apartment houses into smaller ones. This solution often resulted in unusable layouts, worsened by the so-called "flat share system", where usually total strangers were forced to live together. This phenomenon worsened the public opinion of the building type, already influenced by the political views, which connected the ornamented buildings to the oppression of working class by the aristocrats. Perényi (Perényi, 1963) even states, that the demolition of these districts is only a matter of time and financial state, aiming to eliminate even the memory of the previous social and political system. In this regard, it is not surprising that the building type was neglected for decades, resulting in their present bad condition.

The industrialized buildings offered a quick solution for the aforementioned housing crisis. Soon concrete frames and full story-high concrete sandwich panels were manufactured, to build new districts, which became a significant part of the present building stock in Hungary (Figure 25).

In the case study area, some of the post-war empty plots were filled with buildings of this type, often curiously bringing back the hanging corridor system.

- ## Contemporary (1983–)

The end of the Soviet Union influence socialism in Hungary. 1989 meant the end of the state centralized building ideologies and practices. Today, there are no exact characteristics to describe the contemporary multi-story apartment buildings. In appearance, either Neo-Modern elements can be spotted, and also references to the historical styles. In the 1990's more office buildings were erected with High-tech style references (Figure 26).

In the case study area, the layouts are also varied, the staircase-based, the closed corridor system and also the hanging corridor type design can be found. The height of the stories are usually smaller, and underground garages are built for each apartment house, as today it is mandatory to ensure a given number of parking places per flats, resulting in higher number of stories than before.

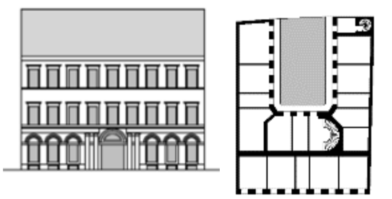
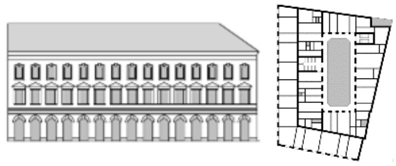
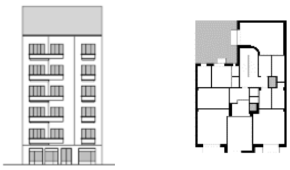
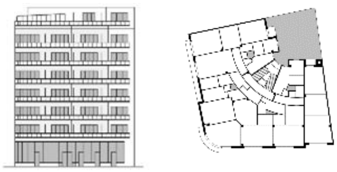
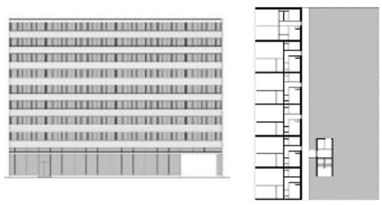
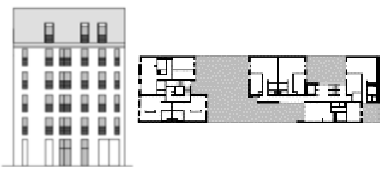
After 1980, the ever stricter energetic and acoustic regulations resulted in a high variety of frame-brick or lightweight concrete elements, which are used to fill the reinforced concrete frame. The walls and roofs are multi-layered with thick heat insulation materials.

In most cases, the forming, the layout system and façade design of these new buildings neglect the characteristics of the original fabric, bringing new ratios and forms to the area (although a few harmonizing solutions can also be found). Their ratio is relatively low in the case study area, but continuously increasing as the older ones are being demolished.

Figure 26: Left: Example of a Contemporary building. Façade, layout, section and detail of a building. Middle and right: Other example façades from the case study area. (c = courtyard, g = gate, s = staircase, h = hanging corridor) (source: Authors' own figure)

Table 2 summarizes the above styles arranged in table format for later use.

Table 2: Summary of the architectural styles in the case study area with example buildings (source: Authors' own figures)

STYLE	CHARACTERISTICS IDENTIFIED IN THIS STUDY	EXAMPLE STREET FRONT FAÇADE AND FIRST FLOOR PLAN
Neo-Classicism (1811-1865)	Clear, calm design, the elementary geometric bodies aim for balance and symmetry. Style and structure are closely connected. Ornaments follow structure. Using Neo-Renaissance and Baroque classic order of ornaments. The façade ornaments contain stone ledges dividing the stories as well as crowning the façade on the top. Their function apart from decoration is to protect the façade from rainfall. Building wings are designed around a courtyard with hanging corridors.	
Romanticism (1845-1875)	Differs from Classicism mainly in the theme of decoration. Uses Romanesque, Gothic, Byzantine or Oriental style decoration elements. The openings are often semi-circular and Islamic hoof shaped.	
Historicism (1864-1913)	The approach towards the connection of style and structure: the structure and materials behind the style elements and decoration were now fully separated from each other. The style can be added at one's choice, as a changeable robe. As decoration, the Baroque and Renaissance style elements were used. The façade is plane, and the body of the building is simple.	
Freestyle (1891-1935)	Layout and forming-wise even the apartment buildings are still designed around a courtyard, using hanging corridors. The heights became larger. The façade became more dynamic, the ordinary flat geometry changed to swirling surface. The buildings were designed for lending resulting several unhealthy, small apartments. The decorative elements mixed together are from various sources: Secession and Art Deco elements can be spotted next to Renaissance-Baroque ones.	
Premodernism (1912-1942)	Simple geometry, less or no classic decoration on the façade, in most cases flat roof. The layout of the apartment houses is mostly without a hanging corridor, the staircases were now closed the flats were opened from the staircases and corridors.	
Modernism (954-1965)	The façades are simple, plastered or stone paved, the windows are unframed. Large glass surfaces for lighting. New, more liberal design methodology for layout. The service rooms were often in the basement or on the flat roof. Thinner structures of reinforced concrete or steel frames with modern fenestration raising new building physics problems.	
Socialist Modernism (1962-1980)	Prefabricated building structure, concrete frames with medium size block and later full story-high concrete sandwich panels. The building design is not considering their surroundings, placed in an original fabric as inclusions.	
Contemporary (1983-)	No exact characteristics to describe the contemporary multi-story apartment buildings yet. Modernist style as well as references to the historical styles or High-tech elements. The layouts are varied, the staircase-based, the closed corridor system, also, the hanging corridor type design can be found.	

- **Ratio of the styles in the case study area**

According to the proposed terminology, the architectural styles of stock are: Neo-Classicism, Romanticism, Historicism, Freestyle, Premodernism, Modernism, Socialist Modernism, Contemporary.

After the categorization of the buildings, it can be concluded that a significant proportion of the buildings belongs to Historicism (39%) and Freestyle (22%) (Figure 27). Together, the styles predating the Second World War can be considered predominant (Neo-Classicism, Romanticism, Historicism, Freestyle, Premodern; in sum 81%), which can be considered traditional regarding their cardinality and design, giving the case study area its character.

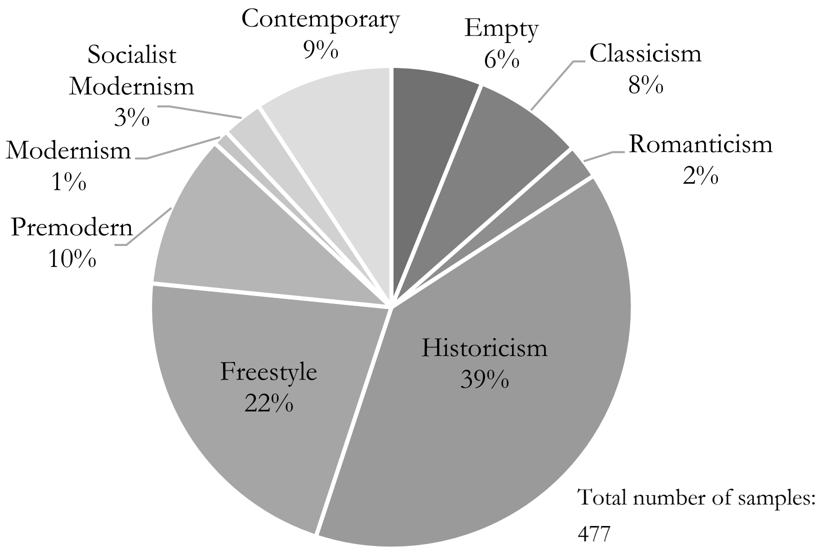


Figure 27: Ratio of the styles in the case study area (source: Authors' own figure)

- **Distribution of the styles in the case study area**

As for the distribution of the different styles in the surveyed area, the oldest part is Király Street, which is the north-western boundary of the area. The buildings first appeared alongside the major streets running from south-west to north-east.

The oldest part of the current building stock (Neo-Classicism) thus can be found near Király Street. The Romanticist buildings are also near the older part. Historicism can be found spread on the area, but densifying on the north-eastern boundary, which is the Erzsébet Boulevard. Freestyle, Modernist and Socialist Modern style buildings can be found scattered. Premodern buildings are more densely built on the south-western corner (Madách Houses), while Contemporary buildings are also scattered, densifying around the presently continued Madách Promenade and the rehabilitated blocks.

In conclusion, the oldest and the newest buildings can be found in the same area (near Király Street), showing that most of the demolitions due to rebuilding was suffered by the oldest and historically most significant part during the surveyed period (Figure 28).

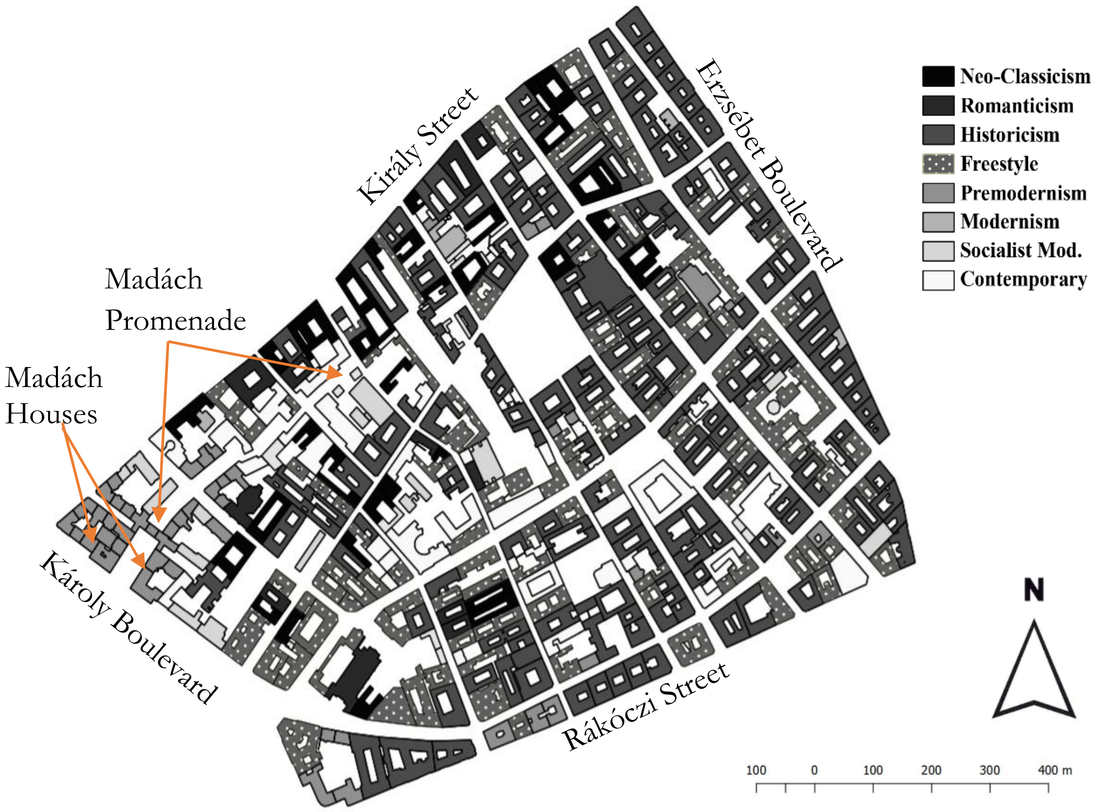


Figure 28: Distribution of styles in the case study area (source: Authors' own figure)

2.6.2 Geometry typology of the buildings

By investigating the footprint of each building and its position on the plot, six different types can be identified:

S-type is a Strip shaped form, L-type is L shaped layout, U-type is U shaped, to which two subgroups were added: U1 type – the bottom of the "U" is parallel to the street. In the case of U2, the branch is parallel to the street. F-type is Frame shaped, B-type is Block shaped, E-type marks the Empty plots.

Figure 29 shows the types of layout, their ideal shapes are shown in 2nd row, examples in 3rd row. Combinations of the clear types can be found, although in small numbers, as shown on the bottom row.

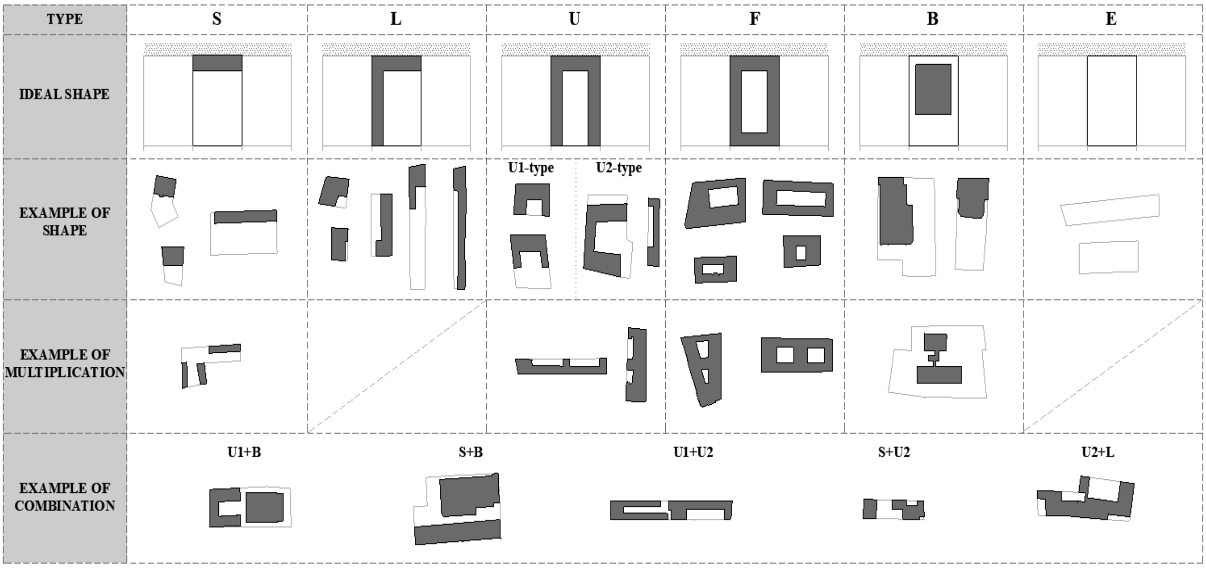


Figure 29: Typology of layout in the case study area (source: Authors' own figure)

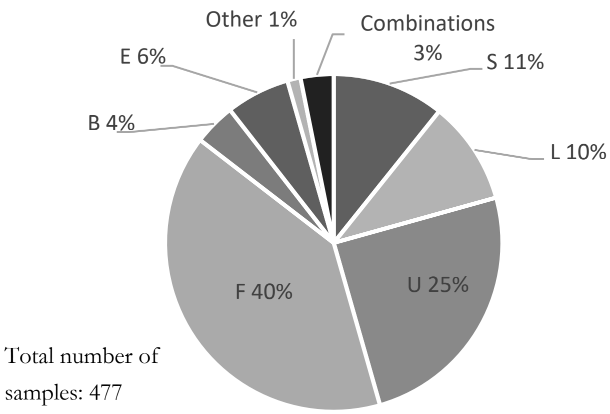


Figure 31: Distribution of layout types in the case study area (source: Authors' own figure)

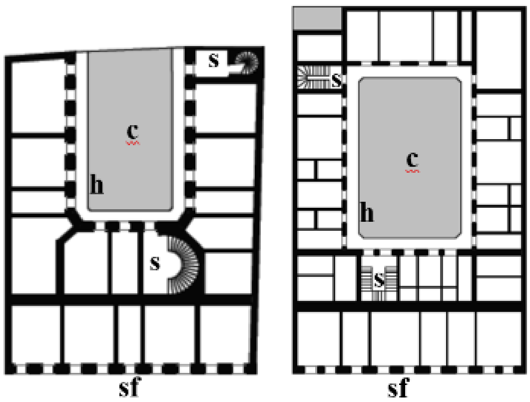


Figure 30: Example layouts of the most common U (Left) and F (Right) types (c = courtyard, h = hanging corridor, s = staircase, sf = street front façade) (source: Authors' own figure)

96% of the building stock can be sorted in the groups. The shapes created by multiplying or combining the types makes up 3% of the total quantity. It can be concluded that the most characteristic type of layout is Frame type (F, 40%). U type is second with 25%. U1 subtype and U2 subtype are in 2/3-1/3 proportion in U type 8 Figure 31). Detailed examples for layouts of the most common styles are shown on Figure 30. See the connection between footprint and body of the building size in Section 3.3.4.

2.6.3 Structural-material typology

For the later energy calculations of buildings, one of the first steps is to specify the structures and materials which envelop the heated volume. Large-scale like district-size calculations require simplifications. The *raison d'etre* of the typology is that given the size and characteristics of the surveyed stock, it is impossible to measure all the structural sizes and layers of every building. Destructive methods like excavation in a dwelled, protected building is not possible.

Fortunately, regarding the building structures and materials used in the surveyed time range, clear information can be found in various sources. The most characteristic period of the stock, the turn of the 19th and 20th century, is especially well documented. Adapting the information of these sources is an accepted method even in professional energy efficiency audit, with structures which cannot be directly excavated.

In the 19th century, and even at the beginning of the 20th century, construction activity was strictly regulated and observed. In the meantime, the available materials and solutions were also quite limited. Information about the usual structures can be extracted from official regulations of the time. The collection of these regulations was published by Edvi (Edvi, 2005).

To expand and refine the data of (Edvi, 2005), other sources of information were (Ritoók, 2003), (Prakfalvi, et al., 2004), (Ritoók, 1991), (Pattantyús, 2013), (Déry, 2010), (Déry, 2010), (Déry, 2002) were used. The post-Second World War buildings are assessed by choosing typical structures, also based on (Bársony, 2008), (Bársony, et al., 2008), (Pattantyús, 2013).

The above information was validated by historical data mining, using the Budapest City Archives collection plans (Budapest City Archives Database, 2019). The used structural materials, layering and sizes were surveyed from the available original plans. For simplification, the structural typology is not considering the damage caused by bombing during the Second World War (the renovation was using mostly the same materials as the original construction, furthermore the damage is not well documented).

As for further validation, photo documentation was used. By this technique, the damaged structures of buildings in the case study area were recorded to confirm the collected data. For example, where the mortar fell from walls or there is damage in the slab, the structure is shown, and can be identified without excavation.

Based on the above studies, the structure is hardly dependent on architectural style, rather on construction time. Thus, the characteristic enveloping, structural solutions were collected and organized on a timeline. The timeline was cut up to shorter periods, where the most important external, enveloping structures were combined to create the 'Packages'. Nine such packages were created. Contrarily to Packages 1–7, Packages 8 and 9, less strict regulations and more possible building material for construction could be used. For these packages, a characteristic combination of elements was chosen to describe the period.

The period based structural packages and their U values are introduced in Table 3. Nine categories were created named packages, for supporting the calculations of the next.

Table 3: Structural-material 'Packages' based on the characteristic structures of the given period

<table>
<tr><th rowspan="2">Package</th><th colspan="4">Enveloping structures</th></tr>
<tr><th>External wall</th><th>Closing slab</th><th>Cellar slab</th><th>Windows</th></tr>
<tr><td>Package 1 (1800–1840)</td><td rowspan="3">Brick-stone</td><td>Covered beam</td><td rowspan="3">Vault</td><td rowspan="2">Plank-type</td></tr>
<tr><td>Package 2 (1841–1850)</td><td rowspan="3">Full timber</td></tr>
<tr><td>Package 3 (1851–1860)</td><td rowspan="4">Box-type</td></tr>
<tr><td>Package 4 (1861–1892)</td><td rowspan="3">Brick</td><td>Prussian vault</td></tr>
<tr><td>Package 5 (1893–1918)</td><td rowspan="3">Reinforced concrete</td><td rowspan="2">Steel with filling</td></tr>
<tr><td>Package 6 (1919–1930)</td></tr>
<tr><td>Package 7 (1931–1954)</td><td>Hollow brick wall with concrete frame</td><td>Reinforced concrete with filling</td><td rowspan="2">Joint wing</td></tr>
<tr><td>Package 8 (1955–1980)</td><td>Block with reinforced concrete frame</td><td>Advanced reinforced concrete</td><td>Advanced reinforced concrete with filling</td></tr>
<tr><td>Package 9 (1981–)</td><td>Reinforced concrete with burnt clay</td><td>Contemporary reinforced concrete</td><td>Contemporary reinforced concrete with filling</td><td>Contemporary one-layer PVC or wood</td></tr>
</table>

To each building in the case study area, one 'Package' of the nine was assigned, based on the construction time. The most commonly used 'Package' was Nr. 4 (43% of the full stock). The second most common was Nr. 5, with 19%.

In the following, the components of the most common Package 4 are introduced (Figure 32). The external walls are built of brick. The wall is the thickest in the cellars, thinnest on the top floor. On both sides, cement mortar is used as cover. The closing slab is full-timber with filling (mostly dross). As a top layer, ceramic bricks were laid. The cellar and middle slabs are Prussian vault, built with I-section steel beams and brick vaults in-between. Here also, filling is used to cover the structure, onto which the flooring is put. The flooring is mostly tile or hardwood. Figure 32 shows an example of the structures of the most common Package 4.

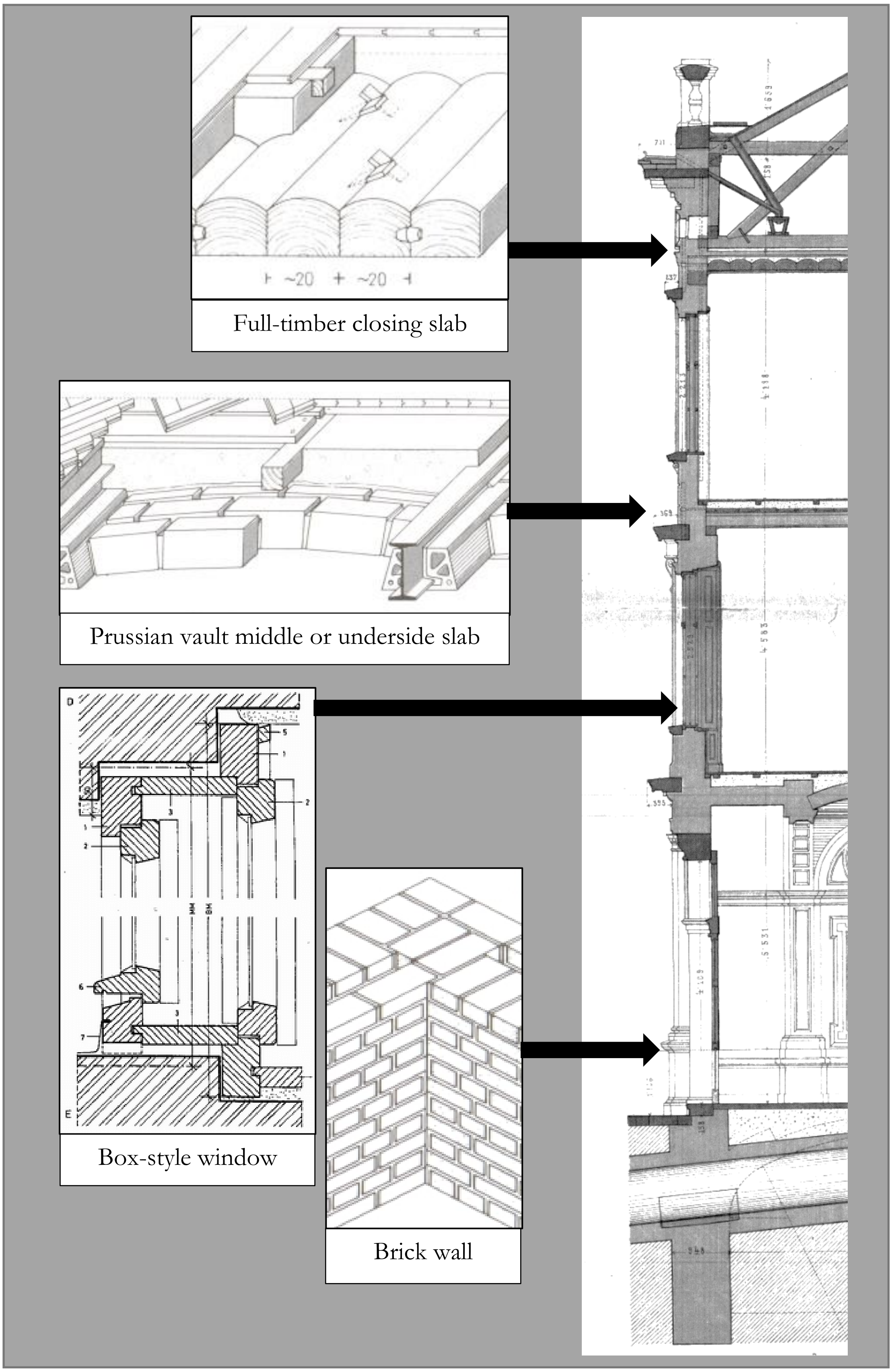


Figure 32: The most common structures in the area, part of Package 4. Source of the section is (Ritter von Riewel & Schmidt, 1881) the structural drawings are from (Bársony, 2008) and (Bársony, et al., 2008).

2.7 CONNECTIONS AND QUANTITATIVE DATA OF TYPOLOGIES

2.7.1 Connection between Architectural style and Layout

Table 4 shows the correlation between the architectural style and layout form. The rows show the styles in approximately time order. The columns show the type of layout in order of complexity from simple to complex, from right to left. The numerical value in each column shows the number of the buildings.

It can be concluded that the most significant F and U types can be found with Historicism and Freestyle buildings. As an overall conclusion, as time goes, the F and U types are simplified to L and S types during the Premodernism and Social Modernism. The Contemporary style, however, uses again various forms almost evenly.

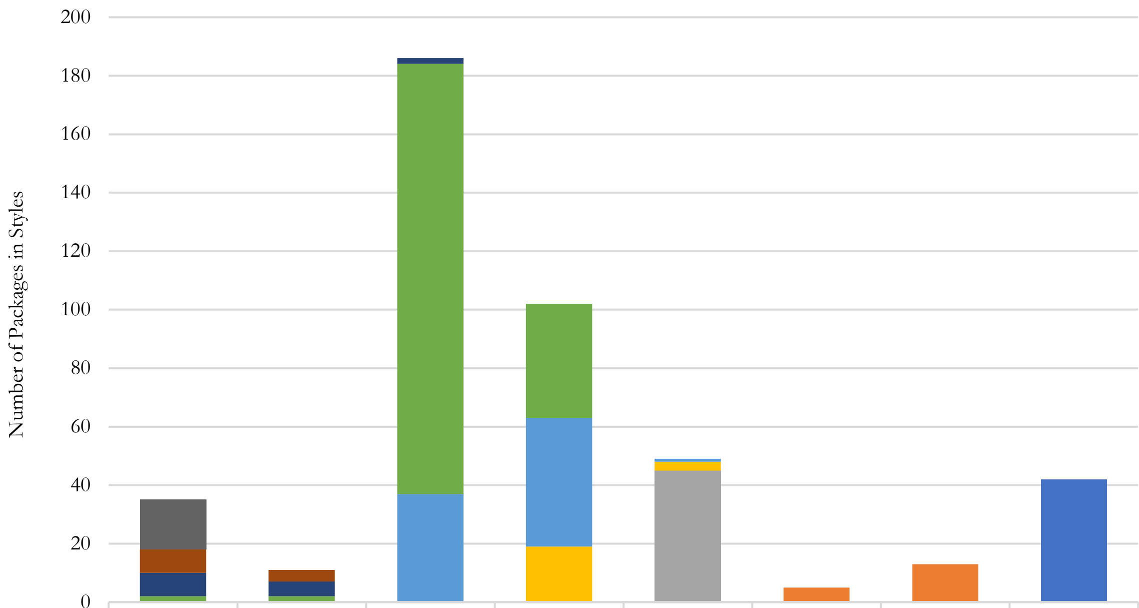
Table 4: Correlation between Architectural style and Layout typology (source: Authors' own table)

Style/Type	B	S	L	U	F	COMB	E	Sum
Empty							29	**29**
Classicism			3	18	14			**35**
Romanticism		1		2	7			**10**
Historicism	3	2	7	57	112	6		**187**
Freestyle	2	5	10	30	50	6		**103**
Premodernism	3	19	19	4	3			**48**
Modernism	2	1	1	1				**5**
Socialist Modern.	2	10		1				**13**
Contemporary	7	11	7	11	3	5		**44**
Sum	**19**	**49**	**47**	**124**	**189**	**17**	29	**474**

[ratio of sub-total number] ■: more than 50% ■: more than 25%

2.7.2 Connection between Architectural style and Packages

Figure 33 shows the correlation between the architectural style and packages. The columns list the styles, while the different shades in rows show the packages. The most significant Package 4 can be found in case of Historicism with brick wall, full timber closing slab, Prussian vault cellar slab and box-type windows. The other most significant package 5 is in case of Freestyle, constructed with brick wall, reinforced concrete closing slab, steel with filling cellar slab, box-type window. Concrete frame is firstly applied in Premodern buildings, where the simple forming was supported by the usage of frame structure.



	Classicism	Romanticism	Historicism	Freestyle	Premodernism	Modernism	Socialist Modernism	Contemporary
PACKAGE 1	17							
PACKAGE 2	8	4						
PACKAGE 3	8	5	2					
PACKAGE 4	2	2	147	39				
PACKAGE 5			37	44	1			
PACKAGE 6				19	3			
PACKAGE 7					45			
PACKAGE 8						5	13	
PACKAGE 9								42

Figure 33: Type and number of 'Packages' in case of every Architectural style (source: Authors' own figure)

2.8 SUMMARY AND CONCLUSIONS OF PART 1

This part of the study aims to find the architectural character of the traditional apartment houses of Budapest to support the heritage respecting refurbishment methodology of later parts. Surveys are focusing on geometry, style, structure, material, and their correlation to each other. The chosen case study area is part of Budapest 7th district, referred as the Old Pest Jewish Quarter.

The area is special from several points of view: its formation, plot and street system are organic, from agricultural origin, unique in today's regulated Pest. The main building stock was built after the great Flood of the Danube in 1838. In terms of heritage protection, its uniqueness is internationally respected, as it is part of the UNESCO World Heritage zone in Budapest. The area holds both cultural and historical values, as a Jewish Quarter and the location of the past WW 2 Ghetto.

Due to decades of neglect, the building stock is now deteriorated, requiring rehabilitation. Nowadays the architectural character and the buildings are endangered. In recent years, the area has undergone an intensive functional transformation. Historical buildings are often victims of modernization or demolition. These intrusions are mostly not respecting the character and heritage of the buildings. The reasonings behind the demolitions are usually their unsustainability and poor energetic state. A complex rehabilitation is thus required to maintain the unique values. The rehabilitation should contain both heritage and energy efficiency measures.

First, the construction time and function of the buildings were analysed. The oldest building in the area is from 1811, the newest was built in the year of survey, 2016. The peak of the constructions was between 1885 and 1915.

Architectural style is a commonly used classification method of the buildings. The 19th–20th century terminology is, however, contradictory. As a result of the survey, clear terminology, definition of styles and periods for the area has been created. This study proposes that for multi-apartment residential buildings of the turn of the 19th and 20th century, the name *Historicism* should be used only to describe buildings using mainly Renaissance-Baroque elements of decoration, and Freestyle to be used to describe the buildings containing either Secession, Art Deco and other style elements, but not belonging decisively in a clear style group.

A typology of the geometry of the building stock was defined and its connection with architectural style was investigated. The present study introduces "Strip (S) shape, L shape, U shape, Frame (F) shape, and Block (B) shape" types to describe the layout. The quantity of F (40%) and the U (25%) types are most significant of the area. The survey on the connection between layout shapes and style shows that the most significant and older styles, Historicism and Freestyle were mostly designed with F or U shape layout. The newer styles use simpler geometry, mainly L or S shape.

For later energetic calculations, structural-material packages were created and assigned to time periods. It can be concluded that the most characteristic package is Package 4, containing brick wall, full timber closing slab, Prussian vault cellar slab and box-type windows. This package can be found mostly in the case of Historicism buildings.

3 PART 2: ENERGY

- **Aim of Part 2**

Survey of energetic characteristics, energy demand and usage, and their connection to architectural character.

- **Methodology**

As the first step, the literature was reviewed. The previous studies and research projects concerning building energetics (Section 3.1.2), measures for energy efficiency (Section 3.1.4), and previous building energy typologies (Section 3.1.6) were investigated.

An analysis of the EU conform Hungarian building energy calculation was also completed. This helped to identify the main architectural data affecting the energy demand of a building. These values were used in Part 1: Architecture, where field survey aimed to record these data. Also, the typologies of Part 1 were chosen to support the energy calculations and Part 3.

Based on the conclusions of Part 1 and the results of building energy usage data of Hungary, the residential buildings of the case study area are analysed in this part (see Section 2.5.2). Using the Hungarian official calculation system, the energy values of the 386 buildings in the area were calculated, focusing on energy demand and energy utilization. The structural-material typology (Packages) is used in this part to simplify the calculation of the thermal transmittance values.

After the large-scale calculations, the statistical analysis of the values was carried out. The connection between architectural data of Part 1, and the energy values were surveyed. The architectural styles are used for identification and classification. See the results in 3.4. The conclusions of this part are used also as input data for Part 3. Figure 34 summarizes the methodology of this part.

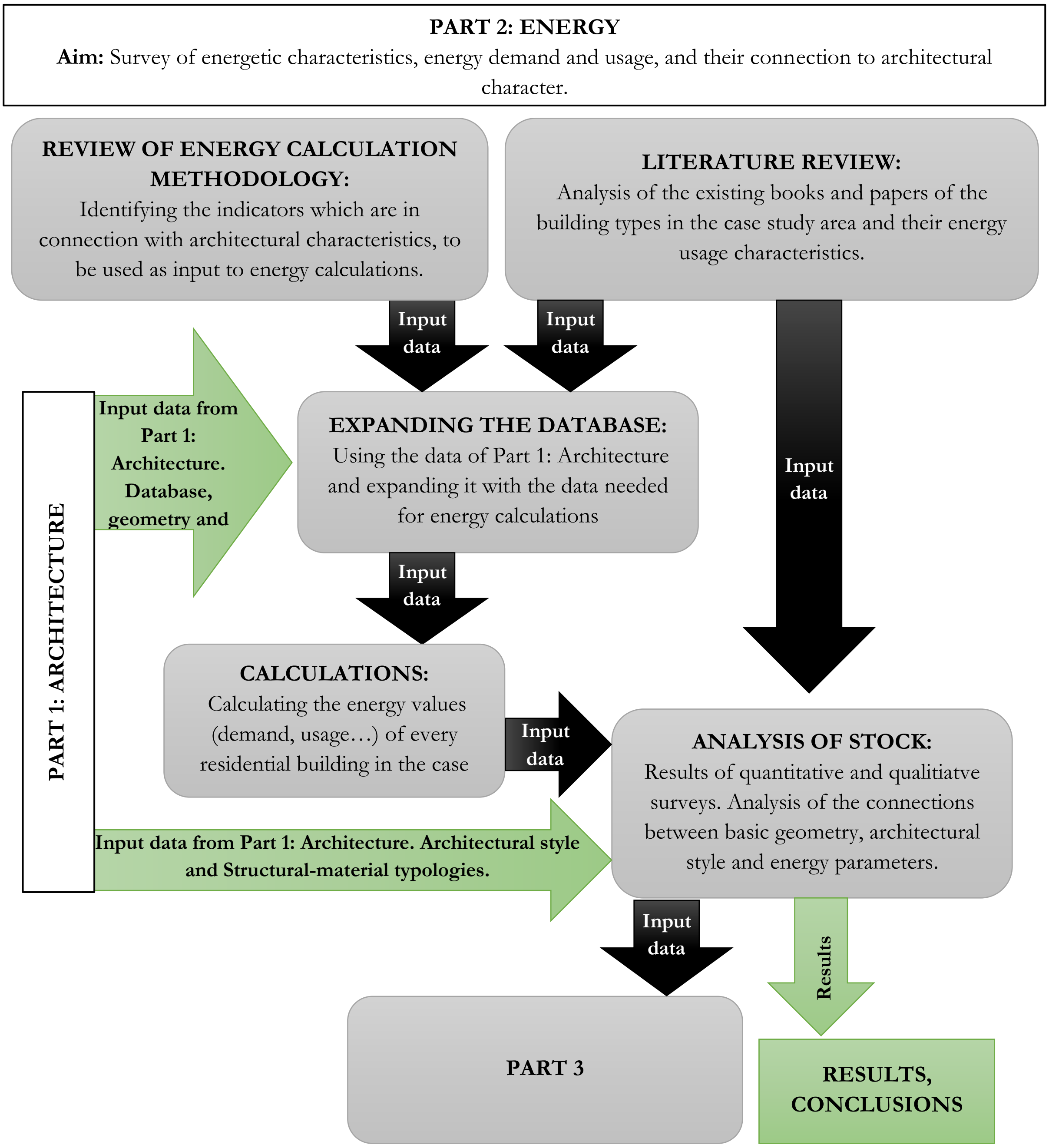


Figure 34: Methodology and workflow of Part 2: Energy (source: Authors' own figure)

3.1 BUILDING ENERGETICS IN HUNGARY

3.1.1 Hungary's energy usage

Hungary imports a significant part of its primary energy demand. There is a relatively large difference between energy production and usage (only the 35% of the total energy demand is produced domestically), thus the country depends considerably on the imported energy. 80% of the domestic crude oil demand, 83% of the natural gas demand originates from the former Commonwealth of Independent States, which import is predicted to increase even further (Deputy Secretariat of State for Green Economy Development and Climate Policy for the Ministry of National Development, 2010). Furthermore, the ratio of renewable energy in the primer energy consumption of Hungary is quite small, around 11% (OECD Enrvironmental Performance Reviews, 2018). Thus, to reduce the import dependency, decreasing the energy usage and increasing the ratio of domestic produced energy of renewable source is a long-term aim of the country.

3.1.2 The ratio of buildings in the energy usage of Hungary

The building sector is one of the most influential energy consumers in Europe, where energy utilization has been constantly increasing in the last 20 years. In most European Union countries as well as in Hungary, the buildings are responsible for around 40% of the total primary energy consumption (European Commission, 2019). Improving the building energetics is thus an important segment of the energy efficiency developments.

In Hungary, the households use 60% of energy usage out of the total energy utilization of buildings (Figure 35), 69% of the above is used for heating, 11% for hot water (Figure 36) which are often provided by the same system (ÉMI Építésügyi Minőségellenőrző Innovációs Nonprofit Kft., 2015). Approximately 70% of the 4.3 million flats of Hungary are not satisfying the present technical, functional and thermal requirements (Deputy Secretariat of State for Green Economy Development and Climate Policy for the Ministry of National Development, 2010), which is increasing the complexity of the problem.

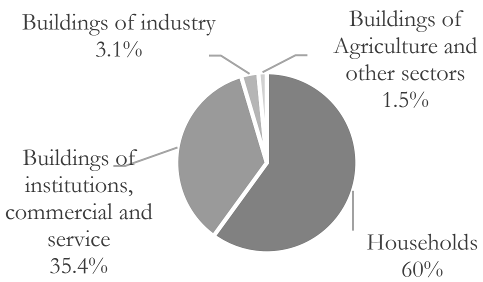


Figure 35: Different building functions and their ratio of energy utilization (source: (ÉMI Építésügyi Minőségellenőrző Innovációs Nonprofit Kft., 2015))

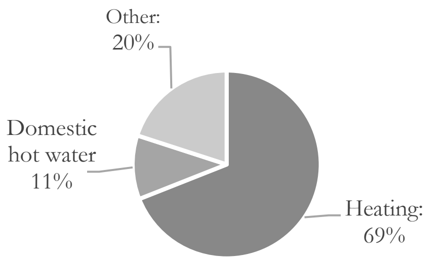


Figure 36: Ratio of energy utilization forms in a household (source: (ÉMI Építésügyi Minőségellenőrző Innovációs Nonprofit Kft., 2015))

Based on the above reasoning, **the residential buildings should be investigated in detail, focusing on heating energy demand,** as that is the most dominant form of energy consumption. The case study area is especially practical in this regard, given the high ratio of residential buildings.

3.1.3 The climate of Budapest

The heating energy demand of the Hungarian household mostly results from the climate of the area. According to the Köppen-Geiger climate classification, the city belongs to humid continental climate, warm summer subtype, group Dfb. The average annual temperature is 11.0 °C in Budapest. The average annual rainfall is 564 mm (Climate-Data.org, 2019), during the winter, snowing occurs. The heating season is normally between 15th October and 15th April.

The average monthly temperature, rain, humidity and solar radiation values are shown in Figure 37.

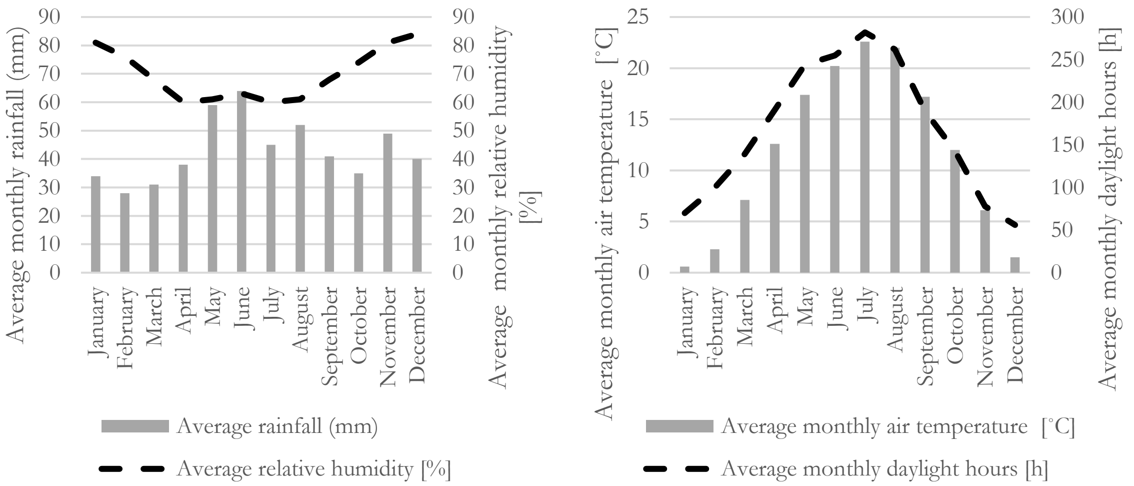


Figure 37: Rainfall [mm], humidity [%] (left), and average monthly temperature [˚C] and daylight hours [h] (right) in Budapest (Hungarian Meteorological Agency, 2019)

3.1.4 Measures for energy efficiency of buildings

Various measures are taken worldwide to cope with the ever-increasing energy demand and to expand the possibilities of efficient utilization. In order to decrease the import dependency of the European Union, the European Parliament accepted multiple action plans and directives, aiming to reduce the energy demand and the carbon dioxide emission. In March 2010, European Commission published the Europe 2020 Strategy in which the main objectives are to reduce the greenhouse gas emissions by 20% compared to the 1990 level, to reach a 20% share of the renewable energy sources of the total energy consumption and furthermore, to realize 20% energy saving until 2020 (European Parliament and Council, 2010). As a component of the above, energy efficiency of the buildings should be increased.

For newly constructed buildings, strict efficiency measures are mandatory: according to Article 5(2) of Directive 2010/31/EU (European Parliament and Council, 2010), Member States were required to create cost-optimal energy performance requirements based on methodology established by the European Commission.

'Cost-optimal level' means the energy performance level which leads to the lowest total cost during the estimated economic lifecycle. The requirements of the above level in Hungary are provided in detail by Decree No 7/2006 of 24th May 2006 in Hungary (7/2006. (V. 24.) TNM rendelet: Az épületek energetikai jellemzőinek meghatározásáról (7/2006. (V. 24.) Minister without Portfolio Decree determining the energetic characteristics of buildings), 2006).

Introducing the cost-optimal level of requirements; however, is only a preconditioning for the more energy efficient 'Nearly Zero Energy Buildings' (NZEB), which level is mandatory after 2020. Although this level is not yet used for the renovations of the existing building stock, they should be considered as a future requirement.

Given its vastness and the slow exchange rate of the existing building stock, various energetic retrofit programs supported by the European Union and the Government have been issued (European Commission, 2014). In the boundaries of these projects, the renovated buildings already should comply to all of the above requirements.

3.1.5 Question of special buildings

As mentioned above, although the newly designed buildings must comply to strict energy efficiency prescriptions, their ratio is insignificant compared to the vast number of ineffective buildings. In Hungary, the phasing out of the buildings (including demolitions and new constructions) is only 1,7% annually (Hungarian Central Statistical Office, 2019). This means that the present building stock plays and will play significant role in the energy usage of the country for a long time – which should be considered when planning energy efficiency measures on country level.

The historical districts and the heritage buildings stand as special part of the above question, as several limitations increase the complexity of their retrofit. Therefore, it is highly important to establish renovation guidelines for these buildings, which provide better life quality for the residents by increasing the energy efficiency, while respecting the unique, historical architectural character. Planning an energetic rehabilitation for heritage buildings; however, meets several limitations, due to the guidelines narrowing down the possible energy efficiency interventions. The above problem is topped by their generally bad condition (Nagy, 2008) and the large number of inhabitants (Szabó, 2012).

Apart from their high energy usage, buildings are responsible for a significant amount of greenhouse gas emission in the form or carbon dioxide, altering the planet's climate. By the highly efficient renovation of these buildings, the living conditions can be improved, and significant amount of energy can be saved at the same time.

3.1.6 Building typologies used for energy efficiency surveys

Typologies are commonly used for large, even country scale energy estimation. In Hungary the most commonly used two typologies are the following: The National Building Energy Strategy (NÉES) (ÉMI Építésügyi Minőségellenőrző Innovációs Nonprofit Kft., 2015), and the Tabula Episcope Project (Csoknyai, et al., 2014).

The National Building Energy Strategy system covers public and residential typology based on country scale field survey and national statistical data. Those data are used for energy utilization assessment as well as decision support for future Government Funding Programs. The Strategy defines fifteen different residential building types. The multi-storey apartment buildings of the downtown in question belong to the types Nr. 10–15.

The traditional apartment houses in focus are mentioned with the following specification: Nr. 10: built before 1945, brick or stone walls, more than ten flats in an apartment house. 15.3% are in a run-down condition, 50.1% is satisfactory. Total of 14 million m^2 of which 88.3% is in Budapest. The other groups are: Nr. 11: 1946–2000, built of brick; Nr. 12–14: various prefabricated buildings built between 1946–2000; Nr. 15: built after 2001.

The Tabula Episcope is a European Union scale project with many participating countries, in which the professionals of each country used similar methodology to determine the characteristics of the countries' buildings. Age and size-based grouping is used with characteristic structures, materials and engineering solutions for each. Here also, the traditional downtown stock is classified into one group as: MFH.01.: built before 1944, 2–5 stories, 10 or more flats per building. Built of traditional structure: brick wall, wooden slab or Prussian-vault, empty attic. The other groups consisting of building types of the downtown stock in question are: MFH. 02.: built between 1945–1979, brick; AB. 02.: built between 1945–1979, prefabricated; MFH. 03.: built between 1980–1989, brick; AB. 03.: built between 1980–1989, prefabricated; MFH. 04.: built between 1990–2005, brick; MFH. 05.: built after 2005, smaller; AB 05.: built after 2005, larger.

The Tabula takes the typology one step further compared to the NÉES. The project offers two renovation scenarios for each of its types (standard refurbishment and ambitious refurbishment), thus the possible energy saving potentials and costs can be estimated. According to these calculations, there is significant energy saving potential in the traditional apartment house type in question: primary energy demand for heating and domestic hot water can be decreased by 51% in case of standard, and 61% in case of ambitious renovation. The carbon-dioxide emission for heating and domestic hot water can also be reduced on a similar scale.

The recommended renovation scenarios; however, do not consider the architectural heritage value of these traditional, ornamented buildings, where the structural and surface adjustments may be severely restricted.

The Negajoule 2020 project is a less known typology, which uses a somewhat different residential building classification. The three main groups are family houses, traditional and prefabricated apartment houses. Based on bottom-up methodology, the aim of the study is to estimate the energy saving potential, also to gain better understanding of the residential energy utilization, to support the official strategies and policies. For the calculations, statistical data was used of the structural and heating devices, then summarized to the three above mentioned groups. The authors also add materials and engineering systems based on the most characteristic data of the groups (Fülöp, 2011). See the comparison of the three above typologies in Table 5.

Table 5: Comparison of the groups of the mentioned typologies dealing with the downtown residential buildings NÉES, TABULA and NEGAJOULE2020 (source: Authors' own table)

<table>
<tr><th rowspan="2">Typology</th><th colspan="8">Timeline of the typologies</th></tr>
<tr><th>–1944–45</th><th>–1945</th><th>–1960</th><th>–1970</th><th>–1980</th><th>–1990</th><th>–2000</th><th>–2010</th></tr>
<tr><td>National Building Energy Strategy</td><td>Nr. 10: built before 1945, brick or stone walls</td><td colspan="6">Nr. 11: 1946-2000, built of brick;
Nr. 12–14: various prefabricated buildings built between 1946-2000</td><td>Nr. 15: built after 2001</td></tr>
<tr><td>Tabula Episcope Project Typology</td><td>MFH.01.: built before 1944, 2-5 stories, 10 or more flats per building.</td><td colspan="2">MFH. 02.: built between 1945-1979, brick;
AB. 02.: built between 1945-1979, prefabricated</td><td>MFH. 03.: built between 1980–1989, brick
AB. 03.: built between 1980-1989, prefabricated</td><td colspan="2">MFH. 04.: built between 1990–2005, brick</td><td colspan="2">MFH. 05.: built after 2005, smaller;
AB 05.: built after 2005, larger</td></tr>
<tr><td>Negajoule 2020</td><td colspan="8">Traditional and prefabricated apartment houses</td></tr>
</table>

As an example of application of the above typologies, Hrabovszky-Horváth, et al. (2013) used the simplified residential typology for mitigation and sensitivity estimations in a Hungarian city.

The introduced typologies use the size of the building in some extent for energy assessment, but are not going further into details of geometry, which are significant factors of energy usage. In a case study of Milan, however, the authors (Troglio, et al., 2011) use simple geometry values of buildings to estimate the energy demand. By using general information, like footprint area, floor height and age, they provide a broad estimation to district scale energy demand. The study also highlights the importance of compactness of the building, since the cooling surface to heated volume ratio is the most important geometry indicator to estimate heat losses. The study uses the energy demand for evaluation, instead of energy consumption values (see Section 3.3.2). The principal advantage of the above approach is that the input data can be easily reached even via GIS databases or satellite images. They also can be calculated similarly simply, not only by professionals: thus, this kind of generalization can be used in decision support systems for different stakeholders.

As a summary of the above, the introduced Hungarian typologies classify the buildings based on size, main construction technology and year of construction. The details of downtown traditional buildings, however, are not considered. All of them, which were built before 1944–45 are classified as one type, which causes some limitations in terms of accuracy. None of the above typologies are specifying the difference between free standing and downtown buildings. The latter are most commonly built in an unbroken row: these buildings are squeezed into a plot, with averagely 2-3 sides connected to their neighbours with firewalls.

I suggest that this type of building can further be divided into subgroups, because there were significant changes in structure and geometry even before the end of the Second World War, which influences the buildings' energetic values.

In conclusion, the methodology of the above introduced Hungarian typologies will be used as a baseline with some changes: a new method of differentiating the buildings by style and geometry instead of size and construction time will be introduced.

3.2 THE HUNGARIAN BUILDING ENERGY CALCULATIONS

In correspondence with European Union regulation 2010/31 EU, Hungary implemented the below Decrees to lay the foundations of the energy efficiency of buildings:

- 7/2006. (V. 24.) Minister without Portfolio Decree determining the energetic characteristics of buildings (2006)
- 176/2008. (VI. 30.) The Hungarian Government Decree on the certification of energy characteristics of buildings (2008)
- 20/2014 (III.7.), amending decree of 176/2008, of Home Secretary (2014)

The Hungarian calculation system is EPBD conform (Energy Performance of Buildings Directive) based on EU guidelines (European Parliament and Council, 2010) and various international and national standards (Baumann, et al., 2009). The main idea of the system is that three levels of energetic requirement should be analysed. The different levels target different aspects of energy efficiency: structures, geometry and engineering systems. All the levels should be analysed separately; the levels are, however, dependent and built on each other. The result values in the end show a complex assessment of the buildings' energy utilization. The requirements of each level have limiting values, and by reaching these, the buildings can be classified into groups between *poor* and *very efficient*. The limiting values and the calculation methodology are stated in the Decrees above. To gain the Nearly Zero Energy Building (NZEB) classification, the strictest limiting values should be complied in all three levels.

The three levels of requirement are shown on Figure 38 and detailed below.

- ### Level 1: Compliance of structures (U, thermal transmittance value [W/m^{2}K]);

This requirement aims for the sufficient heat insulation capability of the structures enveloping the heated volume. The value is affected by material, layering and position of the structure as well as the quantity of heat bridges.

- ### Level 2: Compliance of geometry (q, heat loss coefficient [W/m^{3}K]),

The second level of requirement is using data from the first step and combines it with geometry of the building (areas and volumes). The aim of this is to have adequately low heat losses, which is why the limiting value encourages compact buildings.

In the first and this second level, the calculated values are only dependent on architectural data: the building geometry itself is used to calculate the heat losses caused by the enveloping surface to heated volume ratio. The value includes the solar gains through fenestration but excludes the engineering systems. The value is represented by the heat loss coefficient.

Another important energy indicator values calculated here are: specific net heating energy demand q_F [kWh/m²a], and total net heating energy demand Q_F [kWh/a].

- **Level 3: Compliance of the total building with engineering systems (E_P, Total primary energy consumption [kWh/m²a])**

The third level contains the energy consumption of the engineering systems annually in primary energy. The value shows the total energy usage of all the engineering systems, containing their efficiency on common primary energy value. In the case of residential buildings, the heating energy and the domestic hot water energy consumption should be summed, as they are the predominant form of energy usage.

The main equations of the above levels are detailed in Appendix C.

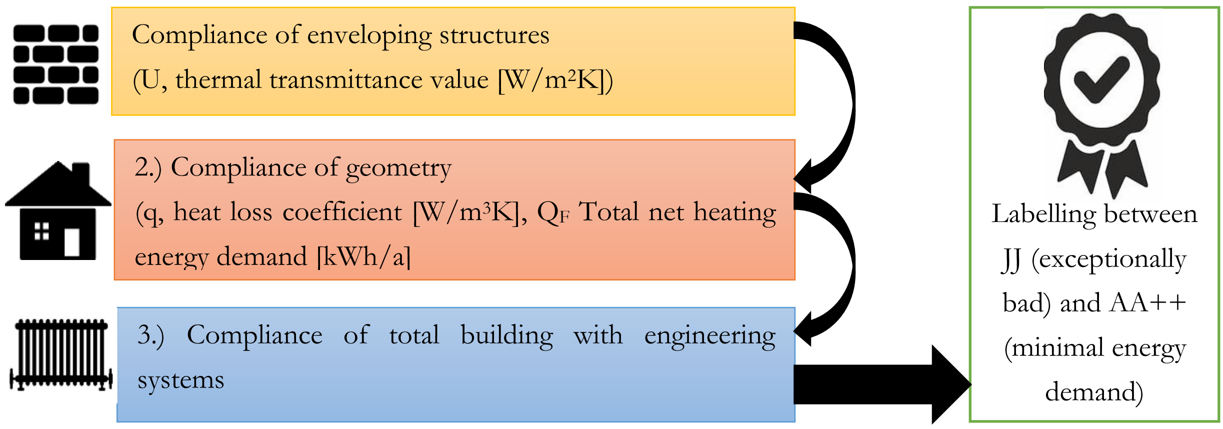


Figure 38: The three levels of the calculation system (source: Authors' own figure)

3.3 ENERGETICS CALCULATION

3.3.1 Boundary conditions

Using the European Union conform Hungarian calculation system described above, the large-scale calculations were carried out with some simplifications. Each building is calculated as one inner space, not by apartments. All the flats are considered used and heated. In the case of two functions, for example: residential and commercial, the main function is considered for the full building. The lighting shafts were not considered. As the walls are thinner on the upper elevations, an average wall width was calculated.

The official calculation methodology also allows certain simplifications, for example: to neglect the orientation of windows, to calculate only with a nominal solar intensity. The exact surface of the fenestration in the case of each building cannot be measured due to the large numbers. For simplification, example buildings were chosen of each architectural style, where the ratio of windows on the façade was measured. The same method was used for the angle of the pitched roofs.

To calculate the heat transmission values of the enveloping structures, the above introduced structural-material typology was used. See the U values of each structure in APPENDIX D. There is an uncertainty of the Total primary energy consumption (E_P) owing to the fact that several calculation values provided by the Decree are based on a standard user profile (Baumann, et al., 2009).

The lack of required data concerning the used heating systems required further simplification: the original heating systems of the traditional apartment houses are known from literature, but these systems were refurbished in an unknown ratio, which is not easily perceived from outside, contrarily to structural changes like insulation or fenestration retrofit. The Author's attempt on answer-sheet surveys resulted low answer ratios on the currently used heating systems of the flats. Both the unwillingness of answering and the lack of knowledge of the residents encumbered the survey. Although assumptions can be made based on statistical data, the accuracy is not satisfactory: the only available information on the heating systems of the buildings is from the Hungarian Central Statistical Office (data assembled on individual request), which only states the ratio of the used heating systems per blocks, not per house or flat.

Using the statistical database, however, the following heating systems were presumed. House-central heating with one main heater device and radiators in the flats. Two variations, an older and a newer technical solution was used for calculations to differentiate between the older and newer buildings. For domestic hot water production in the old case, electric boiler was used. In the new case, indirectly heated water tank was assumed (the house-central heated buildings are easily identifiable via their large, single chimney).

Most of the traditional buildings, however, are not centrally heated, but with room-by-room devices. These are mostly equipped with convectors for heating and gas boiler for domestic hot water. According to the database, averagely 75% of each building is still heated by convectors or even older tile stoves. Averagely 25% of the flats in each building, however, have been modernized to flat central heating with more contemporary gas boilers or condensation heaters, which combine the heating and domestic hot water production.

3.3.2 Values analysed

The following values were analysed to be able to assess the energetic characteristics of the buildings:

Values of geometry:

Geometry and energy related data were analysed and compared with style. The primary aim was to find relative easily accessible or calculated geometry values which can be used for estimation of energy values.

To survey the building geometry, the footprint of the buildings (A, m^2), the net heated area (A_N, m^2), and the total heated building envelope surface per volume ($\sum A/V$, m^2/m^3) were used. $\sum A/V$ describes compactness and a frequently used value in the energy calculation system.

Based on Troglio, et al. (2011), the ratio of footprint per perimeter (A/P, m^2/m) of a building is also used. The storey area indicator (SAI, without unit) is also a common architectural value of regulation plans indicating the density of a given plot (calculated by summing all the storey areas and dividing it with the plot area).

Values of energy:

The analysed values are the main indicators of the energy calculation system: thermal transmittance value (U, W/m^2K) for the compliance of enveloping structures. Heat loss coefficient (q, W/m^3K), for the effect of change in U values together with the given geometry.

The total net heating energy demand (Q_F, kWh/a) and the specific net heating energy demand (q_F, kWh/m^2a) were also important values to classify the buildings. The specific net heating energy demand shows the value based on m^2 annually, while the total considers the area and shows the summed value per building. The net heating energy demand values of the building give us more precise information on the energetic condition since they are based only on architectural, building structure and geometry-based information, which can be measured also by using GIS and satellite tools with relatively simple solutions. Thus, not affected by the uncertain and untypical engineering solutions made by the flat owners individually.

For the complex energy survey, the total primary energy consumption (E_P, kWh/m^2a) was analysed.

As last step of the energetic calculations, the buildings are classified into groups based on their E_P difference to the Nearly zero requirement level (in %), prescribed in the aforementioned decrees. The classification groups with their sign, name and percentage interval compared to the Nearly Zero level are shown in Figure 39. The groups between AA++ and BB are complying the Nearly Zero level.

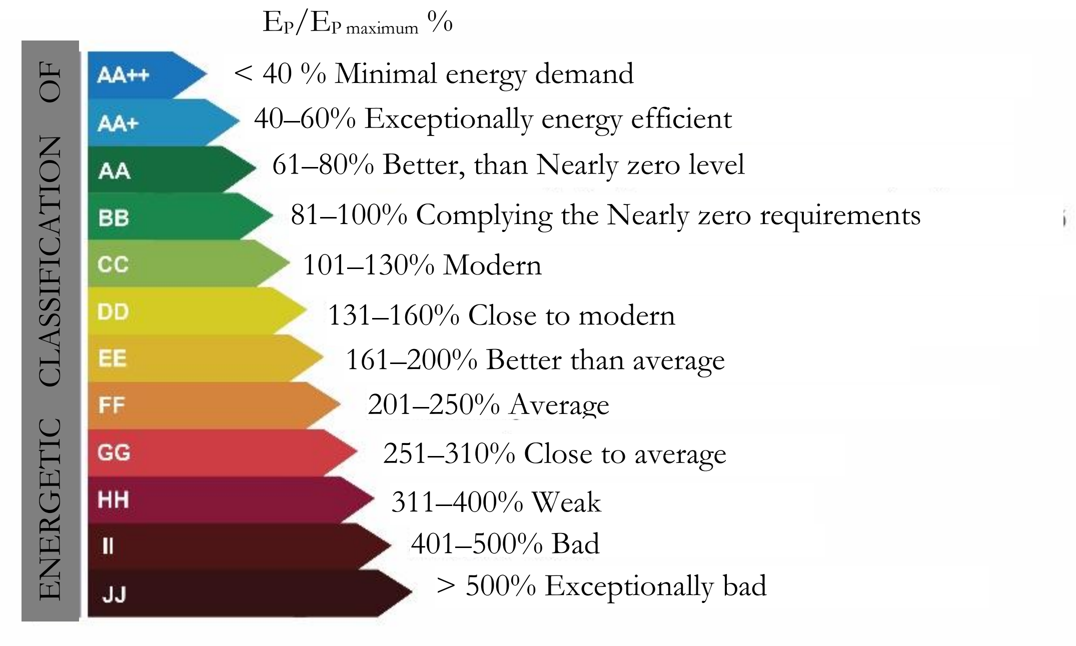


Figure 39: Classification of E_P compared to the Nearly Zero requirement level of 100 kWh/m²a to prove the compliance: Classification between AA++ and JJ (source: Authors' own figure)

3.3.3 Surveyed stock of the case study area

As described above, the case study area stock is apartment house type of which 88% is residential, altogether 386 buildings. In Part 2 and 3, only the residential buildings were surveyed. This function is the most common in the stock. Narrowing down the function supports the better comparison of the energetic characteristics.

The other reason to focus on the residential function is the high ratio of energy utilization of the households described in Section 3.1.2 above. Figure 40 shows in grey the surveyed buildings in the case study area. The white buildings are non-residential.

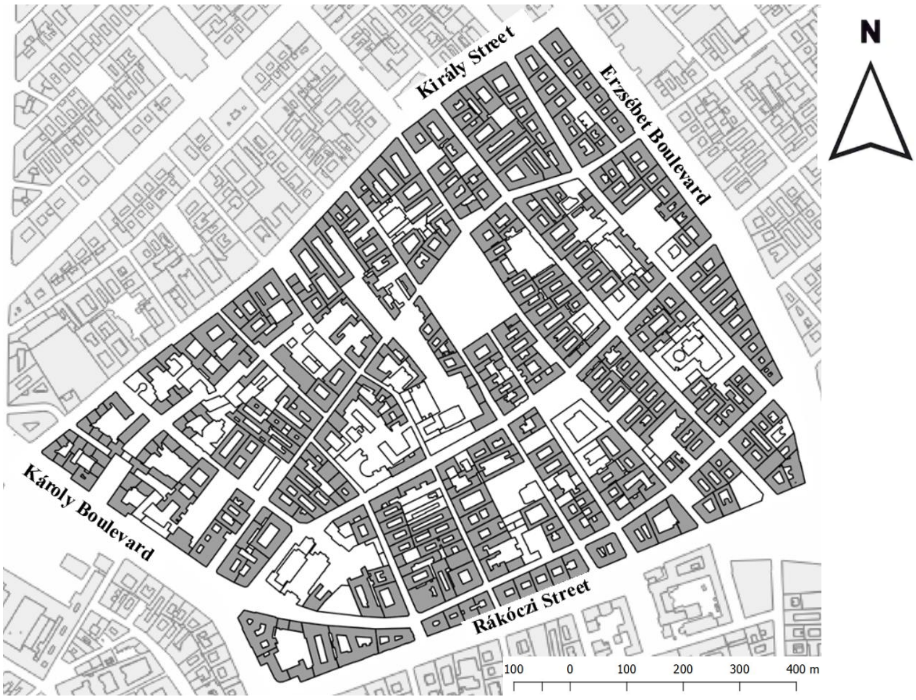


Figure 40: The surveyed buildings are shown in grey. The white ones are non-residential (source: Authors' own figure)

3.3.4 Analysis of stock: results of quantitative and qualitative surveys

- **Change of values per construction time**

The change of average A and A_N through time is uneven. The average ∑A/V is decreasing, the unevenness of the 19th century becoming balanced decline showing that the buildings are eventually becoming more compact Figure 41.

Figure 41: The change of average total heated building envelope surface per volume (∑A/V [m²/m³]) through the surveyed period (source: Authors' own figure)

The above trend is complemented with the rapid increase of Storey Area Indicator (SAI), showing the densening of the area. This trend stops slightly around the end of the Second World War (Figure 42).

Figure 42: The change of average Storey Area Indicator (SAI, N/A) value for heating through the surveyed period (source: Authors' own figure)

It can be concluded that the buildings through the surveyed period became compacter and the plots are significantly more and more utilized, especially during the traditional building period. The post-war period SAI follows the stricter rules for plot-utilization, leaving more area for courtyard. The post-war financial and construction crisis can be perceived, with a decreasing value.

Concerning the average heat loss coefficient (q, W/m^{3}K), a slight decreasing value is shown on Figure 43, but there is no clear, decisive trend through the years. This shows that there is no major trend in the change of the average q, thus the complex effect of geometry and structures do not change significantly. A larger change is shown from the 1980s, where the construction technology and geometry has altered first to prefabricated, then to the contemporary insulation materials and energetic regulation influence the results.

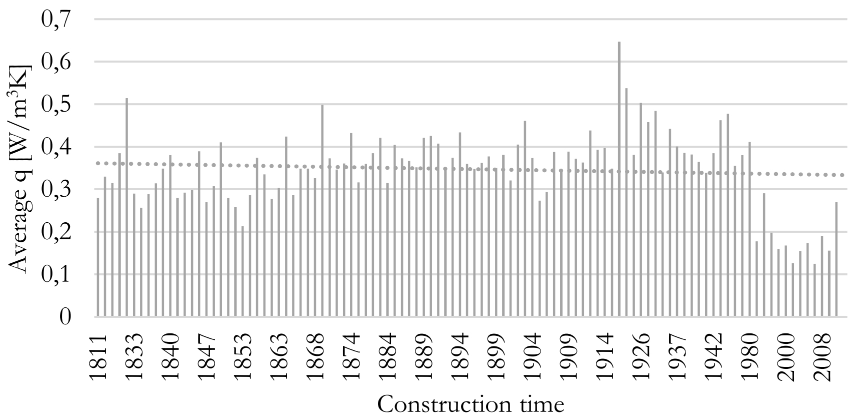


Figure 43: Figure The change of the average heat loss coefficient (q [W/m3K]) through the surveyed period (source: Authors' own figure)

In the case of the average net energy demand value for heating (q_F, kWh/m^{2}a), the trend shows a more rapid decrease (Figure 44). Here, the other larger decline apart from the 1980's is shown around 1930, where the building structure as well as geometry show substantial changes compared to the previous years with more compact forming (Premodernism).

The average Q_F value is generally following the trend of q_F.

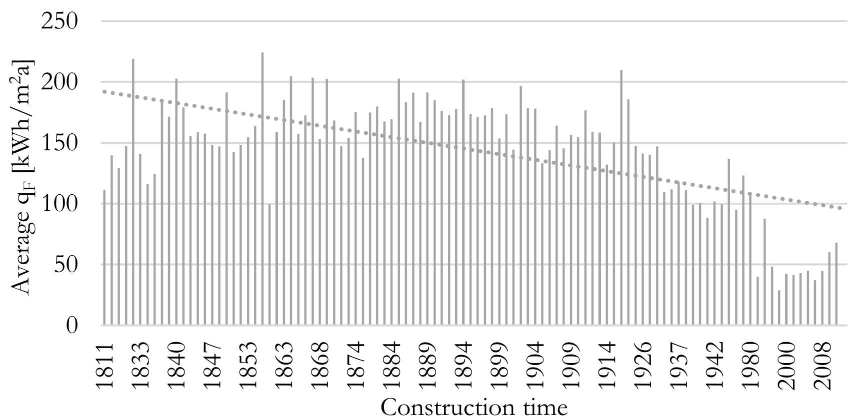


Figure 44: The change of the average specific net energy demand value for heating (qF [kWh/m2a]) through the surveyed period (source: Authors' own figure)

The above time-based assessment shows the average trend of change, but by further dividing the surveyed stock using architectural style groups, the data can be refined.

- ## Connection between geometry and energy values with architectural style

Why to choose architectural style as a reference point of energy estimation? The reason is the same as using simple geometry data and typologies mentioned above: for architects and decision makers, the style data is easy to reach via databases or simple sight-based identification. Table 6 shows the averages of the main geometry and energy values of the different styles, together with the packages used. The diagrams below visualize the data.

Table 6: Styles and packages, and the average geometry and energy values. The colours are showing the scale of the values compared to each other in every column (green is smaller, yellow is middle scale, red is large scale value compared to the order of magnitude of the value) (source: Authors' own table)

Style	Packages										Geometry data				Energy data		
Style names	Total number of buildings	Package 1 (number of buildings)	Package 2 (number of buildings)	Package 3 (number of buildings)	Package 4 (number of buildings)	Package 5 (number of buildings)	Package 6 (number of buildings)	Package 7 (number of buildings)	Package 8 (number of buildings)	Package 9 (number of buildings)	Average footprint A [m²]	Average net heated area A_N [m²]	Average total heated building envelope surface per volume ΣA/V	Average Storey Area Indicator SAI	Average heat loss coefficient q [W/m³K]	Average specific net energy demand value for heating q_F [kWh/m²a]	Average total net energy demand value for heating Q_F [MWh/a]
Neo-Classicism	33	17	7	7	2						751	2 047	0.48	1.9	0.33	163	313
Romanticism	8		4	3	1						867	2 777	0.47	2.5	0.34	169	425
Historicism	176			2	139	35					682	2 514	0.46	3.1	0.38	180	430
Freestyle	91				35	43	13				727	3 810	0.41	4.3	0.38	156	572
Premodernism	46					1	2	43			360	2 669	0.35	5.2	0.4	112	289
Modernism	1								1		275	1 926	0.39	6.4	0.46	100	192
Socialist Modernism	7								7		469	3 718	0.3	4.0	0.4	113	406
Contemporary	24									24	633	4 215	0.4	4.0	0.18	50	186

As stated in Part 1, the most significant styles are Historicism and Freestyle, the mostly used is Package 4. The average footprint (A) values are considerable more from Neo-Classicism to Freestyle buildings, than later. As most of the Premodern and Modern buildings were built as a replacement of demolished, older buildings, their footprint is smaller to be able to utilize more of the plot. This is also reflected in their SAI.

Although the number of buildings is much more in Historicism than in Freestyle, the net heated area (A_N) shows that the Freestyle buildings are larger on average. The Contemporary buildings contain the largest average A_N.

The Premodern buildings have one of the lowest average ∑A/V, but their SAI is almost the largest, showing that the most compactly formed buildings are built most densely on their plots. The most complex form of Neo-Classicism buildings (high ∑A/V) are built most loosely on the plot, leaving large courtyards on average.

The significantly lowest q, q_F and Q_F values are shown in case of Contemporary buildings, which is no surprise, given more excessive usage of insulation materials.

Figure 45 and Figure 46 show that the process of densening by time can be followed with respect to time and style as well. The ∑A/V is gradually decreasing, the SAI is increasing until Modernism, later drops down for Socialist Modernism and Contemporary.

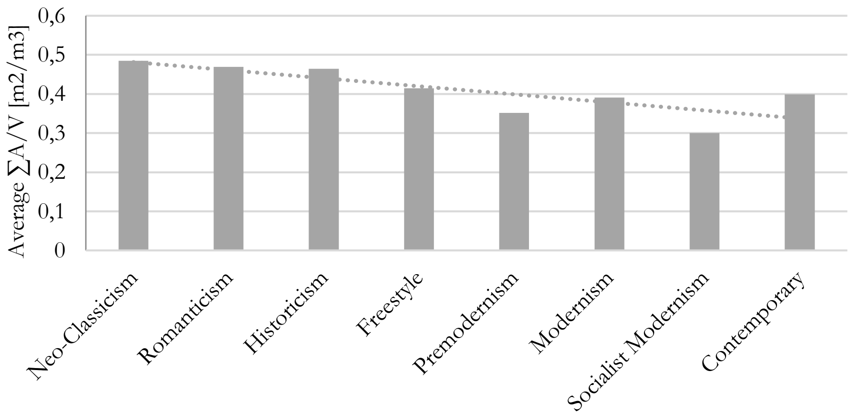


Figure 45: The average total heated building envelope surface per volume (∑A/V [m²/m³]) shows a slight decrease over time (source: Authors' own figure)

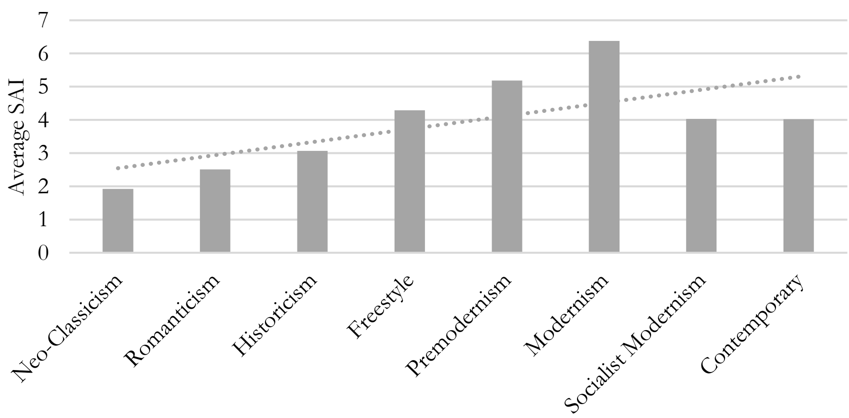
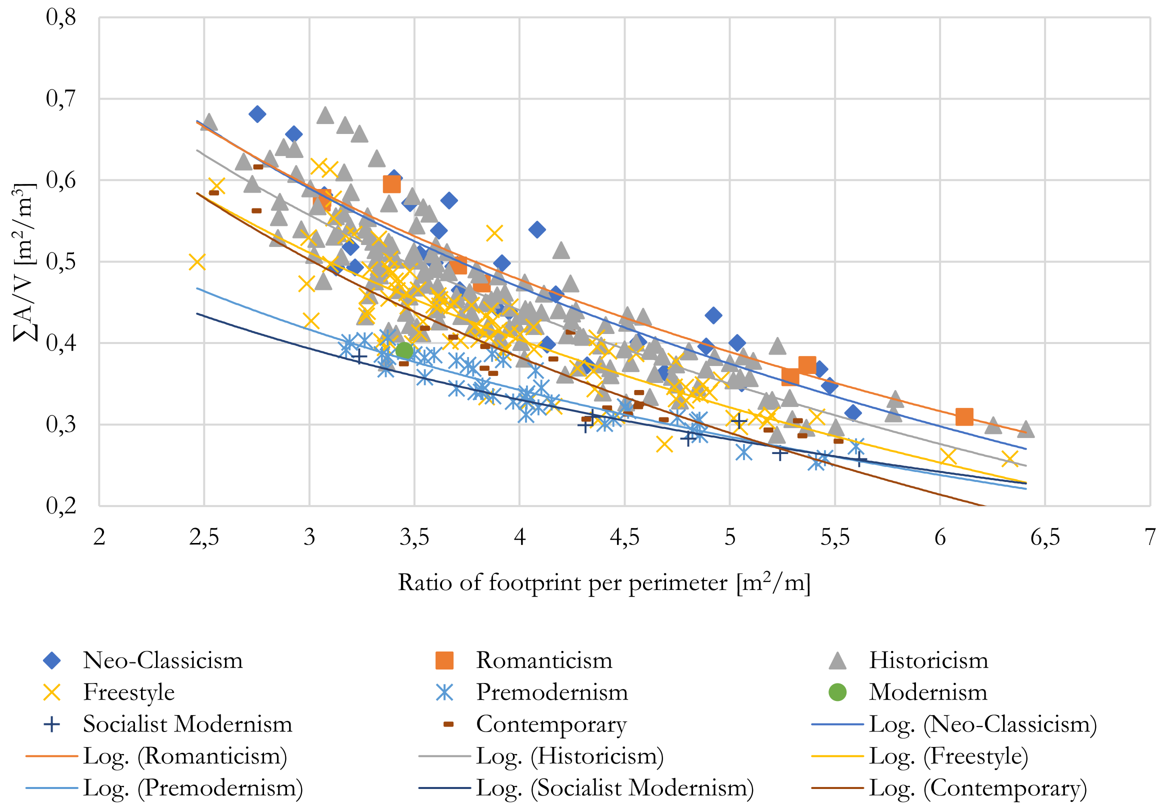


Figure 46: The average Storey Area Indicator (SAI N/A) increases continuously in every style until Modernism (source: Authors' own figure)

Figure 47 shows that by using simple geometry – footprint, perimeter and their ratio – the ∑A/V value directly linked to energy calculation can be estimated. Simple geometry like footprint and perimeter can be gained and measured even by non-professionals, using simple tools or even GIS or satellite images. This ratio can serve as an estimation of the important energetic value of ∑A/V. The respective equations and the R^2 per style to calculate ∑A/V are also shown below.



Style	Neo-Classicism	Romanticism	Historicism	Freestyle	Premodernism	Modernism	Socialist Modernism	Contemporary
Equation and R^2 of ∑A/V depending on the ratio of footprint per perimeter	y = -0.421ln(x) +1.053 $R^2 = 0.78$	y = -0.398ln(x) + 1.0303 $R^2 = 0.96$	y = -0.405ln(x) + 1.0025 $R^2 = 0.75$	y = - 0.372ln(x) + 0.9197 $R^2 = 0.73$	y = -0.258ln(x) + 0.6997 $R^2 = 0.87$	Only two data, not sufficient for equation	y = -0.218ln(x) + 0.6333 $R^2 = 0.90$	y = -0.416ln(x) + 0.9594 $R^2 = 0.88$

Figure 47: Connection between ratio of footprint per perimeter [m²/m] and total heated building envelope surface per volume (∑A/V [m²/m³]) (source: Authors' own figure)

Compliance of geometry of the buildings has been described above (Section 3.2), as Level 2 of energy calculation in Hungary. The building complies to the requirement level if it the combined q and ∑A/V values are under the margin line prescribed (until 2020, the cost-optimal level is mandatory, the nearly-zero level is valid from 2020). On Figure 48, the black line marks the past compliance level, the blue line is the cost optimal level, while the green line is the near zero level.

Figure 48 shows that these buildings in their present state are not complying with the requirement levels. The placement of the points leaning to the left side of the diagram indicate the relative compactness of the stock, especially the Premodernism buildings are on the left side of the mass.

It can be concluded that only a handful of traditional buildings comply with the past requirements. All of the Contemporary buildings comply to the past, numerous to the cost-optimal, and two even for the nearly zero requirements.

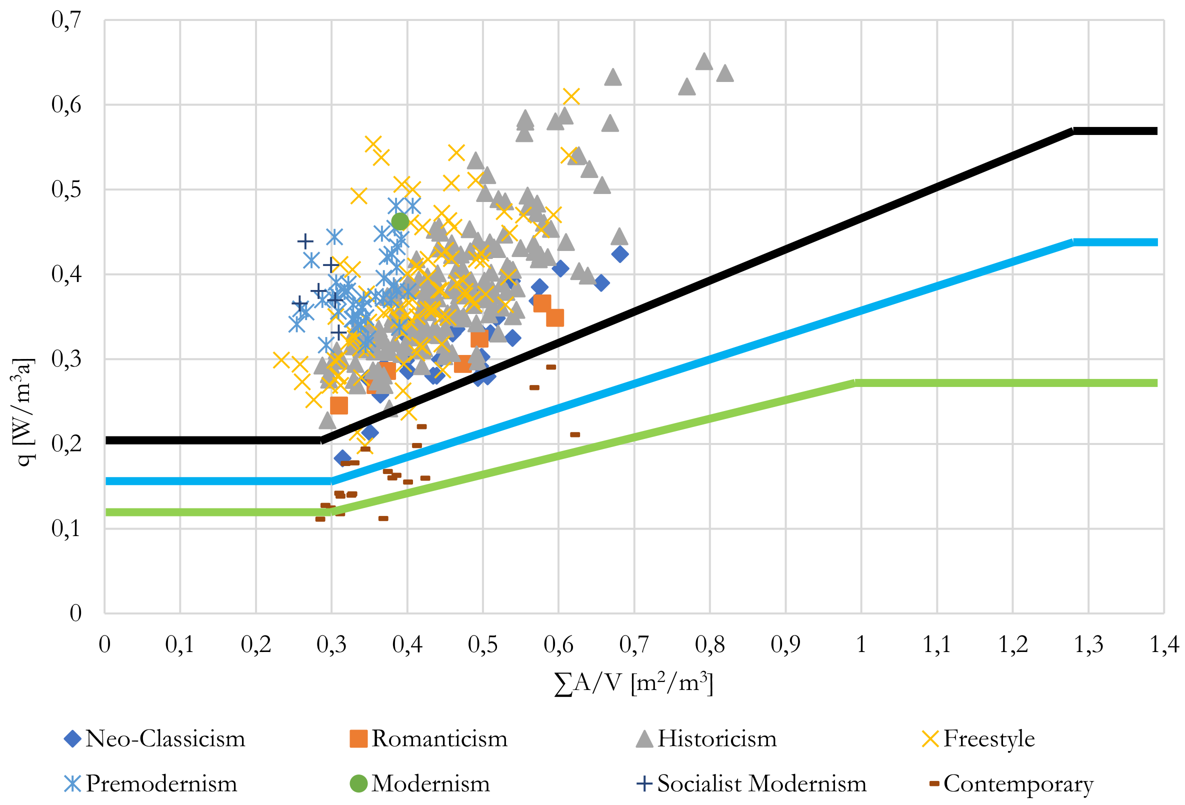


Figure 48: Compliance of geometry of the buildings – the case study block. Black line: past compliance level, blue line: cost optimal level, green line: near zero level. The combined values of total heated building envelope surface per volume (∑A/V [m²/m³]) and average heat loss coefficient (q [W/m³a]) are surveyed for each building to determine the compliance (source: Authors' own figure)

Figure 49 shows the same as Figure 48, highlighting that the marks of the different styles are grouping, and can be separated from each other, thus, the diagram can be used to estimate the q value if ∑A/V is known.

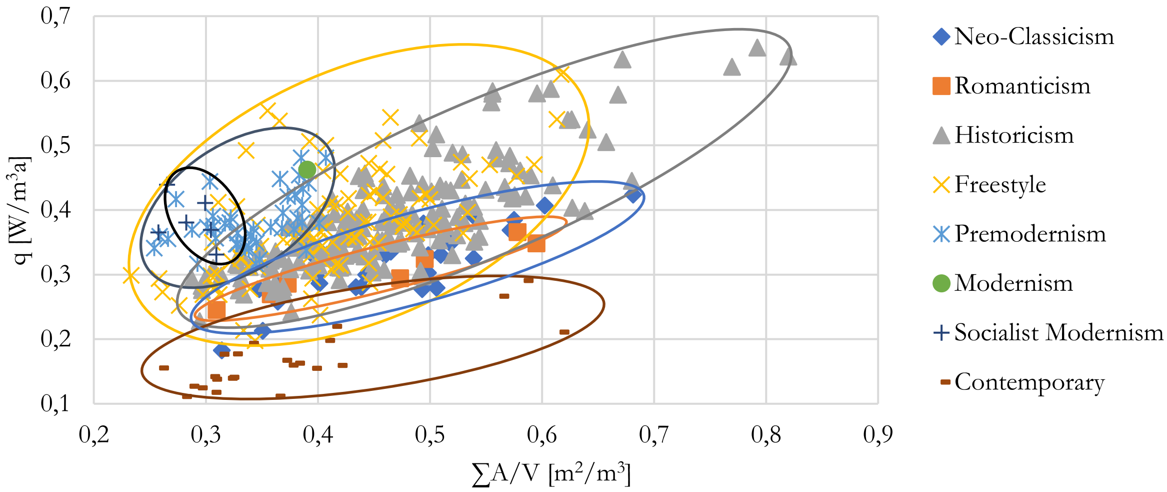


Figure 49: Compliance of geometry of the buildings – the case study block. The grouping of the buildings. (source: Authors' own figure)

If ∑A/V is known, the q_F values can also be estimated per style (Figure 50), underlining the usability of the hypothesis of simple geometry data helping the estimation of energy values estimation for the traditional building stock.

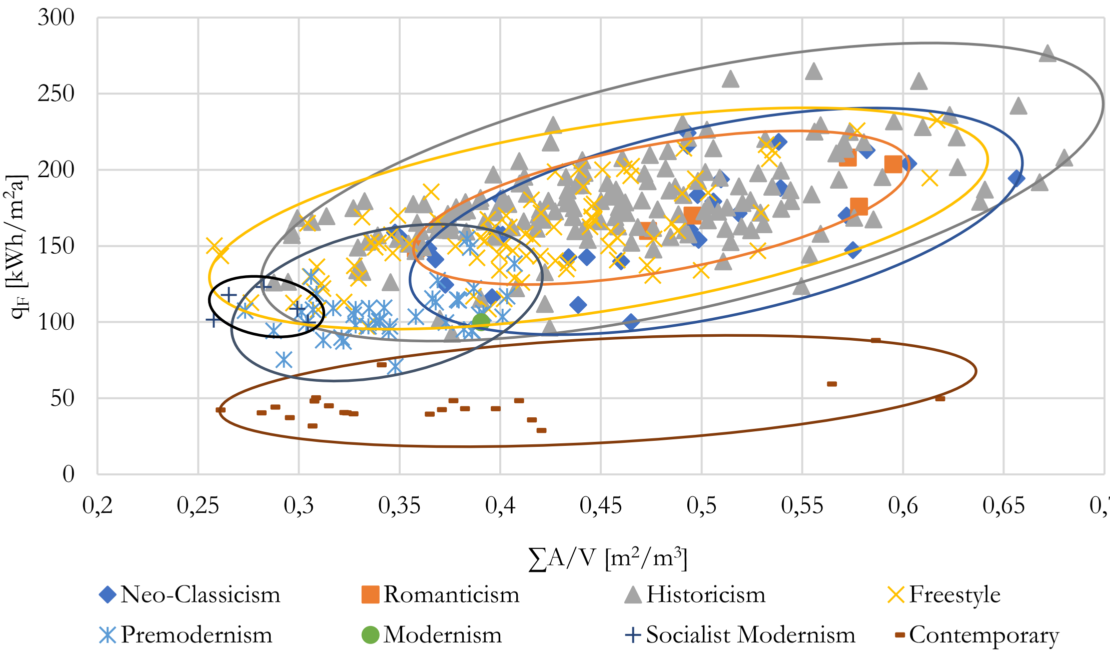
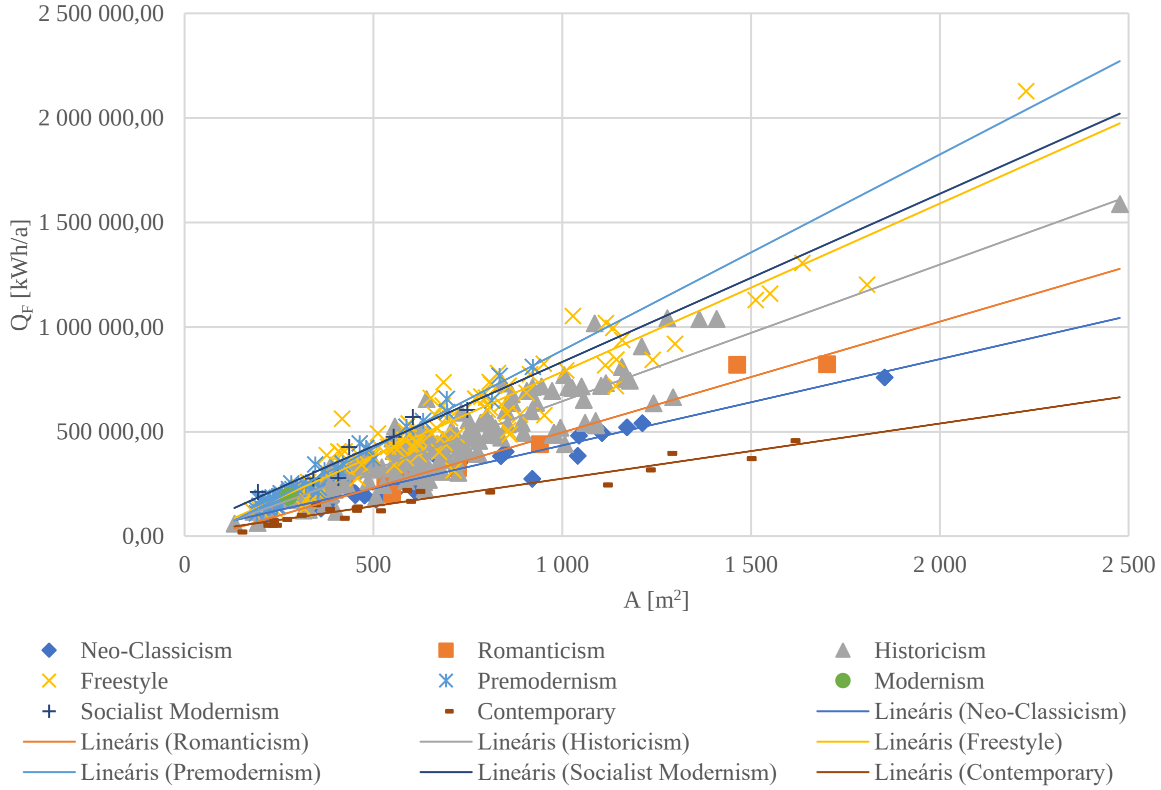


Figure 50: Connection of total heated building envelope surface per volume (∑A/V [m²/m³]) and specific net energy demand value for heating (q_F [kWh/m²a]) (source: Authors' own figure)



Style	Neo-Classicism	Romanticism	Historicism	Freestyle	Premodernism	Modernism	Socialist Modernism	Contemporary
Equation and R^2 of Q_F depending on A (Footprint)	y = 412.68x + 21336 $R^2 = 0.90$	y = 529.64x - 33518 $R^2 = 0.9654$	y = 653.65x - 8598.4 $R^2 = 0.84$	y = 804.45x - 18545 $R^2 = 0.90$	y = 936.63x - 48415 $R^2 = 0.97$	Only two data, not sufficient for equation	y = 804.05x + 28970 $R^2 = 0.90$	y = 263.4x + 11813 $R^2 = 0.94$

Figure 51: Connection between total net energy demand for heating (Q_F [kWh/a]) and footprint (A [m²]) (source: Authors' own figure)

Figure 51 shows a very clear connection between geometry, style and heating energy demand. The marks of different styles can be set on a linear trend line. The equations are also shown, with high R^2.

The result is important, highlighting that for every style, **the total net heating energy Q_F [kWh/a] can be estimated from style if the footprint A [m²] is known.**

The above result is highly usable in decision making or estimative studies.

- **Energy demand of the case study area**

Table 7 shows the significant summed geometry and values and respective energy demand per styles. The total net energy demand for heating in the case study area residential buildings is more than 162 thousand MWh/annually. The body of the buildings is totally more than 4.7 million m^3 of indoor volume and 1.13 million m^2 net heated area. As per style, Historicism with 47%, and Freestyle buildings with 32% are the most significant energy consumers.

The table thus shows very clearly that the summed net heated area is the highest in Historicism and Freestyle, also, the specific heating energy demand is the largest here. The difference is significant when compared to the other styles. It projects that the much-needed renovation should happen here first, because the ineffective structures and geometry here are combined with large quantity of heated area, resulting in high demands.

Table 7: The summed geometry and energy values per styles. The colours show the scale of the values compared to each other in every column (green is smaller, yellow is medium scale, red is large scale value compared to the order of magnitude of the value) (source: Authors' own figure)

Style	Summed footprint area A [m^2]	Summed net heated area A_N [m^2]	Summed heated volume V [m^3]	Summed Total net demand for heating energy Q_F [MWh/a]
Neo-Classicism	24 797	67 558	308 922	10 346
Romanticism	6 933	22 220	104 214	3 404
Historicism	120 079	442 477	2 065 509	75 755
Freestyle	66 123	346 731	1 429 119	52 064
Premodernism	16 554	122 757	416 579	13 278
Modernism	275	1 926	5 458	192
Socialist Modernism	3 284	26 027	88 642	2 843
Contemporary	15 201	101 163	311 782	4 460
Total	**253 247**	**1 130 859**	**4 730 225**	**162 341**

In Figure 52 the maps of the case study area are shown. On the left side, the summed total net heating energy demand per year is presented. The dotted area not surveyed, being non-residential. The darker the form, the more heating energy is demanded. The darkest continuous area on the south-eastern side shows large, mainly Historicism buildings with more free façades (less covered firewalls, increasing the ∑A/V value). For the same reason, the buildings with large courtyards are also darker. The mainly Premodernist and Contemporary buildings on the western side are averagely lighter, due to their more compact form and evolved insulation materials. On the right-side map, the red colour shows the densening of the larger Q_F-s, marking the especially inefficient places in the case study area.

Figure 52: Left: Total net energy demand value for heating (Q_F [MWh/a]) on the area (the dotted buildings are non-residential). Right: Distribution of Q_F as heat map of the area. The red areas concentrate the demand. (source: Authors' own figure)

- **Total primary energy consumption of the case study area**

As described in Section 3.2 above and detailed in Appendix 7.3 below, the total energy consumption of the engineering systems annually in primary energy (E_P [kWh/m^{2}a]) is the main result of the energy calculations. The value shows the total energy usage of all the engineering systems, containing their efficiency on common primary energy value. In the case of residential buildings, the heating energy and the domestic hot water energy consumption should be summed. Figure 53 indicate/

s similar conclusion to Table 7.

Table 8 shows the values visualized on Table 8.

Style	Summed net heated area of the 386 buildings of the case study area	Average total primary energy consumption of the 386 buildings of the case study area per m²
	A_N [m²]	E_P [kWh/m²a]
Neo-Classicism	67 558	267
Romanticism	22 220	276
Historicism	442 477	289
Freestyle	346 731	259
Premodernism	122 757	226
Modernism	1 926	153
Socialist Modernism	26 027	167
Contemporary	101 163	102

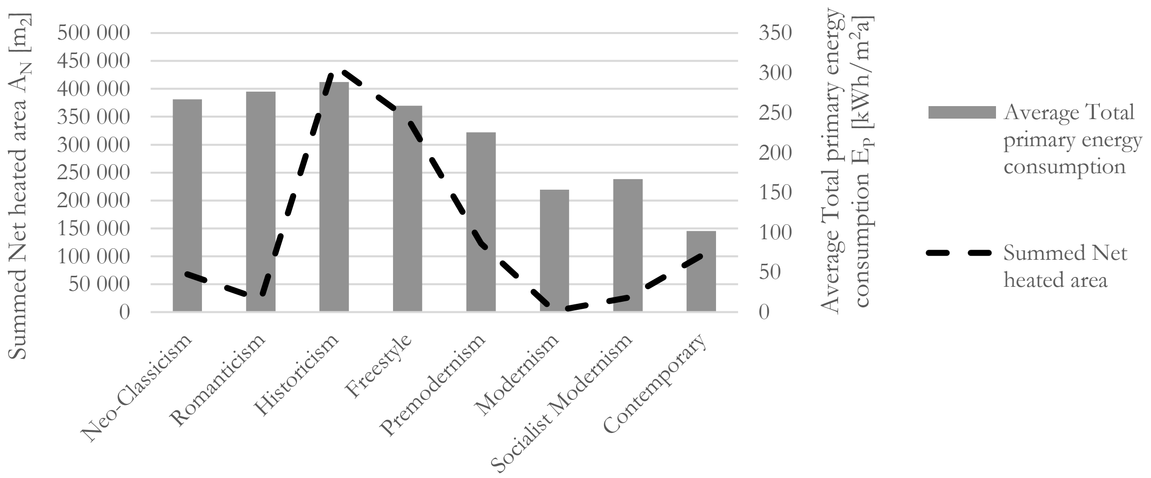


Figure 53: Connection between total primary energy consumption E_P [kWh/m²a] and summed net heated area (A_N [m²]) in case of each architectural style (source: Authors' own figure)

Table 8: Summed net heated area and average value of the total primary energy consumption of the buildings

Style	Summed net heated area of the 386 buildings of the case study area	Average total primary energy consumption of the 386 buildings of the case study area per m²
	A_N [m²]	**E_P [kWh/m²a]**
Neo-Classicism	67 558	267
Romanticism	22 220	276
Historicism	442 477	289
Freestyle	346 731	259
Premodernism	122 757	226
Modernism	1 926	153
Socialist Modernism	26 027	167
Contemporary	101 163	102

The average value of the total primary energy consumption is similar from Neo-Classicism until Premodernism, and from Modernism it starts to decrease. The summed net heated area, however, clearly highlights that the Historicism and Freestyle buildings should be in the focus of renovation. The above Figure and Table show the E_P [kWh/m^{2}a] value. If the net heated areas (A_N, m^2) of each building are considered, the total consumption is multiplied by them for each building, the summed total consumption of the present state can be calculated. The summed consumption of heating and domestic hot water energy of the area is 274,7 GWh/a, of which Historicism and Freestyle are the most prominent ratios (Figure 54).

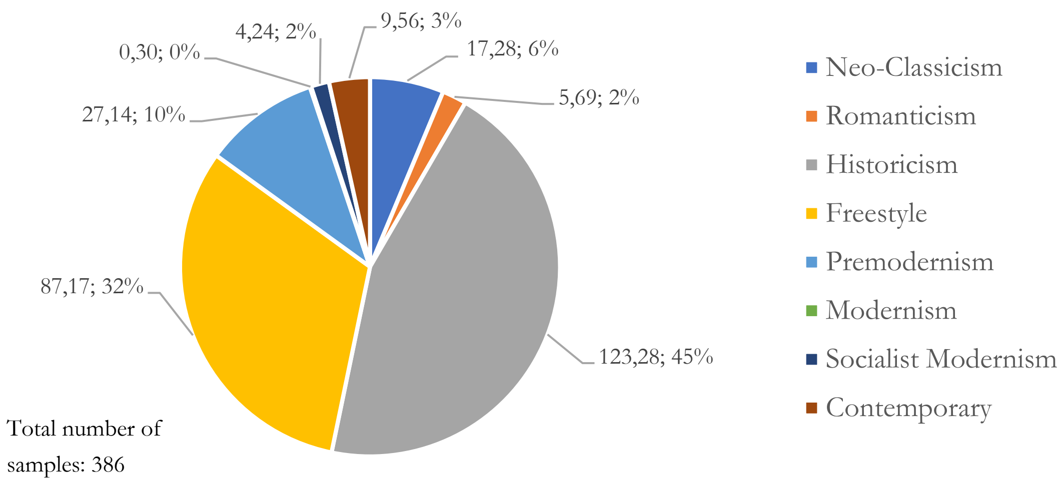


Figure 54: The presently used summed consumption in primary energy E_P [GWh] per style (source: Authors' own figure)

- ## Energetic label of the buildings

Concerning the energy classification and labelling, Table 9 shows the results by architectural style. Only 4,7% of the total stock is complying the nearly zero energy level in the present state, all of them are Contemporary style buildings.

Table 9: Energy labelling of the buildings (source: Authors' own table)

Classification	AA++	AA+	AA	BB	CC	DD	EE	FF	GG	HH	II	JJ	TOTAL NUMBER	% IN NEARLY ZERO CATEGORY
Name of classification	Minimal energy demand	Exceptionally energy efficient	Better, than Nearly zero level	Complying the Nearly zero requirements	Modern	Close to modern	Better than average	Average	Close to average	Weak	Bad	Exceptionally bad		
Ep/Ep maximum (100 kWh/m2a) %	< 40 %	40-60%	61-80%	81-100%	101-130%	131-160%	161-200%	201-250%	251-310%	311-400%	401-500%	> 500%		
Neo-Classicism							2	10	17	4			33	0
Romanticism								2	4	2			8	0
Historicism						1	4	15	117	36	2	1	176	0
Freestyle					1	1	3	31	43	12			91	0
Premodernism							5	39	1	1			46	0
Modernism						1							1	0
Socialist Modernism						3	3	1					7	0
Contemporary			2	16	4	1		1					24	75

3.4 SUMMARY AND CONCLUSIONS OF PART 2

Today, a major part of the historical, downtown buildings of Budapest is in poor condition. Their run-down physical state and low energy efficiency affect the life quality of a considerable number of residents. Therefore, it is highly important to establish renovation guidelines for these buildings. Part 2 aimed to contribute to a heritage respecting rehabilitation, by analysing the energy characteristics of the stock. The connection between architectural style, geometry and energy values was surveyed. The aim was to find simple, easily accessible input data for energy value estimation of buildings.

As a preliminary study, it was concluded that the heating energy demand of residential buildings is a very significant question, due to their high ratio of total consumption. The retrofit is complicated if the building stock has certain limitations, for example historical values. The above led the author to decide on a Budapest downtown case study area, which is mainly residential and contains historical buildings in a dense urban fabric.

As mentioned above, the present energetic state of the area is unsatisfactory. Most of the buildings are in deteriorated condition. In Hungary, the efficiency of heating and domestic hot water production in the residential buildings should be the significant focus of the energy saving attempts.

Based on the European Union conform Hungarian official calculation, the most important geometry and energy related values were defined. An excessive cadastre was created of the case study area buildings. To simplify the large-scale calculations, a detailed structural typology of Part 1 was created focusing especially on the traditional buildings built before the end of the Second World War. The introduced structural typology can also be used for future large-scale calculations of the stock. In current part, using a bottom-up methodology, demand-side energetic values were calculated.

Results on geometry data show that by construction time, the evolution of the urban fabric points to increasing compactness and denseness. Using the ratio of footprint per perimeter and architectural style of each building, the $\sum A/V$ value can be estimated, being an important indicator of energy calculations.

As results on energy values, during the surveyed period, the q_F gradually decreases, showing the evolution of building geometry and structures towards higher energy efficiency. However, as the most net heated area was built at the beginning of this evolution, most of the buildings are ineffective. This is underpinned by the following result: based on regulations, where the q and $\sum A/V$ connection was surveyed, it was found that only a handful of contemporary buildings are complying with todays' energy efficiency aims. The values show that the majority of the buildings are relatively compact, which is positive in the light of energy efficiency. However, due to their ineffective enveloping structures, their heat loss and energy demand is still high. The grouping of the values of q and q_F based on ∑A/V indicates that these values can be broadly estimated using the architectural style data of the building.

The style groups requiring the most energy, due to their large quantity, are Historicism and Freestyle buildings. Their average total primary energy consumption (E_P [kWh/m^{2}a]) is the largest here. This value is 200–300% larger than the level expected today. This difference, when compared to other styles, projects that the renovation should start here.

The total net energy demand for heating for the case study area residential buildings is more than 162 thousand MWh/year, which would heat totally more than 4.7 million m^3 of indoor volume and 1.13 million m^2 area. As per style, Historicism with 47%, and Freestyle buildings with 32% are the most significant energy consumers. If the net heated areas (A_N, m^2) of each building are considered, the total consumption of each building can be calculated: The total consumption of present state is 274,7 GWh/a. Only 4,7% of the total stock is complying the Nearly zero energy level in the present state, all of them are contemporary style buildings.

As a main result, a close relation between geometry and energy values were found. If the architectural style and the footprint is known, the total net heating energy demand per year can be calculated with significant accuracy (Figure 55).

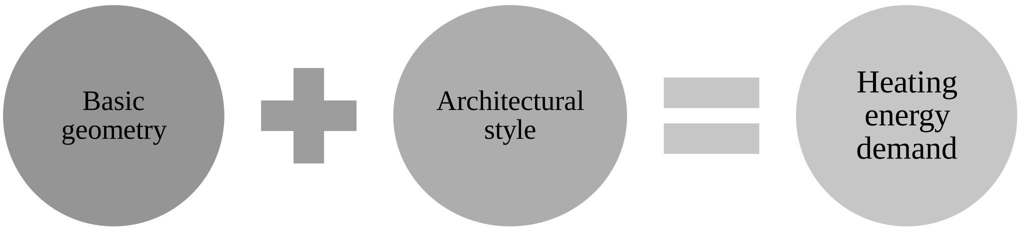


Figure 55: Main result of Part 2 (source: Authors' own figure)

It has to be concluded that using basic geometry and style data, the heating energy demand of a downtown buildings in Budapest can be estimated. The significance of the above is that it can contribute to preliminary decision making of a future rehabilitation project and simplify the large-scale studies. The above input data are simple, easily accessible, helping the estimation, which thus can be made even by non-professionals. The above results can be used as a benchmark for energy demand assessment based on simple geometry and style data of a building.

Based on the data, it was suggested that the previous building typologies of Hungary should be expanded, stating that even for buildings built before the Second World War, there are significant differences in geometry and structure, resulting in different energy values. Also, as a future step, because of the widespread character of the traditional building type, with small modification, the typologies can be expanded to the Middle-European scale.

4 PART 3: REHABILITATION

- **Aim of Part 3**

The aim of Part 3 is to find energetic refurbishment solutions that protect the architectural character.

- **Methodology**

Previous studies showed that the surveyed building types have high potential of energy saving, their heritage respecting rehabilitation is a pending problem worth investigating (see Parts 1 and 2).

During literature review of Part 3, the studies concerning the previous rehabilitations and refurbishment attempts of the traditional apartment buildings were analysed. As a conclusion, a detailed analysis is needed for the building type in question to define the benchmark of interventions, because of the unique characteristics that limit the refurbishment. The complex rehabilitation scenarios require both architectural and energetic aspects to protect the character of the area.

Regarding architectural aspects, input data from Part 1 was used which includes the information about architectural character and the typologies. The architectural style, geometry parameters and the structural-material typology were used in Part 3 to support the refurbishment scenarios.

Concerning energy aspects, from Part 2 the following input data was used. The energy efficiency indicator values, which were defined using the currently valid EU EPDP methodology and the corresponding valid Hungarian Decrees were utilized. The present energetic state, and the results showing strong connection between energy demand, footprint area and architectural style were also input information for Part 3.

Based on the previous conclusions, architectural style as a particular characteristic is a convenient tool for classification, because no complex information is required to determine the style. This simplicity of the style-based classification is especially important, because one of the main aims of the study is that the results should serve as a decision support system for future rehabilitation plans. Hereinafter also, architectural style is used as classification.

In the current part, based on Part 2 calculation methodology, the possible interventions needed for an energy efficiency refurbishment were defined. The limiting factors narrowing down the possibilities were defined next. The heritage protection guidelines and the boundaries of geometry and urban fabric were also collected.

After combining the retrofit intervention possibilities and limiting factors, refurbishment scenarios were created. Solutions for both structural and engineering upgrades are introduced. The effect of the scenarios each, and their combinations were analysed. The upgrades were assessed to find an optimal solution of heritage respecting energetic retrofit. The conclusions drawn and new suggestions for policy concerning the traditional apartment house retrofits were summarized in the conclusions. Illustration of the methodology is shown on Figure 56 Methodology of Part 3.

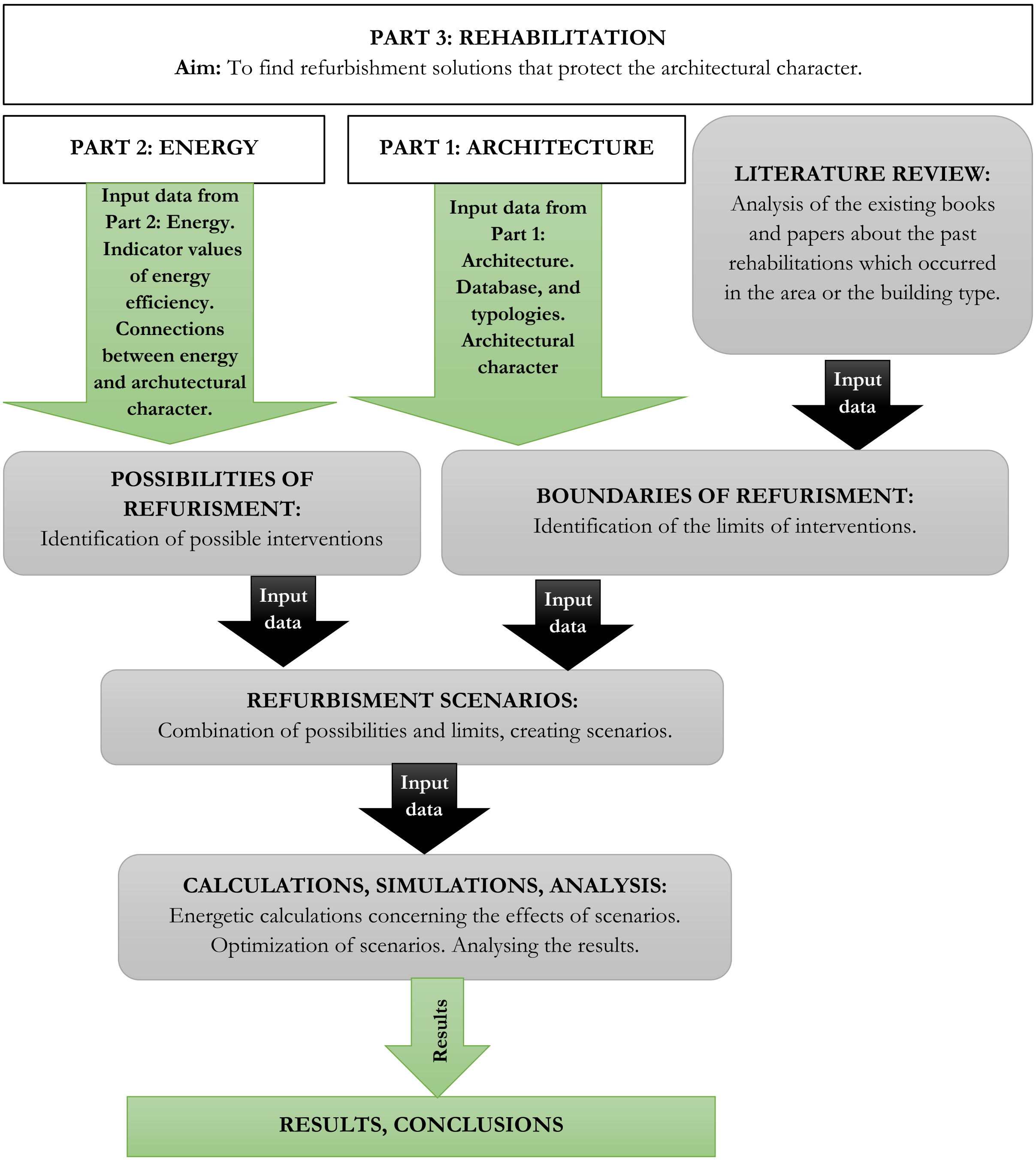


Figure 56: Methodology of Part 3 (source: Authors' own figure)

4.1 PREVIOUS STUDIES AND EXAMPLES ABOUT REFURBISHMENT OF HISTORICAL BUILDINGS

4.1.1 Previous studies of refurbishments

Several studies deal with rehabilitation methods of historical buildings. Webb (2017) extensively reviews the methods and problems of the energetic retrofit for traditional buildings. Collecting the aspects of decision making, Ascione. et al. (2015) write that the energy efficiency upgrades should be a tool for maintaining the heritage buildings, and should not be seen as simple energetic retrofit. The compromise much needed for heritage protection narrows the technological choices of energy efficiency. The authors define guidelines such as least invasive methods.

Okutan, et al. (2018) also state that the need to create a framework is growing, the conflicts between conservation aims and energy reduction should be discussed and compromises reached. Their study compared multiple energy saving measures and surveyed various approaches of professional and public opinion. Apart from heritage protection guidelines, other problems are hindering the large-scale renovation of the buildings.

Almeida and Ferreira (2018) write that improving the enveloping structure is a key question, considering constraints like aesthetics and cultural heritage of buildings or neighbourhoods, which makes the consensus difficult. This is further complicated by the private ownership of flats (as in Budapest).

Complex methodologies were already introduced before to deal with retrofit of historical districts. The European Union founded EFFESUS project (Energy Efficiency for EU Historic Districts' Sustainability) (2016), which focuses on heritage protection. They introduce an evaluation system in which points represent the importance of heritage value and the extent of the effect if certain changes are made. They define various heritage aspects and criteria, such as visual, physical or space related changes.

Specializing in the traditional apartment house type in focus, the Renewal of historical urban fabric (Budapest University of Technology and Economics, Faculty of Architecture, 2016) contains synoptic surveys about the complex problems of the stock.

Ertsey, et al. (2004) suggest drastic intrusions in the urban fabric, such as demolishing the backward wings so the enclosed inner parts are opened up. With this, airy courtyards, passages and parks can be opened. The attics can be utilized, the cars can also be stored inside the block. They state that the buildings beyond repair are demolished, for new buildings to be built. They assume that the building and apartment operational costs are radically reduced via renovated façades and roof, as well as engineering upgrade (solar energy, rainwater utilization). By optionally covering the ground floor and creating passages, the income of the house can be increased. The rehabilitation thus can make the building become self-sustaining and economically independent. In their vision, the rehabilitation uses public participation, private funds, as well as involvement of local residents. For the inhabitants of the demolished buildings, new apartments should be found. The private funds appear in newly created offices, shops, flats and garages. By this, the urban functions broaden, which is further improved by the rehabilitation. As a result, the environmental impact is significantly lowered. By creating parks and green façades, the green biologically active surface, as well as the quality of the microclimate increases. This modification is not only aiming to supporting energy efficiency, rather aims to find a complex solution. Similar methodology was used in Hungary before, with controversial results (see Section 4.1.2).

As part of the international TABULA Episcope project (Csoknyai, et al., 2014) energetic modernization scenarios for the traditional apartment house type are introduced, reaching high energy saving values (61% of the total energy usage) by insulating the enveloping structures, exchanging fenestration, and applying engineering updates. Although the project declares that the historical characteristics should always be taken into account, their scenarios do not give special instructions for heritage respecting solutions.

Multiple studies deal with technical solutions in detail. Iyer-Raniga and Wong (2012) state that insulation of the ceiling, roof and external walls are the most effective building interventions, providing the highest energy saving, and at the same time reducing the life cycle primary energy and carbon emissions significantly. Tadeu, et al. (2015) survey historical buildings from the beginning of the 20th century, focusing on various insulation types and their effect.

Litti, et al. (2018) state that simpler maintenance of the historical windows and added internal glazing provide sufficient energy saving values, at the same time the full replacement of a window does not necessary result in the highest savings. Szalay, et al. (2016) and Becker and Hunyadi (2011) deal with the heat losses and renovation possibilities of the historical windows. They collect and compare the effects of the various solutions. See APPENDIX F.

Harrestrup and Svendsen (2015) investigate the heat insulation possibilities of brick historical buildings. Although heat insulation of the walls is considered as one of the most efficient supplementary upgrades, the practice can cause damage in the original appearance. The indoor insulation (heat insulating layer on the heated side surface of the walls) can be a solution; however, it can cause major building physics problems: unwanted vapor and precipitation cause damage in the structure, and also in human health. The study is presenting a method, where moisture safety is solved by leaving a gap for proper ventilation.

Bakonyi and Kuntner (2012) collects and details of the technical solutions for façade insulation in case of heritage buildings or protected architectural character. See APPENDIX F.

The above studies show that there are many aspects of heritage respecting retrofit, mainly agreeing that the **three main aspects are energy saving, heritage protection and cost effectiveness**. The retrofits are to consider the heritage values in order to prevent the loss of character. Built on the universal conclusions, however, the renovation guidelines should be defined based on detailed investigation, because the differences of climate and building type result in major diversities in the possible retrofit actions.

4.1.2 Previous rehabilitations of traditional apartment houses

After World War 2 in Hungary, the central policy concerning the obsolescent historical districts was mainly demolition (Tomay, 2006) . After the ideology-based neglect during the 1950–70's, the renewal of historical districts again came into focus (Nagy, 2005). In the 1980's, renovations started in some secluded blocks in the centre of Budapest. Demolitions, retrofit and new constructions mixed together were used for several blocks in the 7th and 9th districts.

In the case of the of the 7th district, i.e. the case study area, the idea was the same introduced above (Ertsey, et al., 2004). The Erzsébetváros rehabilitation was started with the Sample Block Nr. 15. in the 1980s (Figure 57).

The Sample Block Nr 15. contained a synagogue and other ecclesiastic buildings. Out of the existing 303 flats, 150 were demolished, to build 170 in entirely new buildings.

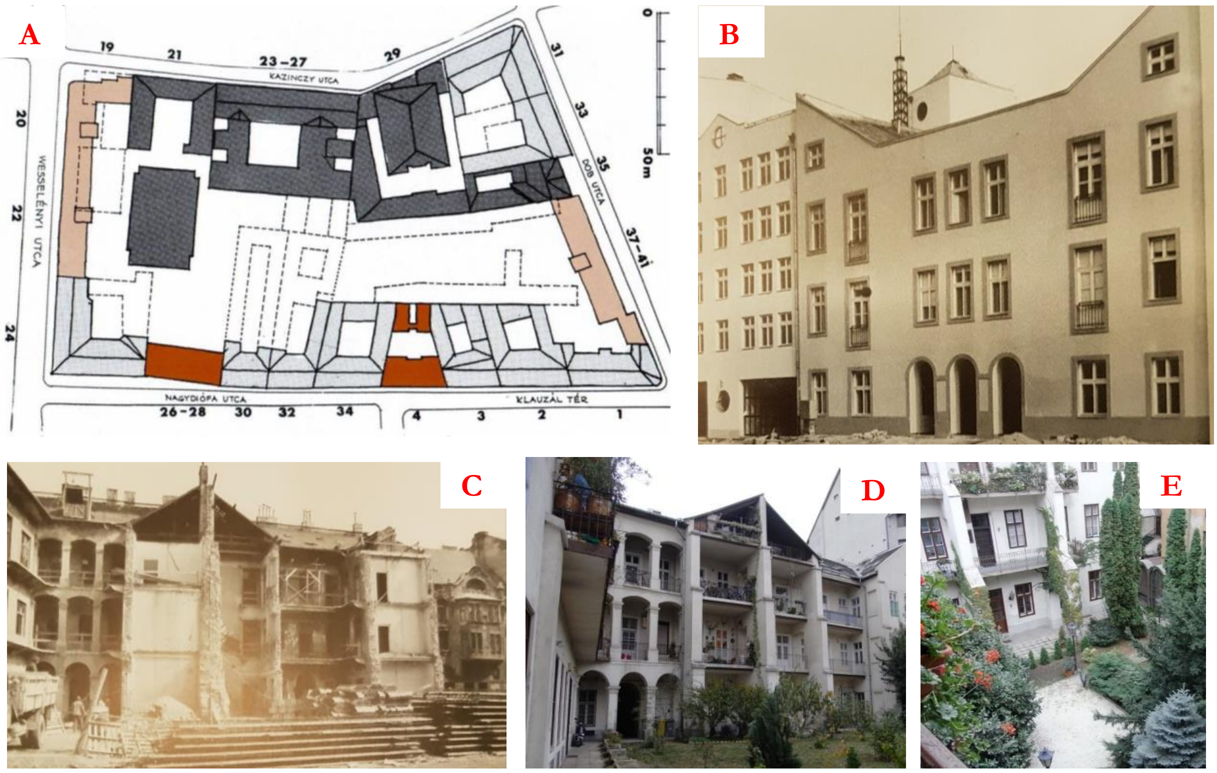


Figure 57: Previous rehabilitation in the case study area: Sample Block Nr 15. A: The demolished wings are marked with dashed line. The new buildings are coloured. The darker shade buildings are renovated institutions. B: Archive photo about the new windows opened on the firewalls. C: Archive photo of the demolition of the inner wings. D: Contemporary photo of the same wings as shown on C. New terraces were created instead of the courtyard wings. E: New green garden in a courtyard where the wings were demolished. Source of A is (Locsmándi, 2008) B and C (Lampel & Lampel, 1998) D, E: source: Authors' own figure

The average 49 m^2 floor space of the existing flats were increased averagely to 65 m^2. The inside of the blocks were rebuilt as parks and playgrounds. Between 1982 and 1985, the construction was finished. Above residential development, the public buildings (a university, a museum and offices) were renovated or given new buildings. The majority of the new residents were the same as before, or moved here from the adjacent blocks (Szendrő, 2013), (Sárkány, 1993). The project was stopped before the final touches of the recreational zone, and was just finished, after decades of waiting (Zubreczki, 2019).

In case of the 9th district, the buildings were assessed, much of the wings inside the blocks were demolished. The remaining traditional buildings were upgraded, with new windows and other additions on firewalls, facing the newly opened parks inside the blocks (Körner & Varga, 2012). The plan resulted in a major development in the area; however, the exchange of population and the disappearance of the original historical streetscapes are still criticized (Figure 58).

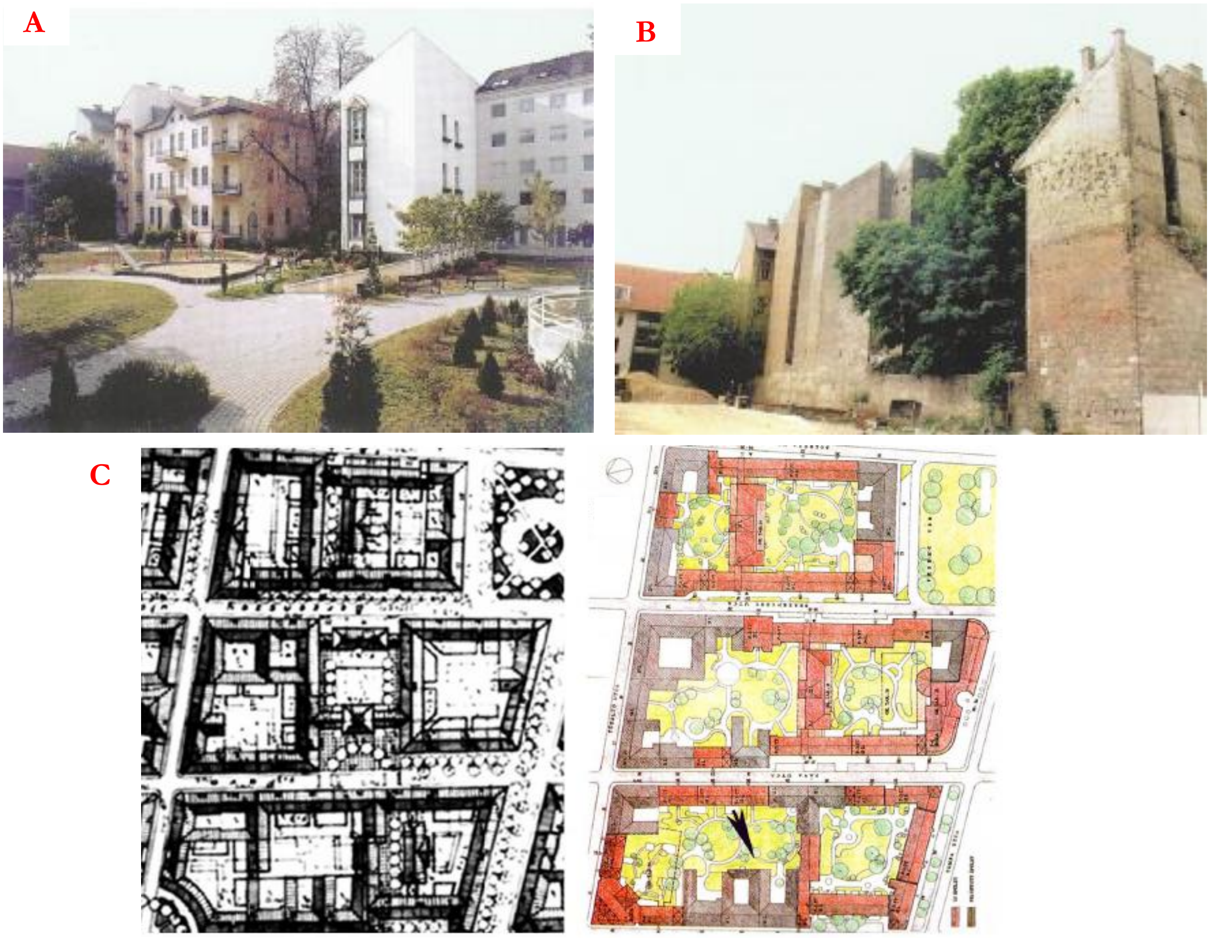


Figure 58: Rehabilitation of Budapest 9th district. A: The new park inside of the block with new windows on firewalls. B: Same buildings as on A, before rehabilitation. C: The urban fabric before and after. The courtyard wings are mostly demolished. Source of A and B (Ertsey, et al., 2004), C (Körner & Varga, 2012)

The above methods only partially demolished the buildings. Unfortunately, the building stock in question sustained 'bulldozer-shaped urban regeneration' on multiple other occasions (Beliczay, 2009). In District 8^{th} , during the 1970's, the 'renovation' plans prescribed full demolition of the building stock and urban fabric, replaced by Socialist Modernist prefabricated blocks. This particular district was also affected by a contemporary project, called the 'Corvin Promenade'. Although it started after the change of regime (and ideology towards heritage), it operated with the same idea of full demolition. Old houses were wiped out, and a fully different structure of new buildings and urban fabric was designed.

Such large-scale rehabilitation programs are more difficult to carry out today. Due to the privatisations in the 1990's, today 93% of the Budapest buildings are in private ownership (Budapest University of Technology and Economics, Faculty of Architecture, 2016). Every decision on the building is based on residents' democratic voting. Refurbishment savings are not mandatory. Partially this system is responsible for the very low number of refurbishments, and even less energetic rehabilitation in the stock. The other disadvantage of the system is that without a common plan or oversight, the owners can decide individually about minor renovations, resulting in unprofessional solutions.

As other European examples, rehabilitations in Berlin and Vienna should be mentioned. Contrarily to Budapest, the renovation here contained energy efficiency aspects. In Berlin, energetics were sometimes deemed more important than heritage protection, resulting in excessive heat insulations on the façade. The insulating boards on the outside façade often consumed and destroyed the original historical decorations and changed the original scale of the house (Figure 59: Historical building heat insulated in Berlin. Left: the original façade; Middle: insulated façade; Right: the insulation damaging the historical decoration).

Figure 59: Historical building heat insulated in Berlin. Left: the original façade; Middle: insulated façade; Right: the insulation damaging the historical decoration (Budapest University of Technology and Economics, Faculty of Architecture, 2016)

In Vienna, the replacement of the historical houses with social flats started during the 1970s. Similarly to Budapest, it sometimes resulted in the destruction of historical values and population exchange. Later, soft rehabilitation started, encouraging the retrofit of the urban fabric itself, including details as insulation, fenestration exchange, engineering system retrofit of the buildings. Connecting to the district heating system was highly encouraged (Budapest University of Technology and Economics, Faculty of Architecture, 2016).

4.2 POSSIBLE INTERVENTION TYPES FOR ENERGETIC REFURBISHMENT

According to the European Union EPBD conform Hungarian energy efficiency calculation system (See APPENDIX C), the focus of the retrofit should be on two major interventions: **architectural intervention**, which should provide decreased energy demand, and **engineering intervention**, used to satisfy the decreased demand with efficient heating technology. The former is containing the upgrade of enveloping structures' U value and geometry (Section 4.4.1), the latter is upgrade of engineering system (Section 4.4.2).

Figure 60 shows the three levels and their indicator comparative value to be assessed.

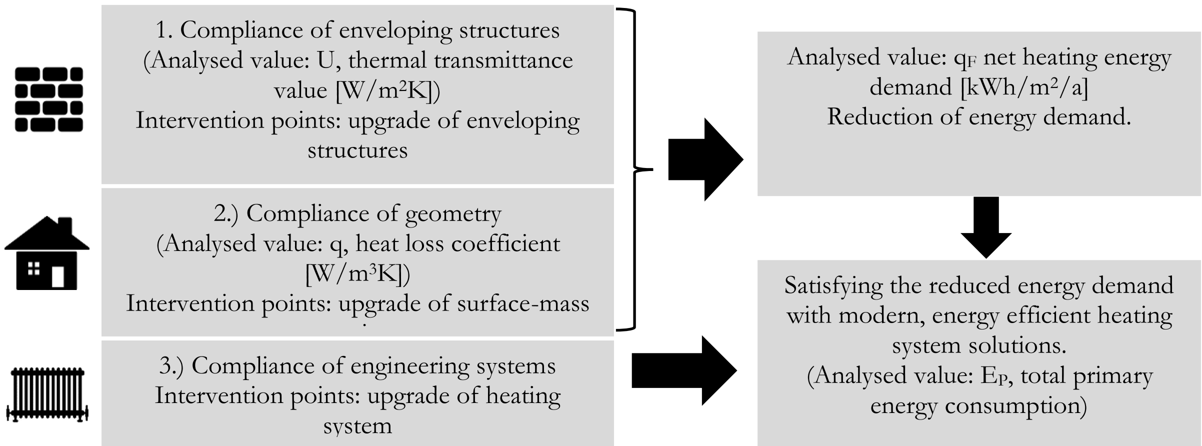


Figure 60: Summary of the intervention points based on the levels of the calculation, with the analysed values (source: Authors' own figure)

4.3 LIMITING FACTORS OF REFURBISHMENT

4.3.1 Dense urban fabric

The dense urban fabric is in several ways hindering the refurbishments. In the case of a construction, it is difficult to move and store the building materials. The devices and implements are also challenging to use. In most cases, only a smaller gate for pedestrian use is approaching the inner courtyard, thus larger machines cannot be operated inside. Some of the technical solutions cannot be used because of the minimal space, for example in the extremely narrow spaces, even scaffolding is impossible, thus alpinists do the insulation work (Figure 61).

Another difficulty is to use renewable energy in the dense urban fabric. For example, hydro or wind-power, ground source heat pump or water-based heat pump in the dense urban fabric, particularly in existing buildings are difficult or even impossible to implement. The construction activity itself is non-accomplishable, and the required space for the above technologies are mostly not available. The biomass heat production in such an area also should be excluded, because of the transportation and storage difficulties, and the amount of dust pollution.

The generally applicable solutions are solar power utilization or air source heat pump. In most cases, solar energy can be utilized, since almost all buildings have suitable roof surfaces to install collectors or photovoltaic panels (Talamon, 2015).

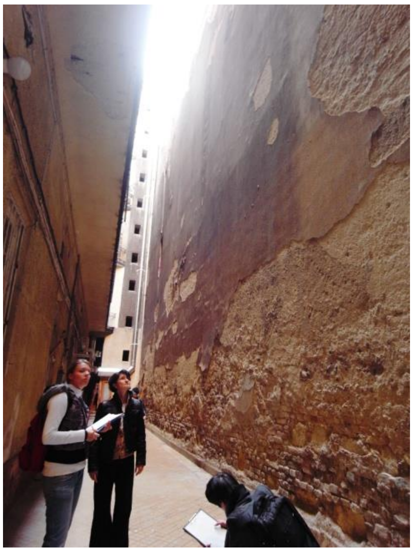


Figure 61: An extremely narrow courtyard in the case study area. Photo is courtesy of Yuta NAGAI MSc Architect

4.3.2 Heritage protection guidelines

In Hungary, the monument protection system consists of multiple levels: national monument protection, local protection, conservation area protection and monument neighbourhood. The case study area is also protected in several ways: the streetscape and its scales, the organic fabric originating from the 18–19th century, multiple buildings with individual protection on national or local level. Individual protection means the protection of the forming of mass, space, the height ratios in buildings, façade design with ornaments, fenestration form, indoor design and space relations. The demolitions are discouraged at every level, even for courtyard wings. Table 10 summarizes the protection forms and their main aspects concerning the case study area.

Although there is a wide range of protection forms for built heritage in Hungary, their enforcement is mostly weak. As a very common example, the individually changed windows (Figure 62), or the destroyed ornamentation if an air conditioning device is installed are usually not reported and penalized, as these interventions are not bound by official permission. It is also a problem that though the characteristic elements of façade are deemed protected in many documents, these elements are not defined squarely (Budapest University of Technology and Economics, Faculty of Architecture, 2016).

The area is also internationally recognized value, as it is part of the UNESCO Word Heritage Zone of Budapest, being a Buffer Zone of the Andrássy Boulevard (Figure 63). Although several buildings in the area are not under monument protection, the author is considering the full building stock as protected in the following, to maintain the historical character of the district.

Figure 62: Individual, unprofessional window exchange or insulation causes uneven façades and loss of character. Pictures are Courtesy of Attila ZSOLDOS BSc Architect

Figure 63: The National or local level protected buildings are marked in a darker shade. The red dotted line marks the border of the UNESCO protected World Heritage Buffer Zone (source: Authors' own figure)

Table 10: Monument protection types and main aspects in the case study area (source: Authors' own table)

TYPE	**National Protection**	**Local Protection**	**UNESCO World Heritage**	**Area of historical monuments**	**Office of Cultural Heritage Protection rehabilitation guide***
Level of protection	National level by law	Local government level by regulation	International level existing legislation does not impose any powers of authority or competence.	National level by law	* is not considered as protection from, or mandatory itself, however, the detailed, building-by-building guideline was created especially for this area to highlight the significance of values of the area. The author deemed the study especially important from heritage protection point of view.
Law or regulation	2001. LXIV. act law; 39/2015. (III. 11.) regulation	Local regulation of Erzsébetváros 9/2008. (IV.25.)	2011. LXXVII Act the World Heritage	7/2005. (III. 1.) Regulation	
What is covered	Individual buildings	Individual buildings	Part of the case study area	Part of the case study area	Full area and individual buildings
Main points	Changes should not affect or endanger the 'set of values' (mass, space relations, ratios, symbolic content, façade design, etc.). A protected building cannot be demolished under any circumstances.	The building cannot be demolished. No intervention can result in total or partial destruction, deterioration, transformation or partial or complete alteration of its architectural character.	To protect the integrity and authenticity of outstanding universal values of the World Heritage Site. '…One of the most authentic sites … the preservation of historical settlement structures and buildings of the protection zone. '	The parts of the settlement placed under such a protection have characteristic structure, fabric, connection to landscape, the buildings and spaces in-between as a system have historical importance and thus therefore worth historic protection.	A unique historical quarter of its kind represents a special value for the country, its capital and its district The scale, the size of the existing buildings to be retained, their height, the special arrangements for their construction, the parcel structure and the space structure of the design area to be retained.
WHAT IS PROTECTED? (- no, 0 neutral; + yes)					
plot structure	-	-	+	+	+
mass, space	+	+	+	+	+
street view, street side façade	+	+	0	+	+
inner courtyard	-	+	0	+	+
structure, materials	+	-	-	-	+
ornamentation	+	+	0	0	+
mandatory?	+	+	-	+	-
enforced?	+	+/ -	-	-	-

4.4 COMBINING THE POSSIBILITIES AND THE LIMITATIONS: APPLICABLE TECHNICAL SOLUTIONS FOR ENERGETIC REFURBISHMENT

The main problem with energetic refurbishment is that the monument protection boundaries and the energetic retrofit possibilities are controversary. The architectural intervention points introduced above (4.2 above) are intruding the same surfaces that the guidelines (4.3.2) aim to protect.

The rehabilitation measures should consider the character of a building, to avoid the loss of values. To avoid the mistakes shown in Figure 62, the limits of the retrofit should be included. These contain the problems of the dense urban fabric, and also the monument protection guidelines, which should be applied to maintain the architectural values and character.

Based on the above, when creating the renovation scenarios, the author considered two limiting data: **the rehabilitation should be complying the heritage protection guidelines, and the retrofitted building should aim to reach the nearly zero energy level.**

4.4.1 Architectural interventions

- **Upgrade of building enveloping structures**

Reducing the heat losses of the enveloping structures of the heated volume (U value) is an important part of the energetic retrofit, aiming to decrease the energy demands. The most common form is heat insulation of the surfaces, which, however, is controversial practice when dealing with heritage buildings (as an example, see Figure 64 where the heat losses are emanating from the windows and the walls).

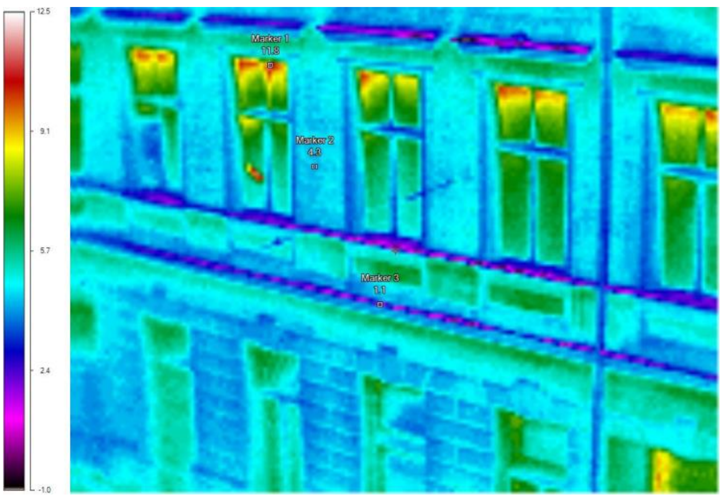


Figure 64: Thermal camera picture of a traditional apartment house (source: Authors' own figure)

In the case of listed monuments, regulations are highly restrictive of the normal insulation methods. Fortunately, multiple technical solutions are available, the objective is to find the ones complying both energetic and heritage protection aspects.

Figure 65 shows an average section of a traditional house wing to introduce the main surfaces to be insulated.

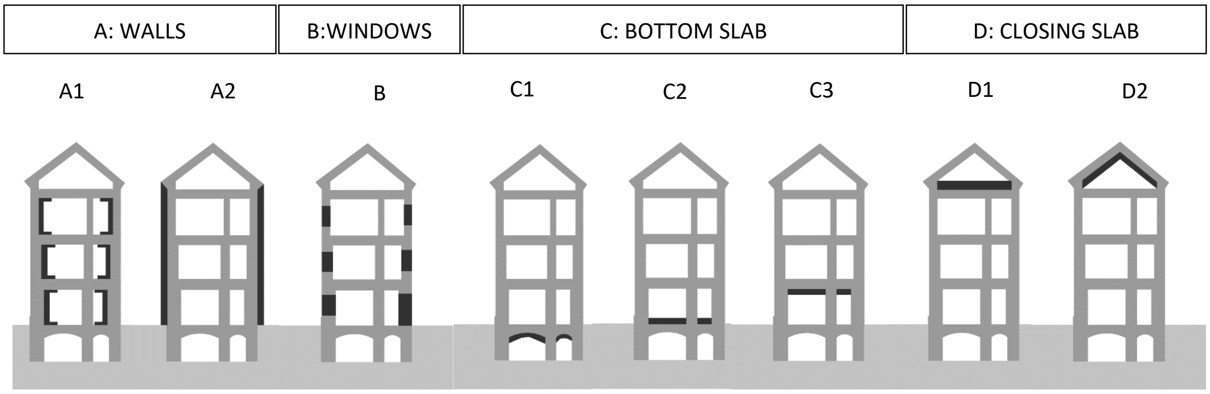


Figure 65: Main heat insulation possibilities on enveloping structures in the case of heritage respecting modernization A: Wall insulation: A1: Outside insulation of the façade, A2: Inside insulation of the façade; B: Window renovation; C: Bottom slab insulation: C1: Underside insulation of cellar vault, C2: Floor insulation, C3: Underside insulation in case of arcade; D: Roof insulation: D1: Closing slab insulation, D2: Pitched roof insulation (source: Authors' own figure)

Technical solutions for the upgrade of the enveloping structures are listed below

Solutions affect the general heritage values of the buildings, thus can only be utilized conditionally, with regard to the architectural character.

- Outside insulation of the façade (A1): In the light of the heritage protection guidelines, the external thermal insulation of the façade can be ruled out in almost all cases. To apply traditional board insulation, it is necessary to remove the ornaments. Naturally, it is possible to replace them with plastic copies; however, these are not lasting and supported solutions. The outside insulation can only be used in the case of empty, uncovered firewalls (where no neighboring building is connected to the firewall, working as an enveloping surface).
- Inside insulation of the façade (A2): The internal thermal insulation can be an option in cases where the inner surface is not decorated. Particular attention must be paid to the appropriate material choice in order to avoid vapor and other physical problems.
- Fenestration renovation (B): As 40–50% of the façade is glazed surface in this type, the energetic state of the fenestration is an important question. It is avoidable to entirely exchange the traditional fenestration to new, PVC framed windows. The mass-produced plastic windows are made with much thicker mullions than the traditional wooden

solutions, which changes the ratios of the window (Figure 62). There are, however, other heritage respecting solutions for modernising the original window structure fully or partially, cost effectively (stated also by Litti, et al. (2018) and Szalay, et al. (2016) dealing with historical fenestration). Some examples: fitting, Low-E glazing, replacement of inner wings with insulated wings etc. See more details in APPENDIX F.

Solutions not affecting the general heritage values of the buildings, thus can be utilized nearly in all cases.

- Bottom slab insulation (C1, C2, C3): Most commonly, these buildings have vaulted cellars, to which bendable insulation can be installed (for example rock or glass wool), but otherwise standard technologies can be utilized (C1). In the case of flat slabs, the generally used solutions are: polystyrene or wood-wool plates. An alternative solution is to renovate the structure from the heated side by installing insulation into the floor structure (C2). In this case, the wooden parquet should be ripped up, which is not an ideal solution. It is unavoidable, however, if there is no cellar, and the floor layers are on the soil. C1 solution can be used for the arcade slab of the gate (C3). The value of the arcade space and ornamentation should also be considered.
- Roof insulation (D1, D2): As the buildings mostly have empty pitched roof without attic rooms, the closing slab insulation (D1) is not problematic. Vapor open insulation should be chosen (for example rock or glass wool). For built-in attics, the commonly used solution for pitched roof insulation (D2) is rock or glass wool filling between and underside the rafter.

In APPENDIX F the above solutions are further detailed with drawings and factual materials.

• Upgrade of geometry

To reduce energy demand, the heated volume or the enveloping surface area per heated volume (A/V) ratio should be reduced. Another possibility is to increase solar gains indoors. Reducing the heated volume can be achieved by repositioning and grouping of heated and non-heated rooms; or covering the courtyard with glass roof to decrease A/V is another option. To increase solar gains, construction of new openings on the façade should be done, which also would affect the heritage values. The present study does not deal with the upgrade of geometry in detail, because the traditional apartment buildings' A/V ratio is commonly good, confirmed by the calculations below (Section 4.6.2 below).

4.4.2 Engineering interventions

As explained before (Section 3.2) in the case of residential buildings, heating and domestic hot water production together make up the largest ratio of energy usage. Upgrading them results in significant energy saving (Csoknyai, et al., 2014). To modernize the heating and domestic hot water system, the restrictions of Section 4.3 should be considered. Generally, placement of a central engineering room and caloric centre should not be a problem. Both the cellar and in most cases the attic is suitable to create a new room for the equipment. Rewiring and repiping the buildings, however, are necessary. These lines now, are mostly old and faulty, mainly installed room-by-room by the residents. During constructions, the path of the pipes should be designed to make the least damage to the structures.

The Hungarian Central Statistical Office database (data assembled by personal request) was used to survey the presently used heating systems of traditional apartment houses (See 3.3.1 above). House-central heating with one main heater device and radiators in the flats is the first type. Two variations, an older and a newer technical solution were used for calculations to differentiate between the older and newer buildings. For domestic hot water production in the old case, an electric boiler was used. In the new case, indirectly heated water tank was assumed (the house-central heated buildings are easily identifiable via their large, single chimney).

Most of the traditional buildings are not centrally heated, but with room-by-room devices. These are mostly equipped with convectors for heating and gas boiler for domestic hot water. According to the database, averagely 75% of flats in each building is still heated by convectors or even older tile stoves (Figure 66). Averagely 25% of the flats in each building, however, has been modernized to flat central heating with more contemporary gas boilers or condensation heaters, which combine the heating and domestic hot water production.

Figure 66: Presently, most flats are heated room-by-room with tile stove (left) or convector (right) (source: Authors' own figure)

4.5 REHABILITATION SCENARIOS – COMBINING POSSIBILITIES

4.5.1 Rehabilitation scenarios for structural upgrade

For the baseline of structural scenarios, the structural typology of the original structures was used (Section 2.6.3 above and APPENDIX D). The scenarios, the structurally upgraded versions of the 'Packages' are created in line with the heritage protection and Nearly zero energetic aims combined. This means that the structure if possible, should comply with the prescribed U value and at the same time should be a heritage protecting technical solution.

Structural Scenario 1 is the 'Original structure (OR)'. This contains the data of the original structures based on the above typology.

Structural Scenario 2 is the 'Least Invasive (LI)' scenario. In this case, the heritage protection guidelines were fully complied and only the necessary, less visible surfaces were insulated. The decorated façade walls, cellar walls, arcades were left intact. The roof and cellar slabs were insulated as well as the uncovered firewalls. The windows were upgraded with the full heritage compatible solution (fitting and exchange of the glass to low-e glazing). In short, not all the surfaces are upgraded, but the insulated structures are reaching the Nearly zero U value requirement level.

Structural Scenario 3 is 'Nearly Zero (NZ)'. Here, the aim was for every enveloping surface to reach Nearly zero energy level. Thus, the missing surfaces of the 'Least invasive' scenario were additionally insulated. The walls were insulated from the inside. As for fenestration, we should differentiate between traditional and post Second World War styles from heritage value point of view. For the former, the strict compliance of heritage protection guidelines should be applied. In the latter case, however, because of their forming and decoration are simple, fenestration replacement is also applicable.

Table 11 summarizes the measures for each scenario, also listing the advantages and disadvantages of application. The listed upgrades were applied to all 9 Packages for both LI and NZ scenarios. A detailed example for the structural rehabilitation scenarios in case of Package 1 is show in APPENDIX E.

In APPENDIX F the above solutions are further detailed with drawings and factual materials.

Table 11: Summary Structural Scenarios, with their advantages and disadvantages (source: Authors' own table)

ENVELOPING STRUCTURE	LEAST INVASIVE SCENARIO (LI)	NEARLY ZERO SCENARIO (NZ)
Wall	none	Traditional apartment buildings: Insulation inside (A2) Non-traditional buildings: Insulation outside (A1)
Closing slab under pitched roof	Insulation outside (D1)	
Pitched roof with attic	Insulation inside (D2)	
Flat roof	Insulation outside (D1)	
Fenestration	Fitting + Low E glass (B)	Traditional apartment buildings: Fitting + Low E glass, inner wing exchange Non-traditional buildings: full exchange (B)
Arcade	none	Insulation outside (C3)
Floor on soil	none	Insulation inside (C2)
Cellar slab of non-heated cellar	Insulation outside (C1)	
Floor on soil in heated cellar	none	Insulation inside (A2)
Cellar wall of heated cellar	none	Insulation inside (C2)
Uncovered firewall	Insulation outside (A1)	
ADVANTAGES AND DISADVANTAGES OF SCENARIOS		
Original scenario: Pro: no intervention; Contra: no energy saving	Least Invasive scenario: Pro: intervention only on less-visible surfaces, or mainly not decorated surfaces; Contra: Heat-bridge problems intensify, medium energy saving	Nearly Zero scenario: Pro: all surfaces are insulated, less heat-bridge problems; Contra: building physics problems may occur: vapor and low temperature of the structures. Inside decorations destroyed.

4.5.2 Upgrade of heating and domestic hot water system

The engineering scenarios were based on the restrictions of Section 4.3.1. The 'Original heating system (OR)' is Scenario 1, detailed in Section 4.4.2. The ratios mentioned were used in the calculations as Scenario 1, or 'Original heating system (OR)'. The upgraded versions are Scenarios 2, 3 and 4.

In Scenario 2, a new 'District Heating (DH)' system is assumed. It is based on the fact that presently there are undergoing constructions to expand the existing system to the inner districts (Bencze, 2018). This upgrade would require the exchange of the full heating system in the traditional houses to contemporary radiators. In the cellar, a caloric centre and a heat-exchanger block is to be placed.

Domestic hot water is produced by the same device and stored house-centrally. As the Budapest district heating system is using renewable energy and other advanced form of energy creation, the utilization would prove more environment friendly and modern. District heating would also reduce air pollution in the city centre, because heat is generated in a separate power plant in a controlled process.

Scenario 3 uses air source 'Heat Pump (HP)', which absorbs heat from outside air and releases it inside the building, through hot water-filled, low temperature radiators, and also produces domestic hot water. Its advantage is that the same system can be reversed in summer, cooling the indoor temperature. The empty attic or the cellar can provide enough space for the system. The pipe systems with radiators should be reconstructed, in the same way as above (Figure 67).

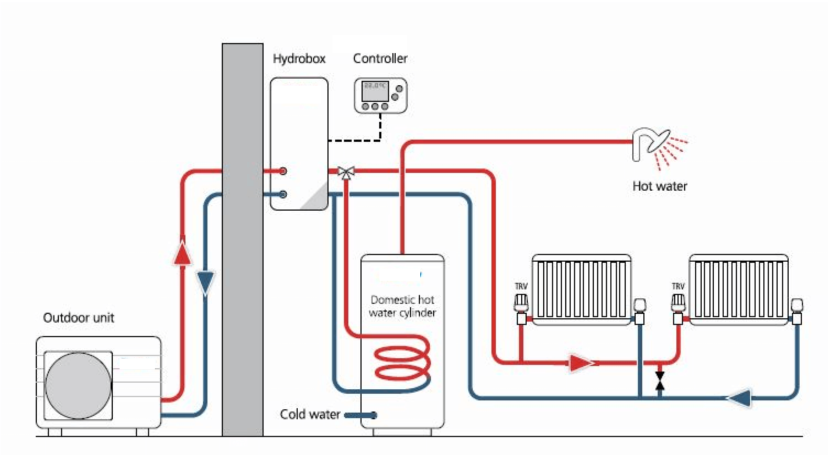


Figure 67: Air to water heat pump system (Energywise, 2019)

Scenario 4 contains the more common upgrade of house central gas 'Condensation Heater (CH)' with the same radiator system as above. Domestic hot water is produced via the same device and stored centrally. The condensation heater is one of the most efficient form of heating with natural gas. The remaining heat in the waste gas is also utilized in the device using condensation. The reason to choose this solution as a scenario is that today the majority of the houses uses gas to heat new and old systems alike in the case study area. The gas system is widespread, all the houses are connected to it.

4.5.3 Combination of structural and engineering scenarios

All the structural and engineering scenarios were combined as per Table 12. In the following, the abbreviations introduced are used in the case of scenario combinations. The first part of the abbreviation is indicating the structural scenario, the second is the engineering scenario. All the scenarios and their combinations were applied to the 386 residential buildings in the case study area, and their effect on the energy efficiency values were calculated and compared. The results are detailed in Section 4.6 below.

Table 12: Summary and combinations of the upgrade scenarios, with their respective abbreviations (source: Authors' own table)

SCENARIO COMBINATIONS			
Structural /Engineering scenarios	**Scenario 1: Original (OR)**	**Scenario 2: Least invasive (LI)**	**Scenario 3: Nearly Zero (NZ)**
Scenario 1: Original (OR)	OR_OR	LI_OR	NZ_OR
Scenario 2: District Heating (DH)	OR_DH	LI_DH	NZ_DH
Scenario 3: Heat Pump (HP)	OR_HP	LI_HP	NZ_HP
Scenario 4: Condensation Heater (CH)	OR_CH	LI_CH	NZ_CH

4.6 RESULTS AND DISCUSSION

4.6.1 Boundary conditions

The case study area was narrowed down to the residential function, which is 386 buildings, 88% of the full stock. The energetic values are calculated using the aforementioned Hungarian EPBD conform system (Section 3.2, APPENDIX C). Simplifications were done to be able to handle the database. The major simplification used in the calculation was structural typology (Section 2.6.3, APPENDIX D). Also, the type of the current heating system was based on statistical data (Section 4.4.2) A particular uncertainty is included in the methodology of the calculation system due to the simplification methods and the estimative parts of the calculation (Section 3.3.1).

The statistical normal distribution of the main input data (for example: footprint) grouped by style was investigated by Kolmogorov–Smirnov test. The significance obtained during the test is around 0.00, so 95% of the sample elements are from a normal distribution. The t-probe significance was also 0.00, thus the model is estimating the actual sample values well. The R^2 values of the equations are between 0,8–097.

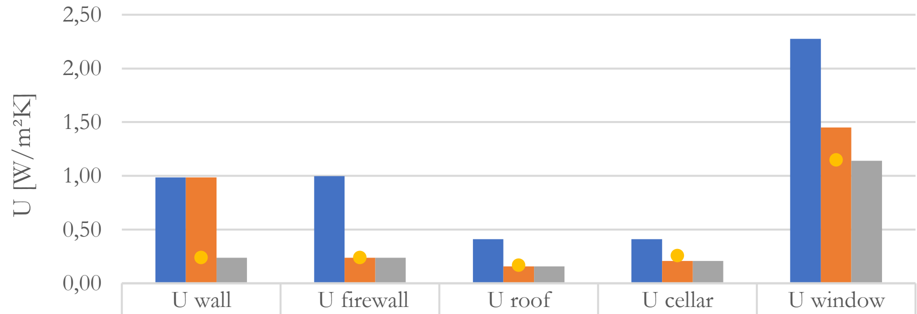
The following values were chosen to be analysed to assess and compare the effects of the scenarios (See a detailed analysis in Section 3.2 and APPENDIX C):

- U, thermal transmittance value [W/m^{2}K] for the compliance of enveloping structures
- q, heat loss coefficient [W/m^{3}K], showing the performance of the U values together with the geometry
- q_F net heating energy demand [kWh/m^{2}a]
- E_P, total primary energy consumption [kWh/m^{2}a] using the above values and including the heating and hot water system performance.

4.6.2 Effect of the structural scenarios on the energetic values

- **Change in the thermal transmittance values**

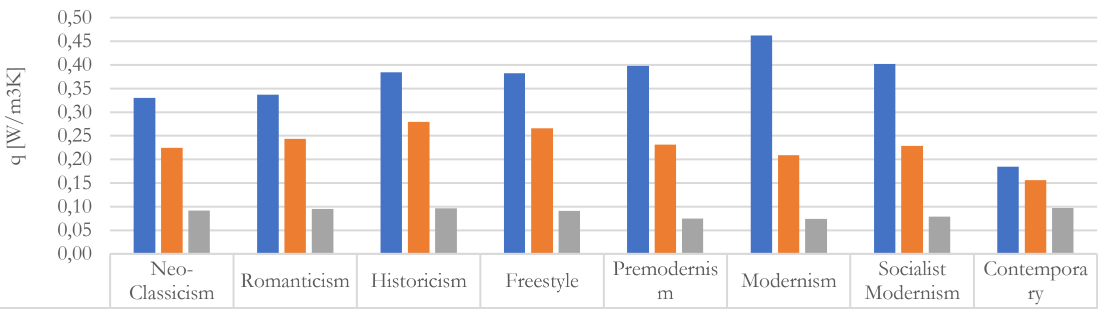
Figure 68 shows the change in the U value on structural 'Package 1' (APPENDIX E) as an example. The main enveloping structures and their U values for each scenario are shown. As mentioned above, in the Least Invasive (LI) structural scenario, not every surface is insulated contrarily to the Nearly Zero (NZ) scenario. The figure also shows the maximum level of requirement prescribed in the Decrees listed in Section 3.2 above.



	U wall	U firewall	U roof	U cellar	U window
Original	0,98	1,00	0,41	0,41	2,28
Least invasive	0,98	0,24	0,16	0,21	1,45
Nearly zero	0,24	0,24	0,16	0,21	1,14
Maximum level of requirement	0,24	0,24	0,17	0,26	1,15

Figure 68: U values for each scenario in structural Package 1. (source: Authors' own figure)

As for the heat loss coefficient (which is affected by the *U* value and geometry), the value decreases moderately from the OR level to LI, and drops more significantly in NZ scenario for each style (Figure 69). As the geometry is not changed by the rehabilitation scenarios, the change is mostly caused by the decreased *U* value (the NZ scenario contains more extensive insulation, for example on the walls).



	Neo-Classicism	Romanticism	Historicism	Freestyle	Premodernism	Modernism	Socialist Modernism	Contemporary
OR q Average	0,33	0,34	0,38	0,38	0,40	0,46	0,40	0,18
LI q Average	0,22	0,24	0,28	0,27	0,23	0,21	0,23	0,16
NZ q Average	0,09	0,10	0,10	0,09	0,07	0,07	0,08	0,10

Figure 69: Heat loss coefficient values in each scenario for each architectural style. (source: Authors' own figure)

The most significant changes are shown for Premodernism, Modernism and Socialist modernism, due to their originally lower *U* values than for other styles. Contemporary buildings are not as affected, as they were originally complying more or less to the requirement levels. Although not with the highest differences, but significant change can be observed for traditional, pre-WW2 styles too (Neo-Classicism, Romanticism, Historicism, Freestyle).

• Change of the heat loss coefficient

As for the heat loss coefficient, the limiting maximum value of the regulation is dependent on the ∑A/V (enveloping surface to heated volume) ratio. Figure 70 diagrams show the change and the compliance using q and ∑A/V for the three structural scenarios respectively, sorted by architectural style.

These results imply that the compactness of the buildings is sufficient, and by upgrading the enveloping surfaces, the Nearly zero energy level can be met ('NZ' scenario). The main contrast between the LI and NZ scenarios are the insulation of walls, which causes major difference between the compliance to this limiting factor.

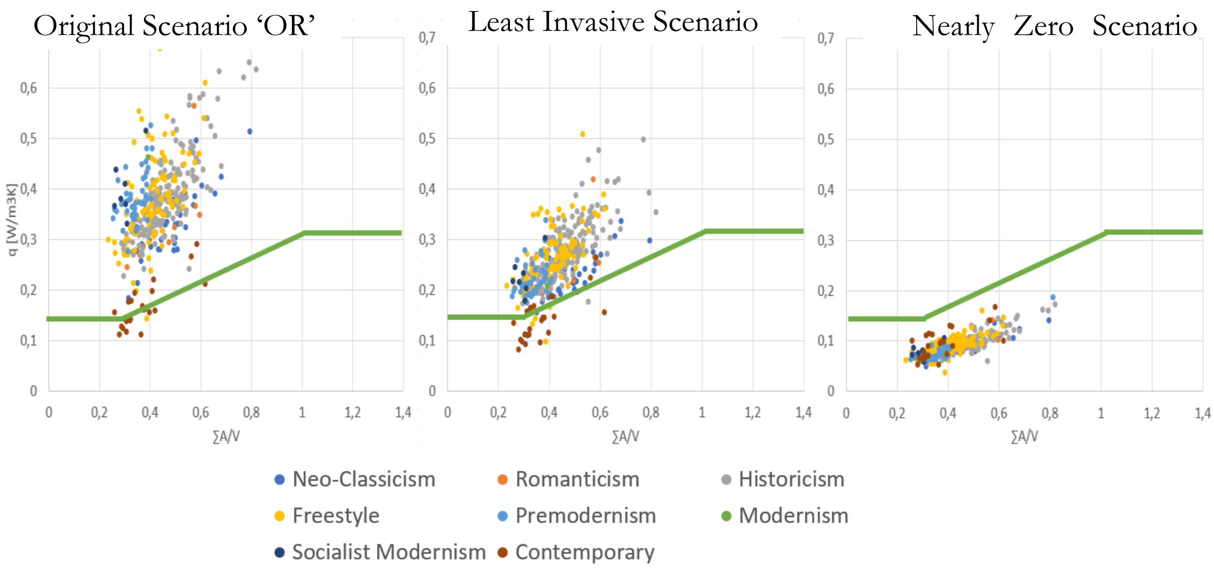
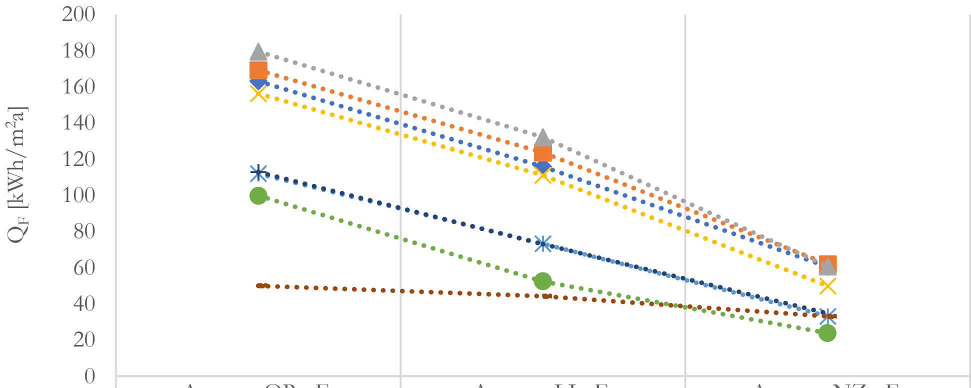


Figure 70: Heat loss coefficient values in each scenario for each architectural style. The compliance of the limiting value of nearly zero-energy requirement level is shown by a green line. The heat loss coefficient is surveyed together with the respective buildings' ∑A/V (enveloping surface to heated volume) ratio. The building complies to the requirements if the dot is under the limiting line. (source: Authors' own figure)

• Change of the specific and total net heated energy demand

The change in the specific net heated energy demand q_F [kWh/m^{2}a] is introduced in Figure 71. The largest decrease is for Modernism, where the Least Invasive (LI) scenario provided 48%, the Nearly Zero (NZ) 76% decline. The potential of energy demand cutback thus is the largest in this style. The Modernist buildings are, however, few in number and net heated area (A_N, m^2). The demand is also reduced significantly for styles where the heated areas are the largest: Historicism ('LI' 26%, 'NZ' 66%) and Freestyle ('LI' 29%, 'NZ' 68%).



	Average OR qF	Average LI qF	Average NZ qF
Neo-Classicism	163,1	115,9	60,4
Romanticism	169,2	123,7	62,0
Historicism	179,5	132,1	60,7
Freestyle	156,3	111,2	49,8
Premodernism	112,0	73,2	33,1
Modernism	99,9	52,4	23,8
Socialist Modernism	112,9	73,0	34,7
Contemporary	50,0	44,2	33,1

Figure 71: The change in the specific net heated energy demand q_F [kWh/m²a] per styles (source: Authors' own figure)

4.6.3 Effect of the scenario combinations, change in the total primary energy consumption

As mentioned above, the total primary energy consumption (E_P, kWh/m²a) contains the structures and geometry performance of the building, combined with the energy consumption of the engineering systems annually in primary energy. In the case of residential buildings, the consumptions of heating and domestic hot water are summed. Thus, the structural solutions are combined with the engineering solutions, their joint effect can be observed in Table 13. The abbreviations of each combination were already introduced above in Section 4.5.3.

To be able to decide which variation should be used for energy saving retrofit, Table 13 shows the effectiveness of each combination. The values show the percentage of the reduced E_P compared to the 'OR_OR' original state per style. The colours indicate that energy saving is relatively high (green), moderate (orange) or smaller (red).

In the case of the same engineering scenarios, the effect of the Nearly Zero ('NZ') solution is the most effective, resulting in smaller E_P compared to the 'OR' and 'LI' scenarios.

Comparing the engineering scenarios, that variations containing 'CH' condensation heater for engineering solutions are less effective. Here, E_P is relatively larger than for the other engineering solutions ('HP' or 'DH') with the same structural scenario. The District Heating 'DH' and the Heat Pump 'HP' scenarios, however, show the same effect in reducing E_P.

The most effective combinations are 'NZ_DH' and 'NZ_HP'. Although the 'LI_DH' and 'LI_HP' are less effective, the difference is not significant.

Table 13: The average percentage of E_P compared to the 'OR_OR' variation per styles. Bold variations were used for optimization (See below) (source: Authors' own table)

Architectural Styles	OR				LI				NZ			
	Average OR_OR E_P [%]	Average OR_DH E_P [%]	Average OR_HP E_P [%]	Average OR_CH E_P [%]	Average LI_OR E_P [%]	Average LI_DH E_P [%]	Average LI_HP E_P [%]	Average LI_CH E_P [%]	Average NZ_OR E_P [%]	Average NZ_DH E_P [%]	Average NZ_HP E_P [%]	Average NZ_CH E_P [%]
Neo-Classicism	100	37	38	71	72	29	29	55	48	19	19	36
Romanticism	100	38	39	73	76	30	31	58	49	19	19	36
Historicism	100	40	41	77	79	31	32	61	48	19	19	36
Freestyle	100	35	36	69	70	28	28	53	44	17	17	32
Premodernism	100	28	28	53	62	21	21	40	46	14	14	26
Modernism	100	26	26	49	35	17	18	33	25	12	12	23
Socialist Modernism	100	28	28	54	43	21	21	40	28	14	14	26
Contemporary	100	17	17	32	33	16	16	30	29	14	14	26

The average E_P for each style in kWh/m^{2}a with each scenario combination is shown in Table 14

Table 14: The average E_P for each style in kWh/m^{2}a for each scenario combination. (source: Authors' own table)

Architectural Styles	OR				LI				NZ			
	Average OR_OR E_P [kWh/m2a]	Average OR_DH E_P [kWh/m2a]	Average OR_HP E_P [kWh/m2a]	Average OR_CH E_P [kWh/m2a]	Average LI_OR E_P [kWh/m2a]	Average LI_DH E_P [kWh/m2a]	Average LI_HP E_P [kWh/m2a]	Average LI_CH E_P [kWh/m2a]	Average NZ_OR E_P [kWh/m2a]	Average NZ_DH E_P [kWh/m2a]	Average NZ_HP E_P [kWh/m2a]	Average NZ_CH E_P [kWh/m2a]
Neo-Classicism	267	106	109	207	209	83	84	159	139	55	55	103
Romanticism	276	109	112	213	219	86	88	167	141	55	56	104
Historicism	289	115	118	223	229	91	93	175	140	55	55	103
Freestyle	259	103	105	199	203	80	81	154	126	49	49	92
Premodernism	226	80	82	155	180	61	62	116	134	41	41	75
Modernism	153	74	76	143	102	50	51	95	71	36	36	66
Socialist Modernism	167	81	82	155	124	60	61	115	82	41	41	76
Contemporary	102	49	50	93	96	46	47	87	83	40	41	75

If the net heated areas (A_N, m^2) of each building are considered, the total consumption is multiplied by them for each building, the summed total consumption of the present state can be calculated. Figure 72 shows the summed total energy saving potential of each scenario variation in GWh/a. The values show the amount of energy which can be saved if the given scenario variation is applied to all the buildings in the case study area (compared to the summed total primary energy consumption of OR_OR scenario variation).

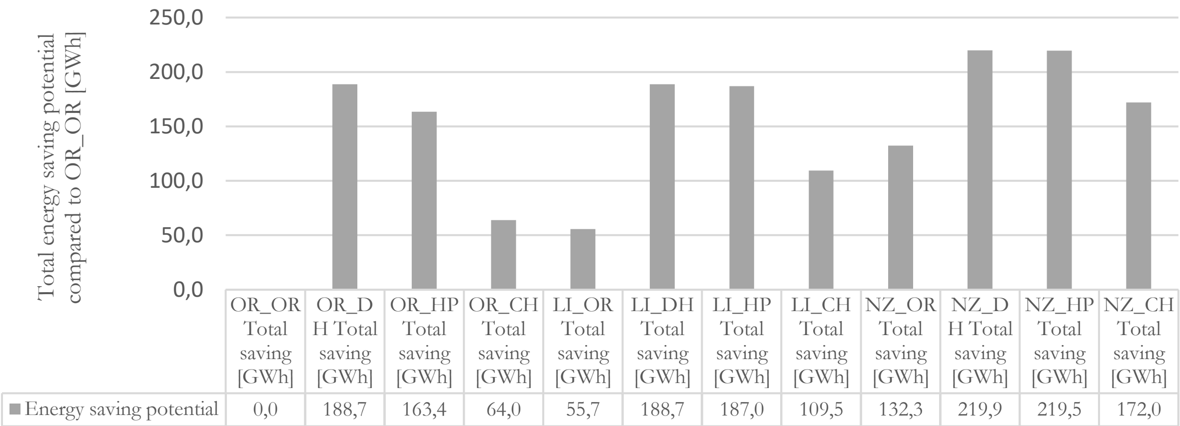


Figure 72: The total energy saving potential all the buildings summed together, with each scenario variation in GWh compared to the total consumption of OR_OR variation. (source: Authors' own figure)

4.6.4 Optimized energy saving potential

Above, the effects of scenario variations were observed, assuming that for every building the same upgrade is applied. The traditional buildings, however, should be dealt with differently than the post-WW2 ones. For traditional styles (Neo-Classicism, Romanticism, Historicism, Freestyle, Premodern styles), heritage protection should be applied more strictly than the post-WW2 styles (Modernism, Socialist Modernism, Contemporary).

In the light of the above, for traditional buildings, the 'LI' Least Invasive Structural scenario should be applied. Their façades are more elaborate, the forming is more complex. For newer buildings, the 'NZ' Nearly Zero Structural scenario is recommendable. Their historical values are not high priority, also their façade ornaments and forming elements can be upgraded with insulation easily, without changing the character.

From an engineering system point of view, the above tables and diagrams show that District Heating ('DH') and Heat Pump ('HP') scenarios are the most efficient (with almost the same energy saving potential). As the construction of the district heating system in the case study area is only a future plan yet (the system has not reached the borders of the area yet), the authors decided to choose the 'HP' scenario as the best option.

Combining the above, for traditional styles the 'LI_HP', for post-WW2 styles the 'NZ_HP' combination were chosen as optimal from heritage protection and energy saving point of view (see bold cells in Table 13).

By calculating the E_P total primary energy consumption before and after the theoretic retrofit, the energy saving potential of each style and the full district can be assessed. Figure 73 illustrates the results. Table 15 shows the energy saving potential based on style, individual building and m² level.

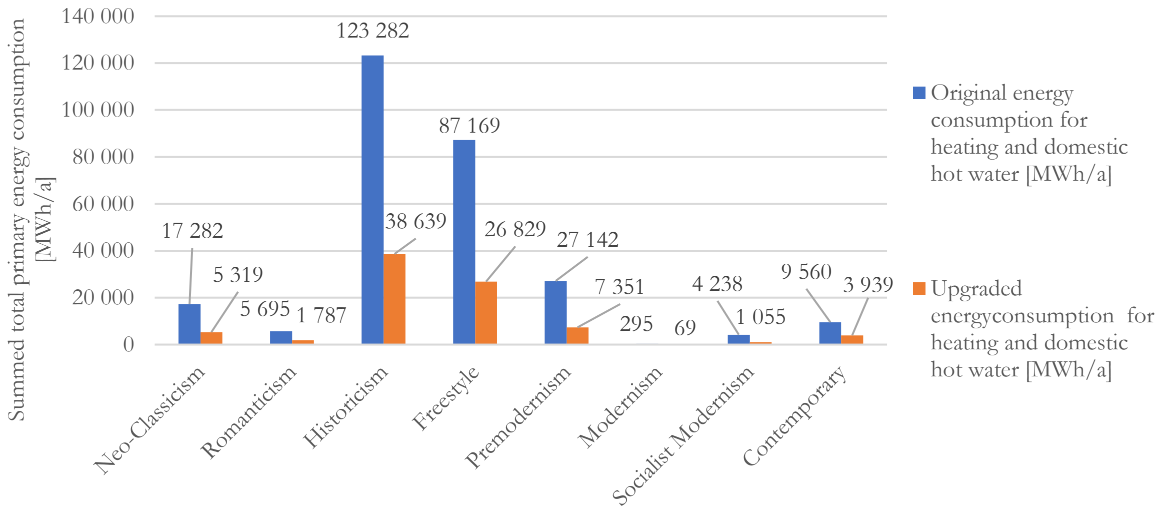


Figure 73: The summed total primary energy consumption before and after renovation (source: Authors' own figure)

Table 15: The energy saving potential based on style, individual building and m² level (source: Authors' own table)

Style	Quantity of buildings	Original energy consumption for heating and domestic hot water (summed) [MWh/a]	Upgraded energy consumption for heating and domestic hot water (summed) [MWh/a]	Difference: The total energy saving potential of the case study area (summed) [MWh/a]	Difference (total) [%]	Average energy saving potential per individual buildings [MWh/a/blg]	Average energy saving potential per m2 [kWh/m²a]
Neo-Classicism	33	17 282	5 319	11 962	69.2	359	182.4
Romanticism	8	5 695	1 787	3 908	68.6	484	188.1
Historicism	176	123 282	38 639	84 643	68.7	476	195.9
Freestyle	91	87 169	26 829	60 340	69.2	657	177.4
Premodernism	46	27 142	7 351	19 791	72.9	428	163.9
Modernism	1	295	69	226	76.6	226	117.6
Socialist Modernism	7	4 238	1 055	3 183	75.1	454	125.7
Contemporary	24	9 560	3 939	5 621	58.8	234	61.2
Total	386	274 662	84 988	189 674			

It can be concluded that the building stock of Historicism and Freestyle have the largest potential if the summed primary energy saving of the styles is analysed. On the individual building level, the Modernist and Social Modernist buildings can be upgraded with the highest energy saving ratio compared to their original state. If the average energy saving potentials are compared to each other, the buildings of Freestyle, Historicism and Romanticism stand out with the highest saved energy per building, and per net heated m^2.

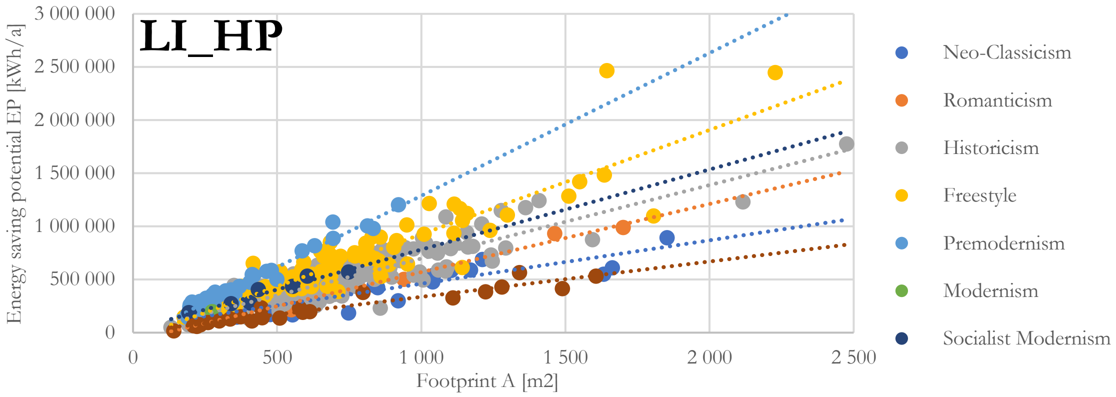
If using the above scenario variations for upgrade, totally **189 GWh heating and domestic hot water production energy can be saved annually, reducing the original consumption by 69%**.

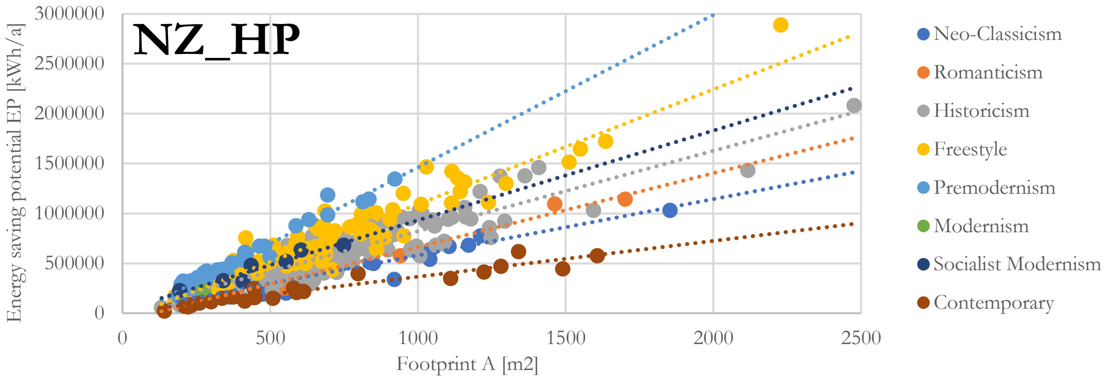
4.6.5 Change in energetic classification and complying to the Nearly Zero energy level

As the last step of the energetic calculations, the buildings are classified into groups based on their deviation from the Nearly zero requirement level (in %), prescribed in the aforementioned decrees. After the proposed retrofit, 85% of the upgraded buildings are complying to the Nearly zero requirements compared to the original 4.7%, which shows the effectiveness of the above described scenario variations.

4.6.6 Decision support: Estimation of energy saving based on simple data of a building

In the preliminary steps of decision making, especially when a large-scale project is planned, simple solutions for estimations are highly recommended. Figure 74 introduces an estimation diagram which can be used to approximately calculate the energy saving of a building from the stock (applying LI_HP and NZ_HP scenarios), using the footprint and the architectural style. The footprint (ground floor area) is easily accessible data, as open-access satellite applications can be used for measuring it, such as Google maps. To define the architectural style too, a field survey or satellite image is mostly enough (Table 2 helps the identification). Both input data can be accessed even by non- professionals, thus the diagram can be used by residents and housing associations too, to assess their energy saving potential.





Style	Equation and R^2 for Energy saving potential in case of LI_HP		Equation and R^2 for Energy saving potential in case of NZ_HP	
Neo-Classicism	y = 408.18x + 52467	R^2 = 0.8051	y = 563.83x + 15834	R^2 = 0.8901
Romanticism	y = 641.6x - 72195	R^2 = 0.9768	y = 740.45x - 77283	R^2 = 0.9715
Historicism	y = 691.46x + 5667.5	R^2 = 0.8284	y = 806.19x + 15515	R^2 = 0.8408
Freestyle	y = 981.62x - 56089	R^2 = 0.8255	y = 1152.1x - 60300	R^2 = 0.8961
Premodernism	y = 1343.4x - 55525	R^2 = 0.9615	y = 1528.5x - 67215	R^2 = 0.965
Modernism	N/A (only 2 examples)			
Socialist Modernism	y = 753.35x + 28552	R^2 = 0.9276	y = 898.88x + 32724	R^2 = 0.9237
Contemporary	y = 332.52x + 4308.6	R^2 = 0.9146	y = 359.05x + 6693.9	R^2 = 0.9167

Figure 74: Decision support: estimation of energy saving potential [kWh/a] using architectural style and footprint [m²] as input (source: Authors' own figure)

4.7 COST EFFECTIVENESS AND FINANCING OPTIONS

4.7.1 Factors hindering refurbishments

Financing problems are the most crucial factors hindering refurbishments. The price level of construction industry increased by 34% since 2010 (Hungarian Central Statistical Office, 2019). 93% of the buildings in question are in private ownership (Budapest University of Technology and Economics, Faculty of Architecture, 2016). Most commonly, each flat has its owner, the common spaces have shared ownership. Every decision on the building is based on residents' democratic voting. Refurbishment savings are not mandatory.

There is a lack in general knowledge and approach towards energy efficiency. In most cases, the residents do minor upgrades in their flats, mostly solutions do not consider the architectural character (see Figure 62 for examples). State support foundations are available for energy efficiency retrofits, but they prefer new constructions and public buildings. Moreover, the tenders alone cause a lot of administrative and financial burdens.

The above factors together are responsible for the very low number of retrofits, and even less energetic rehabilitation in the stock. Availability of affordable financial sources is crucial when it comes to rehabilitation. To increase the number of rehabilitated buildings, it is important to enumerate current possibilities in Hungary. Taking all these into consideration, possible financial sources have been sought here (see Section 4.7.5 below) to make rehabilitation feasible for all households.

4.7.2 Aspects and renovation scenarios surveyed

Below, three scenarios were compared to each other using three main aspects defined in Part 3: Aspect 1 energy efficiency, Aspect 2 heritage protection and Aspect 3 cost efficiency of the refurbishment project. Three scenarios, the original state, and two rehabilitation versions were considered and compared to each other. The scenarios are named based on the architectural intervention and engineering upgrades included:

- OR_OR: Original structure with original engineering system, basically the present state of the buildings. This scenario is used as a baseline of comparisons.
- OR_CH: Original structure with upgraded heating system, where heating is provided by modern condensation heater. This is a common upgrade option of the houses.
- LI_HP: Least invasive structural upgrade with heat pump. This scenario is the most optimal renovation solution complying all the heritage protection guidelines and the Nearly zero energy requirements.

4.7.3 Costs and returns of a refurbishment

The main cost of the refurbishment is the construction work. The expenses for each building for each scenario were calculated with the help of TERC VIP Gold software (TERC Kft, 2019), which is a cost calculating tool Hungarian construction industry mostly uses. Both material and labour costs were included into the amount. This amount was divided by the number of flats the building contains to enable a household level study.

As annual costs, the heating and hot water energy and public services were considered. Currently, costs of electricity and gas are laid down by the state since 2010 in Hungary owing to socio-political reasons. Therefore, utility cost calculation of households after energetic refurbishment were counted with current prices without estimating inflation and price volatility of energy on the worldwide market.

On the return side of the financial balance of households, the saved money due to decreased energy consumption (lower utility costs) were considered as positive cash flow (CF) of the project. CF was discounted with the interest rate of long term Hungarian treasury bonds (Államadósság Kezelő Központ Zártkörűen Működő Részvénytársaság, 2019), as authors regarded risks of energetic retrofit as almost 0 like in the case of Hungarian treasury bonds.

After calculating project costs and returns, the Cash flow and Net Present Value (NPV) were studied. NPV (Net Present Value) was calculated for 20 years with project cost as starting expenditure (negative CF) and savings of households (positive CF, discounted).

4.7.4 Calculations and results

Considering the three aspects mentioned above (Aspect 1: energy efficiency, Aspect 2: heritage protection, Aspect 3: cost-effectiveness), the scenarios were applied to all 386 residential buildings of the case study area. The results are analysed below:

The optimal choice for Aspect 1 would be to use LI_HP scenario. In OR_OR scenario, the present energetic state is averagely bad (E_P = 274,7 GWh/a). Using OR_CH would only partially help (20–40% average energy saving, 69.9 GWh/a), increasing the energy efficiency only a little. LI_HP would result averagely 70–80% energy saving (204 GWh/a).

As for Aspect 2, OR_OR and OR_CH would only maintain the present, slowly deteriorating state. For Socialist Modernism and Contemporary styles, the buildings and structures are not yet old. LI_HP would comply to all the heritage protection guidelines.

In the case of Aspect 3, the payback period of the scenarios was surveyed. For OR_OR, it is not applicable. OR_CH has a short (5–15 years), LI_HP offers quite a long (20–40 years) payback period.

To sum up the three aspect, OR_CH would have a fast payback period, but moderate energy saving, which is not upgrading the building structures, thus leaving them to further deterioration. LI_HP is the best choice from energetic and heritage protection point of view, but on the other hand, the upgrade is expensive and hardly pays back within reasonable time. The author nevertheless suggests to use LI_HP scenario, based on the reasons below.

- Energy efficiency is a key question today and saving most of the energy is an obligation.
- Protecting and maintaining our built heritage should not be measured only in cost-efficiency. These buildings are highly regarded as cityscape, historical and architectural values, thus should be saved. Using standardized guidelines would stop the individual modifications of the buildings, which are currently problematic (see above).
- Large numbers of residents live in these buildings, which underlines the need of renovation to improve their life quality.

The main disadvantage of the LI_HP scenario is undeniably the cost (averagely 347 000 Euro per house). Not surprisingly, NPV calculation showed negative numbers, thus an inadequate result as a business case for any profit-oriented organisation. Payback period for the most expensive scenario would be 64 years. We must keep in mind that positive CF was calculated with current utility costs, which is a clear underestimation, but might be reality because of socio-political reasons. If we had counted with inflation and price increase of energy, household saving would have been bigger, thus CF per period and as a result NPV would be higher.

To summarize, the amount of the investment required for the retrofit is impossible to be covered by households themselves in a lump. Therefore, additional funds are to be collected.

4.7.5 Possible funding of the refurbishment

Although as a business opportunity, no one would vote for energy saving rehabilitation, there are other factors that provide justification for such investments. Heritage protection and obligations to energy saving are reasons enough to search for funds that can finance the projects. The main possibilities are using own savings of households and/or condominium, housing loan with low interest rate or subsidized housing savings account of residents.

One possible solution is the Energy Efficiency Loan Scheme for Residents which can be raised by condominiums also. Financial institutions offer credits especially for refurbishments and even free-use credits could be a source. The most advantageous conditions (0% interest) are offered by the state owned Magyar Fejlesztési Bank (Hungarian Development Bank) as Energy Efficiency Loan Scheme for Residents. The loan can be raised by individuals (max. 30,800 euro) and condominiums (max 21,540 euro per flat) for energy efficient rehbailitation and/or renewable energy resource usage of dwellings (Hungarian Development Bank, 2019). In this case, repayment of the loan could be based on the savings coming from the previous utility costs.

A similar solution is called Energy Efficient Mortgages launched currently by the EU or an example from Great Britain. The latter (The Green Deal Financy Company, 2019) is a service provided to owners including a consultation about the most efficient retrofit and pre-financing of the project. Repayment of the loan is connected to the bills, thus also tenants can pay it. If the flat is sold, the loan is transferred automatically to the new owner.

Calculations show that LI_HP retrofit scenario advised by the author can be almost fully financed by household savings on utility costs as these cover repayment for the duration (20 years). For less than 10% of the houses (37 out of 386, mainly Historicism and Classicism style) some additional fund is needed, apart from the savings from less energy usage. For these cases authors suggest a combination of the following existing possibilities:

4.7.6 Further sources to support refurbishments

As described above, in most cases the houses are able to fund the projects in the boundaries of the Energy Efficiency Loan Scheme for Residents. This would enable them, to use the money saved on public utility cost to repay the loans on a 20 year span. In some cases, the above is not enough, additional funds should be involved. Below are some possibilities:

Own resources can arise from residents (household savings or subsidized housing saving fund and/or refurbishment savings of communities). Cash and deposit are the second biggest group of financial assets of Hungarian households and it shows a continuous decrease between 1995–2015 (Hungarian National Bank, 2019). In the last ten years gross savings were around 11–12% (Hungarian Central Statistical Office, 2019). The amount that households keep in cash, deposits and short term securities (so it can be quickly and easily used for funding reconstruction costs) is currently on average 12,630 euro per household (Hungarian Central Statistical Office, 2019). There is no data available about the average refurbishment savings of communities.

Funding for projects could also be household savings in subsidized housing saving fund which was a commonly used tool for home-savings accounts. It had the advantage of government support until end of 2018, since then it serves as own source of households. The average level of this source (rounded up in 6–9 years) can reach approximately 13,850 euro per household. Although the purpose of use is to change fenestration and insulation according to a representative research of one of the biggest actors in the country, the amount planned for reconstructions is only 5,540 euro per household. Those living in the central region with high level education this amount reaches 7,080 euro (Fundamenta, 2019).

Normal bank loans could also be considered. The average amount of housing loans (APR between 4–10%) is 8,600 euro, but these are generally used less and less for modernization (ca. 5%)

(Hungarian Central Statistical Office, 2019). A rapidly increasing ratio of loans raised for purchasing new flats are clearly driven by CSOK (Funding for Dwellings of Families, a Hungarian support for family housing (CSOK Információ, 2019)). Unfortunately, energetic features of newly built flats do not reach cutting edge solutions.

Additionally, the author found that CSOK (see above) is possible to raise for retrofit but currently only for houses situated in small villages. An extension towards energy efficient rehabilitation everywhere in the country is essential to support the goals highlighted in this study. It would not be an unprecedented support, as prefabricated Social Modernist buildings already received this possibility some years ago.

The government also realized the problem of funding for energetic renewal. The Warmth of a Home program is announced every year for different purposes. In 2019 change of convectors was the goal of the grant. A disadvantage of the program is that the goal is not foreseeable, and the total amount of the grant is low, thus many households miss the opportunity. Different other forms of support are available for energy saving projects financed by the state and there are some examples of ESCO (Energy Service Company) model also.

To sum up the above, the households and common condominium management do not have real planning options for large-scale rehabilitation of these houses, they receive no foreseeable funding and guidelines to help the decisions and the reconstruction itself. The result is that mostly individual smaller retrofits are made, and the much-needed complex rehabilitations are rare.

4.8 SUMMARY AND CONCLUSIONS OF PART 3

The key innovation of Part 3 is that complex renovation scenarios were created especially for the traditional apartment building type. These scenarios are synthesizing the results of the previous analytical and experimental studies. Concerning the methodology of creating the scenarios, the heritage protection guidelines as limiting factors were combined with the possible technological details to find optimal solutions, which comply both to the new low-energy prescriptions, but at the same time help protecting the architectural character of the buildings.

Two groups of scenarios were considered: structural upgrade and engineering system upgrades. Each and every scenario and their combinations were applied to all 386 residential buildings in the area. Their effect on the buildings' energetic indicator values were analysed and compared.

After assessing the effectiveness of each scenario on energy saving, the optimal variation of structural and engineering upgrades was chosen. It is concluded that for traditional buildings, the Least Invasive 'LI' structural scenario combined with Heat Pump 'HP' engineering scenario is sufficient for energy efficiency aims. At the same time, in this structural scenario, the insulations are used on a minimal, non-intrusive level, preserving the forming and elaborate decoration of the buildings, which are considered historical values. For newer buildings, built after the Second World War, the Near Zero 'NZ' and 'HP' scenarios combined can be applied to reach the maximum level of energy saving. The results show that with certain upgrades, high energy savings can be reached even for historical buildings.

As a main numerical result, the energy saving potential of the scenarios is calculated, which can be used as simple estimation for future rehabilitation projects. By using the above scenarios, 69% of the currently used heating and domestic hot water production energy can be saved on average, which amounts to 189 GWh annually for the whole of the case study area.

If considering the energy saving ratio of the styles, Premodernist, Modernist and Socialist Modernist buildings show the highest percentage compared to their original consumption. Their number is, however, low in the case study area. On a full district level, however, the buildings of Historicism and Freestyle have the largest energy saving potentials due to their large quantities, but they also stand out with their high average energy saving potential per building.

Considering the energetic classifications, before retrofit, only 4,7% complied to Nearly Zero requirements. After upgrade, 85% of the case study area would reach this high efficiency level.

As a main result, diagrams and equations were introduced for the two optimal retrofit scenario combinations (the Least Invasive structural scenario with heat pump and the Nearly Zero scenario with heat pump, mentioned above), helping the estimation of energy saving potential of a building, using the architectural style and footprint as input data. The significance of the above is that the energy saving potential of a building from the stock can be estimated using only simply accessible data. The estimation thus can be carried out even by non-professionals in a fast and efficient way.

Based on the above results, it can be concluded that even without destroying the heritage values, historical buildings can be renovated to reach the highly energy-efficient level of Nearly Zero requirements. With careful planning and combination of heritage protection guidelines and energy efficiency measures, optimal solutions can be reached between energy saving and heritage protection. The average energy consumption values per heated m^2 can help the typology-based energy usage estimation in the case of a similar building stock.

To support the above, the valid regulations should be expanded to deal separately with the heritage buildings, by allowing certain exemptions from the compliance of structures. For example, the required U value for the façade walls should not be complied for heritage buildings. Using the above special permit, the heritage values could be protected more effectively, but at the same time the Nearly Zero level certificate could be awarded for these buildings, increasing their viability and sustainability.

Concerning cost-efficiency of the refurbishments, it can be concluded that the energy saving and heritage respecting solutions for rehabilitation are not economically feasible enough to be appealing for private investors. The renewal of these buildings is, however, much needed to increase the life quality of residents, save energy, and protect the unique architectural character, now constantly endangered by demolitions. Beyond serving energy efficiency and protection of our built heritage, refurbishment of these buildings creates positive externality: renewed streetscapes, better comfort of life and last but not least, the apartments become much more valuable on the long term.

The solution can offer technical guidelines together with financing options for the complex, building-scale retrofit. One option is, for the buildings to apply for Energy Efficiency Loan Scheme for Residents. In this case, repayment of the loan could be based on the savings coming from the previous utility costs. The results of the calculations show that even for the relatively expensive LI_HP scenario, the retrofit can be almost fully financed by household savings on utility costs for the duration (20 years). In the case of less than 10% of the houses, additional funds are needed, apart from the savings from energy usage. The author collected various suggestions for additional funding.

As these large-scale upgrades should not be dealt as standard cost-efficiency based investments, but as a way to reach the energy saving goals and support the sustainable protection of our heritage, the projects should be supported by the government by upholding and extending the presently already available options (for example Warmth of the Home or CSOK).

5 GENERAL SUMMARY AND MAIN RESULTS OF THE DISSERTATION

Increasing the energy efficiency of our buildings is an important factor of the energy saving measures implemented worldwide. Renovation of the existing buildings is difficult when they have unique architectural character, historical and cityscape values, which are limiting the possible technical solutions.

Present dissertation focuses on the rehabilitation of the traditional multi-storey apartment houses of Budapest, dating from the turn of the 19^{th} and 20^{th} century. They were usually built in an unbroken row, with enclosed courtyards, ornamented façades and other characteristic architectural elements. In the last few years, the demolitions affecting this building type increased in number. Multiple irreplaceable buildings were destroyed under the pretence of modernization. One of the reasonings to destroy a building is the insufficient energetic state.

Surveying the energetic characteristics of the historical buildings and offering guidelines for heritage respecting renovations might help saving more and more historical buildings, and maintain the unique, historical cityscape of Budapest downtown. The case study area was the Old Jewish Quarter of Budapest, due to its highly endangered status and unique cultural values.

Based on the above, the aim of this study was, to find heritage respecting energetic retrofit solutions for the traditional apartment houses of Budapest.

As the problem of the heritage respecting rehabilitation is multi-sided, the research contains three main separated, but interrelated parts: Architecture, Energy and Rehabilitation. To find the consensus between energy efficiency and heritage protection, a complex methodology was used to combine the aspects.

The below conclusions and results can be used as decision support for planning heritage respecting rehabilitations in the future, as well as helping to increase the general knowledge about the characteristics of this building type and the Old Jewish Quarter itself:

Result 1: Architectural style typology and terminology

1a

Architectural style is a commonly used classification method of buildings. Based on a literature review of style terminology, I concluded that the names and time intervals of the style periods around the turn of the 19^{th}–20^{th} century are not consistently used. As a result of the survey, I created a straightforward terminology and provided definitions for the case study area residential buildings.

1b

I propose the following terms to be used: Neo-Classicism, Romanticism, Historicism, Freestyle, Premodernism, Modernism, Socialist Modernism and Contemporary. The newly added part is Historicism and Freestyle. I propose to use Historicism only to describe buildings using mainly Renaissance-Baroque elements of decoration, and Freestyle to be used to describe the buildings containing mixed style elements, but not belonging decisively to a clear style group.

1c

Based on the new terminology, I classified the buildings of the case study area into the style groups. I concluded that Historicism (39%) and Freestyle (22%) are the most common styles.

1d

Using the classified groups, I defined the time period of each style in the case study area, using the construction time of the buildings (Neo-Classicism 1811-1865, Romanticism 1845-1875, Historicism 1864-1913, Freestyle 1891-1935, Premodernism 1912-1942, Modernism 1954-1965, Socialist Modernism 1962-1980, Contemporary 1983-.

Result 2: Layout typology

2a

I created a typology of layout geometry of the building stock. I defined "Strip shape, L shape, U shape, Frame shape, and Block shape" types to describe the layout. F (40%) (frame) and the U (25%) (U-shaped) types are most common in the case study area.

2b

I surveyed the connection between layout shapes and architectural style. I concluded that the evolution during time shows the simplification of the layout form. The most common Historicism and Freestyle buildings were mostly designed as F or U shape layout. The newer styles use simpler geometry, mainly L or S shape.

Result 3: Structural-material typology

3a

I created a structural-material typology for the case study buildings based on the year of their construction. Using the typology, the main enveloping structures can be identified without destructive excavation. I assembled the structures into 9 Packages with defined construction periods.

3b

I calculated thee thermal transmittance value of all structures in the Packages, thus they can be instantly used in energetic calculations. I concluded that the most characteristic package is Package 4, containing brick wall, full timber closing slab, Prussian vault cellar slab and box-type windows. This package can be found mostly in case of Historicism buildings.

Result 4: Present energetic state

4a

I used the Hungarian energetic calculation system to determine the present energy characteristics of the building stock in the case study area. I found close correlations between certain values of architectural style, geometry and energy.

4b

Results on geometry data show that by construction time, the evolution of the urban fabric points to increasing compactness and denseness.

4c

I concluded that given the relatively high net heating energy demand and the large amount of net heated area, the Historicism and Freestyle buildings have the largest energy demand, thus the refurbishment should start with them.

Result 5: Estimations concerning present energetic state

5a

I defined equations per architectural style to estimate the important energy indicator value ∑A/V by using the ratio of footprint per perimeter of the buildings. Using the diagram or the equations, the complex ∑A/V van be closely estimated via easily accessible data.

5b

I concluded that using basic geometry and style data, the heating energy demand of a downtown building in the case study area can be estimated. I created a diagram and equations to describe with significant accuracy the correlation between the footprint and the total net heating energy demand per year, per architectural style. The significance of the above is that it can contribute to preliminary decision making of a future rehabilitation project and simplify the large-scale studies. The above input data are simple, easily accessible, helping the estimation, that thus can be made even by non-professionals. The above results thus can be used as a benchmark for energy demand assessment based on simple geometry and style data of a building.

Result 6: Expanding typologies

Based on a literature survey, I suggest the expansion of the previous building typologies of Hungary, stating that even for buildings built before the Second World War, there are significant differences in geometry and structure, resulting in different energy values.

Result 7: Refurbishment methodology

7a

I introduce a new, bottom-up methodology to deal with the complex energetic refurbishment of the building types with special architectural character. By combining the possible interventions to increase energy efficiency and the boundary conditions of heritage protection and dense urban fabric, I created refurbishment scenarios The aim was to find optimal solutions, which comply both to the new low-energy prescriptions, but at the same time help protecting the architectural character of the buildings.

7b

I applied multiple scenario variations to the 386 buildings in the case study area. After comparing and analysing the calculated results, I chose the optimal scenarios that comply with the boundary conditions. I concluded that for traditional buildings built before World War 2, the Least Invasive 'LI' structural scenario combined with Heat Pump 'HP' engineering scenario is sufficient for energy efficiency aims. At the same time, in this structural scenario, the insulations are used on a minimal, non-intrusive level, preserving the forming and elaborate decoration of the buildings, which are considered historical values. In the case of newer buildings, built after the Second World War, the Near Zero 'NZ' and 'HP' scenarios combined can be applied to reach the maximum level of energy saving.

7c

I concluded that it is possible to reach high energy savings, but at the same time protect the architectural character. By using the 6b scenarios, 69% of the currently used heating and domestic hot water production energy can be saved on average, which amounts to 189 GWh annually in the case study area.

Result 8: Estimation of energy saving potential

I introduce diagrams and equations to estimate the energy saving potential of a building, using the architectural style and footprint as input data. The equations have significant accuracy for the above-mentioned optimal scenario variations: Least Invasive structural scenario with heat pump and the Nearly Zero scenario with heat pump. The significance of the above is that the energy saving potential of a building from the stock can be estimated using only simply accessible data. The estimation thus can be carried out even by non-professionals in a fast and efficient way.

Result 9: Modifying the geometry of the buildings

Based on the heat loss coefficient values [q, W/m^3K]I concluded that the buildings in the case study area are compact enough, thus modifying their geometry is not necessary for only energy efficiency reasons.

Result 10: Suggestions for new regulations

I suggest that the valid regulations should be expanded to deal separately with the heritage buildings, by allowing certain exemptions from the compliance of structures. The required U value for the façade walls should not be complied for heritage buildings, as they can reach the required energy saving levels without insulating them. Using the above special permit, the heritage values could be protected more effectively, but at the same time the Nearly Zero level certificate could be awarded for these buildings, increasing their viability and sustainability.

Result 11: Cost-efficiency of refurbishments

11a

I concluded that the introduced energy saving and heritage respecting solutions as a refurbishment project are not economically feasible enough to be appealing for private investors. As these large-scale upgrades should not be regarded as standard cost-efficiency based investments, but as a way to reach the energy saving goals and support the sustainable protection of our heritage, the projects should be supported by the government by upholding and extending the presently already available options.

11b

I suggest for buildings to apply for Energy Efficiency Loan Scheme for Residents. In this case, repayment of the loan could be based on the savings coming from the previous utility costs. The results of the calculations show that even in the case of the relatively expensive LI_HP scenario, the retrofit can be almost fully financed by household savings on utility costs for the duration (20 years). In the case of less than 10% of the houses, additional fund is needed, apart from the savings from energy usage.

6 RELATED PUBLICATIONS

Main publications concerning the dissertation topic:

Sugár, V., Talamon, A., Horkai, A., Kita, M. (2018): Architectural style in line with energy demand: Typology-based energy estimation of a downtown district, *Energy and Buildings* Vol. 180 pp. 1–15. https://doi.org/10.1016/j.enbuild.2018.09.031

Energy and Buildings (Elsevier): 5 Year Impact Factor: 4,823; Impact Factor 2018: 4,495; CiteScore: 5,36

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Journal of Building Engineering (Elsevier): Impact Factor 2018: 2,378; CiteScore: 3,06

Sugár, V., Talamon, A., Horkai, A., Nagai, Y., Kita, M. (2019): A Study on Architectural Style, Structure and Geometry in the Old Jewish Quarter Building Stock of Budapest, *Journal of Architetcure Planning and Environmental Engineering 84(762) pp 1835-1843.* https://doi.org/10.3130/aija.84.1835

Further publications in the topic of the dissertation:

REVIEWED JOURNAL PAPERS IN ENGLISH:

Sugár, V., Talamon, A., Horkai, A., Kita, M. (2017): Assessment of Rehabilitation Possibilities in Case of Budapest Jewish Quarter Building Stock, *World Academy of Science, Engineering and Technology, International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering* Vol. 11, No. 3: pp. 361–366. https://waset.org/publications/10007025/assessment-of-rehabilitation-possibilities-in-case-of-budapest-jewish-quarter-building-stock

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Sugár V., Laczó, Z., Horkai, A., Kiss, Gy., Talamon, A. (2018): Energy Saving, Heritage Conserving Renovation Methods in Case of Historical Building Stock, *World Academy of Science Engineering and Technology* Vol. 12: 2 pp. 102–110. https://waset.org/publications/10008828/energy-saving-heritage-conserving-renovation-methods-in-case-of-historical-building-stock

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Sugar, V. (2019): Energetic retrofit of the traditional apartment houses, *Tamás, Molnár; Aleksandra, Krstić-Furundžić; Eva, Vaništa Lazarević; Aleksandra, Djukić; Gabriella, Medvegy; Bálint, Bachmann; Milena, Vukmirović - Conference Proceedings 6th International Academic Conference on Places and Technologies Pécs,* pp. 564-571.

REVIEWED CONFERENCE PROCEEDINGS IN HUNGARIAN

Sugár, V., Horkai, A., Pap, Zs., Talamon, A. (2018): Századforulós bérházak energetikai lehetőségei *Lázár I. (ed.) Környezet és energia: Hatékony termelés, tudatos felhasználás*, pp. 93–98.

Sugár, V., Horkai, A., Talamon, A., (2018): A belvárosi épületállomány energetikai modernizációs lehetőségei – jellegmegőrző felújítási módszerek értékelése. *In Tavaszi Szél 2018, Spring Wind 2018*. pp. 208–218.

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Horkai, A., **Sugár, V**., Talamon, A. (2018): Nagypaneles technológiával épült lakóépületek és a közel nulla energetikai szabályozás. *In Tavaszi Szél Konferencia* 2018. pp. 355–355.

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Conference presentations in the topic of the dissertation

- ICAE 2019: International Conference on Architecture Environment, Venice, Italy, 2019
- Places and Technologies Conference, Pécs, 2019.
- ICACC 2018: International Conference on Architecture, Construction and Conservation, Venice, 2018.
- V. Környezet és Energia Konferencia, Debrecen, 2018.
- SZIE Kiváló Tehetségei konferencia, Budapest, 2018.
- Tavaszi Szél Konferencia, Győr, 2018.
- Ybl Építőmérnöki Tudományos Tanácskozás 2018.
- 22. Nemzetközi nyári Egyetem, Kőszeg, 2017.
- ICBAU 2017: 19th International Conference on Building, Architecture and Urbanism, 2017
- ICASEPEA 2017: 19th International Conference on Architecture, Sustainable Environmental Planning and Engineering Applications, 2017.
- International Conference of Engineering and Natural Science: Summer Session, Kyoto, Japan, 2016.
- The Effect of Spreading Renewable Energy Sources and new European Union Directives on Hungarian Energy System's Future, Hungarian Academy of Sciences, Budapest, Hungary, 2016.
- Sustainable Built Environment, Towards Post-Carbon Cities, Torino, Italy, 2016.
- 3rd International Multidisciplinary Scientific Conference on Social Sciences and Arts, Vienna, Austria, 2016.
- 2nd International Conference on Energy and Environment: Bringing together Engineering and Economics – Guimaraes, Portugal, 2015
- Questions: 3rd International Workshop: Continuity and discontinuity in urban space Cluj Napoca, Romania, 2014.

7 APPENDIX

CONTENTS:

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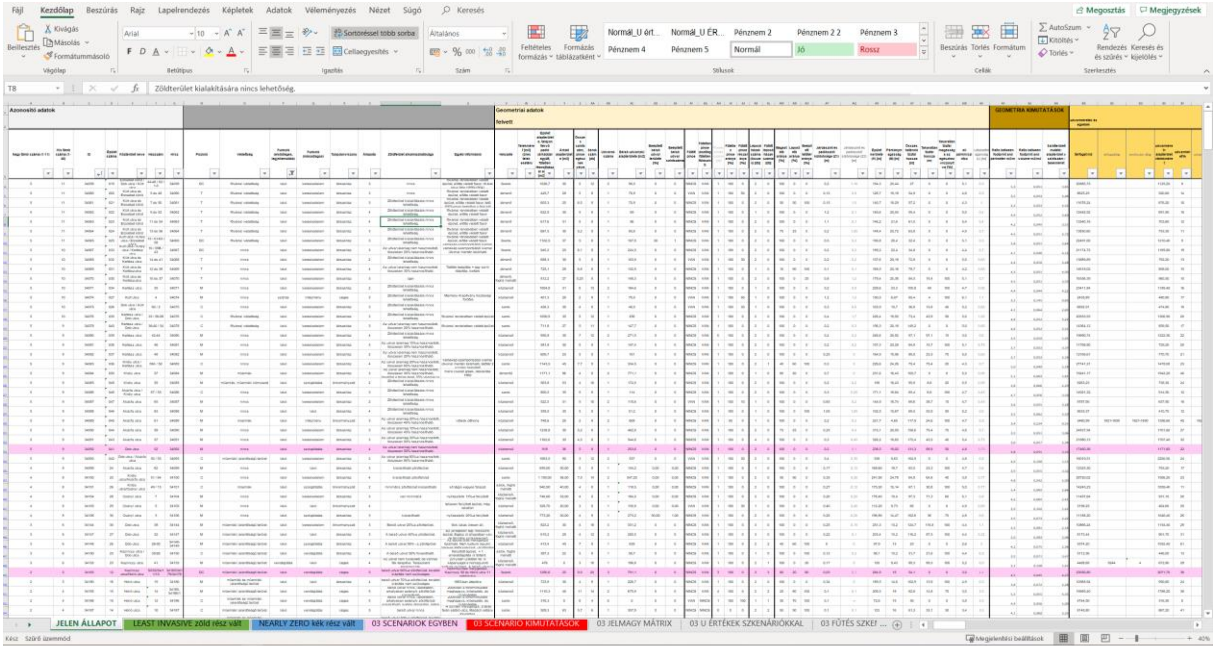
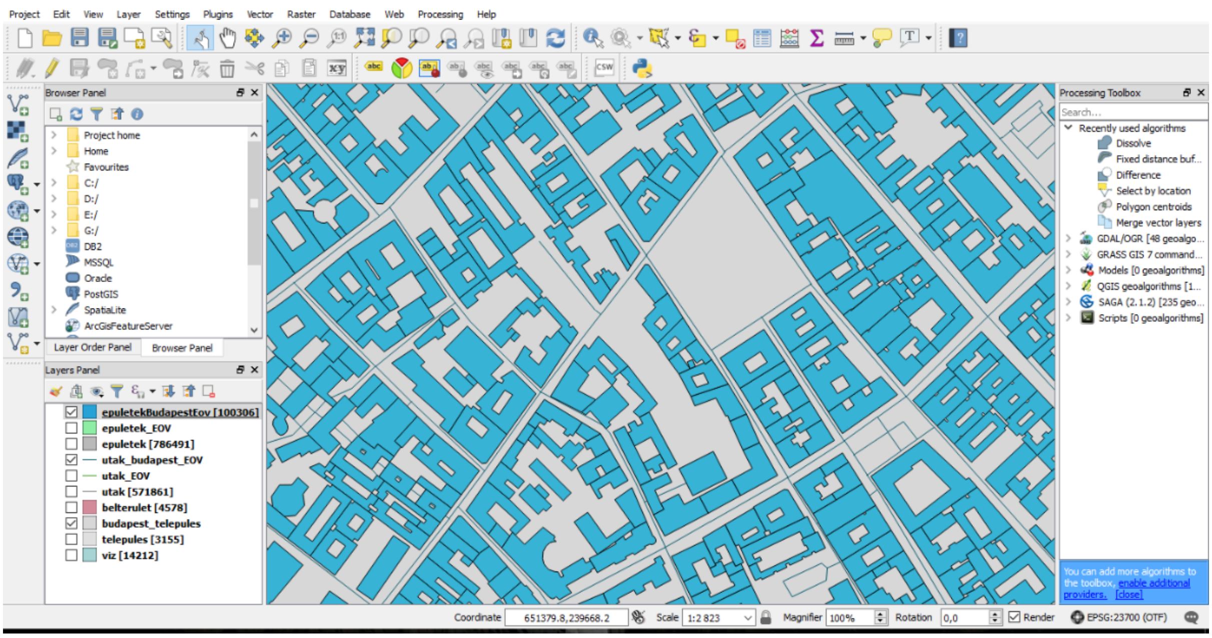
7.1 APPENDIX A

Example of the data sheet of each building in the case study area (Acknowledgement: The SZIU Ybl Miklós Faculty of Architecture students took part in the field study).

7.2 APPENDIX B

Example of the Excel sheets linked to QGIS for each building in the case study area.





7.3 APPENDIX C

Description and main equations of the currently valid Hungarian EPDP energy calculation methodology.

Based on European Union regulation 2010/31 EU (European Parliament and Council, 2010), the Hungarian Government Decree 176/2008. (VI. 30.) (2008) on the certification of energetic characteristics of buildings implemented, with the 7/2006. (V. 24.) Minister Without Portfolio Decree determining the energetic characteristics of buildings (2006), and its amending decree of Home Secretary number 20/2014. (III.7.) (2014). (the calculation system includes the EN ISO 13790/2008 standard methodology)

The requirements of each level are satisfied if the calculated values of the building complyto the limiting value stated in the Decrees above. For new buildings, the Nearly-zero level is mandatory from 2021, but in the light of the ever-stricter requirements, it can be expected to be extended to the renovation of the existing buildings as well. To reach the Nearly zero building classification, all the three levels should be fulfilled.

The three levels of requirements are the following:

- **Compliance of structures (U, thermal transmittance value [W/m²K]);**

This requirement aims for the sufficient heat insulation capability of the structures enveloping the heated volume. A maximum value is defined in [29]. The value is affected by material, layering and position of the structure.

$$U = \frac{1}{\sum R} = \frac{1}{R_{si} + \left(\sum \frac{d_i}{\lambda_i}\right) + R_{se}}$$

where:

U: thermal transmittance [W/m²K]

R: thermal resistance [m²K/W]

R_{si}: thermal resistance of the indoor surface [m²K/W]

R_{se}: thermal resistance of the outdoor surface [m²K/W]

d: thickness of structural layer [m]

λ: thermal conductivity of the structural layer [W/mK]

The U value should be modified (U_{mod}) if the structure is not connecting with outside air (ξ-value):

In case of cellar: $\xi = 0,5$, in case of closing slab-roof: $\xi = 0,9$.

Further modification is needed when considering heat bridges (χ-value):

For example: in case of a wall with strong heat bridges: $\chi = 0,4$]

Thus:

$$U_{mod} = U * \xi * (1 + \chi)$$

- ## Compliance of geometry (q, heat loss coefficient [W/m³K])

The second level of requirement is using data from the first step also combining it with the geometry of the building (areas and volumes). The aim of this limit is to have adequately low heat losses, which is why the limit encourages compact buildings.

At this level, the calculated values are only dependent on architectural data: the building geometry itself is considered, calculating the heat losses caused by the enveloping surface to heated volume ratio, including the solar gains through fenestration, excluding the engineering systems. The value is represented by the heat loss coefficient.

$$q = \frac{1}{V} (\sum A * U_{mod} + \sum l * \Psi - \frac{Q_{sd}}{72})$$

where:

q: heat loss coefficient [W/m^{3}K]

V: heated volume [m^3]

A: surface of enveloping structures [m^2]

U_{mod}: modified thermal transmittance[W/m^{2}K]

l: perimeter of structure in connection with soil (floor) [m]

Ψ: linear heat transmission [none]

Q_{sd}: Direct radiation gain for heating season

Another important energy indicator values calculated here are: specific net heating energy demand q_F [kWh/m^{2}a], and total net heating energy demand Q_F [kWh/a].

$$Q_F = H * V * (q + 0,35 * n) * \sigma - Z_F * A_N * q_b$$

where:

Q_F : total net heating energy demand [kWh/a]

H: the thousandth of the annual heating degree days (constant)

V: heated volume [m^3]

q: heat loss coefficient [W/m^{3}K]

n: average heat exchange rate (combination of indoor ventilation possibilities and protection from outside wind, from table in)

σ: correction factor of periodic run (depends on function)

Z_F: length of the heated season (constant)

A_N: net heated area of the building [m^2]

q_b: Inner heat load

$$q_F = \frac{Q_F}{A_N}$$

where:

q_F: specific net heating energy demand [kWh/m^{2}a]

Q_F: total net heating energy demand [kWh/a]

A_N: net heated area of the building [m^2]

- **Compliance of engineering systems (E_P, Total primary energy consumption [kWh/m^{2}a])**

The third level contains the energy consumption of the engineering systems annually in primary energy. The value shows the total energy usage of all the engineering systems, containing their efficiency on common primary energy value. In the case of residential buildings, heating energy and the domestic hot water energy consumption should be summed, as they are the predominant form of energy usage.

$$E_P = E_F + E_{HMV}$$

where:

E_P: total primary energy consumption [kWh/m^{2}a]

E_F: primary energy demand of heating [kWh/m^{2}a]

E_{HMW}: primary energy demand of domestic hot water [kWh/m^{2}a]

$$E_F = \left(q_F + q_{f,h} + q_{f,v} + q_{f,t}\right) * \sum\left(C_k * \alpha_k * e_f\right) + \left(E_{F,Sz} + E_{F,T} + q_{k,v}\right) * e_v$$

where:

E_F: primary energy demand of heating [kWh/m^{2}a]

q_F: specific net heating energy demand [kWh/m^{2}a]

$q_{f,h}$: losses caused by heat demand and efficiency fitting inaccuracy [kWh/m^{2}a]

$q_{f,v}$: losses of heat distribution [kWh/m^{2}a]

$q_{f,v}$: losses of heat storage [kWh/m^{2}a]

C_k: heater performance coefficient

a_k: energy ratio covered by the heater (1, if only 1 heater device

e_f: heater primary energy conversion factor (1 in case of natural gas)

$E_{F,Sz}$: support energy demand of circulator [kWh/m^{2}a]

$E_{F,T}$: support energy demand of storage [kWh/m^{2}a]

$q_{k,v}$: support energy demand [kWh/m^{2}a]

e_v: electricity primary energy conversion factor

$$E_{HMW} = q_{HMV}\left(1 + \frac{q_{HMV,v}}{100} + \frac{q_{HMV,t}}{100}\right) * \sum(C_k * \alpha_k * e_{HMV}) + (E_c + E_K) * e_v$$

where:

E_{HMV}: primary energy demand of hot water [kWh/m^{2}a]

q_{HMV}: net energy loss of hot water supply [kWh/m^{2}a]

$q_{HMV,v}$: hot water distribution losses [kWh/m^{2}a]

$q_{HMV,t}$: losses of hot water storage [kWh/m^{2}a]

C_k: heater performance coefficient

a_k: energy ratio covered by the heater (1, if only 1 heater device

e_{HMV}: primary energy conversion factor used for hot water (1 in case of natural gas)

E_c: support energy demand of circulator [kWh/m^{2}a]

E_K: support energy demand of storage [kWh/m^{2}a]

e_v: electricity primary energy conversion factor

7.4 APPENDIX D

Summary table about the structural typology Packages.

The Packages contain the type and details of the main enveloping structures, with their U values. A certain building can be classified based on the year of construction.

<table>
<tr><th rowspan="2">Package</th><th colspan="4">Enveloping structure</th></tr>
<tr><th>External wall</th><th>Closing slab</th><th>Cellar slab and arcade slab</th><th>Fenestration</th></tr>
<tr><td>Package 1
(1800–1840)</td><td rowspan="3">Brick-stone
U = 0.98 W/m^{2}K</td><td>Covered beam
U = 0.83 W/m^{2}K</td><td rowspan="3">Brick barrel vault
U = 0.41 W/m^{2}K</td><td rowspan="2">Plank-type
U = 2.28 W/m^{2}K</td></tr>
<tr><td>Package 2
(1841–1850)</td><td rowspan="4">Full timber
U = 0.62 W/m^{2}K</td></tr>
<tr><td>Package 3
(1851–1860)</td><td rowspan="4">Box-type
U = 2.28 W/m^{2}K</td></tr>
<tr><td>Package 4
(1861–1892)</td><td rowspan="2">Brick
U = 1.2 W/m^{2}K</td><td>Prussian vault
U = 0.56 W/m^{2}K</td></tr>
<tr><td>Package 5
(1893–1918)</td><td rowspan="2">Steel with filling
U = 0.64 W/m^{2}K</td></tr>
<tr><td>Package 6
(1919–1930)</td><td>Brick
U = 1.66 W/m^{2}K</td><td>Reinforced concrete
U = 2.13 W/m^{2}K</td></tr>
<tr><td>Package 7
(1931–1941)</td><td>Hollow brick wall with concrete frame
U = 1.34 W/m^{2}K</td><td>Reinforced concrete
U = 2.18 W/m^{2}K</td><td>Reinforced concrete with filling
U = 2.32 W/m^{2}K</td><td rowspan="2">Joint wing
U = 2.5 W/m^{2}K</td></tr>
<tr><td>Package 8
(1955–1980)</td><td>Block with reinforced concrete frame
U = 1.4 W/m^{2}K</td><td>Advanced reinforced concrete
U = 2.36 W/m^{2}K</td><td>Advanced reinforced concrete with filling
U = 2.32 W/m^{2}K</td></tr>
<tr><td>Package 9
(1981–2016)</td><td>Reinforced concrete with burnt clay
U = 0.41 W/m^{2}K</td><td>Contemporary reinforced concrete
U = 0.58 W/m^{2}K</td><td>Contemporary reinforced concrete with filling
U = 0.39 W/m^{2}K</td><td>Contemporary one-layer PVC or wood
U = 1.5 W/m^{2}K</td></tr>
</table>

7.5 APPENDIX E

Example of the structural Scenarios and upgrades on a Package introduced in Appendix 3.

The original state ('OR') and the two upgrade scenarios ('LI', 'NZ') are introduced on the structural typologies' 'Package 1'. This' Package' contains the characteristic enveloping structures for the traditional apartment buildings built between 1800–1840.

Enveloping structure		Structure type	'OR' Original state Layers	λ [W/mK]	Thickness [cm]	'OR' U [W/m2K]	'LI' Upgrade	'LI' U [W/m2K]	'NZ' Upgrade	'NZ' U [W/m2K]	Requirement level U [W/m2K]
A	External Wall	Stone brick mix	Whitewash sand mortar	0.81	1.5	0.98	none	0.98	Indoor insulation (A2) 20 cm (e.g. glass foam boards)	0.24	0.24
			Stone brick mixed (average of limestone and brick)	0.65	79						
			Whitewash sand mortar	0.81	1.5						
	Not covered. empty firewall	Stone brick mix	Whitewash sand mortar	0.81	1.5	1.00	Outdoor insulation (A1) (e.g. mineral wool) 20 cm	0.16	Same as LI	0.16	0.24
			Stone brick mixed (usually limestone and brick)	0.65	79						
	Cellar Wall (in case of heated cellar)	Stone brick mix	Stone brick mixed (usually limestone and brick)	0.65	79	0.86	none	0.86	Indoor insulation (A2) 10 cm (e.g. glass foam boards)	0.30	0.30
B	Window	plank framed (pre-box style)	Standard plank framed window structure with two wing layers opening outside and inside. Wooden frame.			2.28	Fitting and Low E glass replacement	1.45	Fitting. Low E glass for outside layer. new wing for inside layer	1.14	1.15
C	Cellar upper slab (in case of none heated cellar)	brick vault	Wooden plank (Oak)	0.22	2.5	0.41	Underside insulation (C1) (e.g. mineral wool) 5 cm + mortar 1.5 cm	0.21	Same as LI	0.21	0.26
			Wooden plank (Oak)	0.22	2.5						
			Filling	0.58	30						
			Brick	0.78	30						
	Floor on soil	standard wooden parquet	Wooden plank (Oak)	0.22	2.5	2.5	none	2.5	In-layer insulation (C2) (e.g. mineral wool) 15 cm	0.23	0.30
			Wooden plank (Oak)	0.22	2.5						
			Filling	0.58	10						
	Arcade	Brick vault	Wooden plank (Oak)	0.22	2.5	0.81	none	0.81	Underside insulation (C3) (e.g. mineral wool) 20 cm + mortar 1.5 cm	0.17	0.17
			Wooden plank (Oak)	0.22	2.5						
			Filling	0.58	30						
			Brick	0.78	30						
			Whitewash sand mortar	0.81	1.5						
D	Closing upper slab	Covered beam	Filling	0.58	10	0.83	Outdoor insulation (D1) (e.g. mineral wool) 20 cm	0.16	Same as LI	0.16	0.17
			Wooden plank (Oak)	0.22	2.5						
			Timber (oak)/air	R =	0.14						
			Wooden plank (Oak)	0.22	2.5						
			Reed 3 layers	0.06	3						
			Whitewash sand mortar	0.81	1.5						
	Attic	standard pitched roof	Wooden plank (Oak)	0.22	2.5	0.81	Indoor insulation (D2) (e.g. mineral wool) 30 cm	0.15	Same as LI	0.15	0.17
			Insulation stone wool	0.048	5						
			Timber (oak)/air	R = 0.14							
			Sheetrock	0.4	2						

7.6 APPENDIX F

Examples of refurbishment technical solutions with materials:

7.6.1 Outside insulation of the façade:

As mentioned in Section 4.4.1, the outside insulation can only be used in the case of empty, uncovered firewalls. It is recommended to use mineral wool (stone), which is fireproof, less sensitive to UV and moisture than polystyrene. The material is built up from threads, have open capillary system, thus lets through vapour if needed. The rock wool slabs can be applied easily using adhesive and mechanical fixing. The surface is plasterable. Polystyrene is a less desirable solution, because its sensitivity to water and UV light. The boards can also be fixed in multiple ways.

In the calculations the technical data of Rockwool Frontrock slabs were used. (https://www.rockwool.hu/termekeink/homlokzati-szigetelesek/frontrock-max-e/?selectedCat = term%C3%A9kadatlapok)

7.6.2 Inside insulation of the façade (Bakonyi & Kuntner, 2012):

Installing insulation on the inner, heated side of a structure is not without difficulties. Three main disadvantages can be listed:

- the heat buffer, heat storage attribute of the wall cannot be utilized,
- the vapor can cause major damage if precipitates between the layers,
- the usable area of the room decreases.

The most common solutions can be grouped into four types:

Vapor-tight material (Figure 75): as the name shows, no amount of vapor can access the structure (for example built of glass foam boards directly installed on the existing structure)

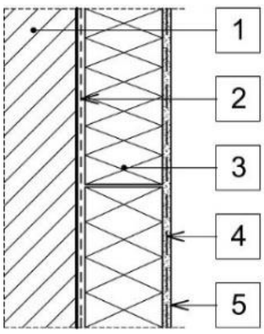


Figure 75: Vapor-tight material inner surface insulation. 1: wall; 2: base layer; 3: foam glass board; 4: base for mortar; 5: mortar

In current study's calculations, the above solution was used in the calculations. The material was a mineral based, crystal structured, brick-like product, called Multipor. (https://www.ytong.hu/termekek-maganszemelyek/multipor)

Insulation plates with vapor-tight surface (Figure 76): for example, built of expanded polystyrene with sheetrock. In this case, the external layer stops the vapour from entering the structure.

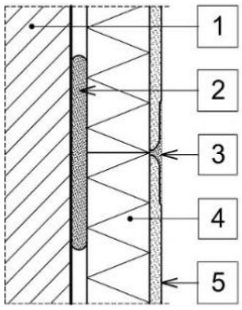


Figure 76: Insulation plate with vapor-tight surface. 1: wall; 2: glue; 3: joint-strengthening; 4+5: insulation built together with hard surfaced gypsum-board

Mounted structure with vapor-restraining surface (Figure 77): for example, standard insulation material between wooden frame covered by vapor-restraining foil and gypsum-board. Assembled on site, it is easily customizable for every surface; however, the foil is easily damaged.

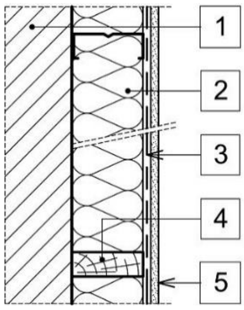


Figure 77: Mounted structure with vapor-restraining surface. 1: wall; 2: insulation; 3: vapor-restraining foil; 4: wooden frame; 5: gypsum-board

Materials enabling vapor diffusion (Figure 78): as these particular materials are containing capillaries, they can uphold a balanced vapor quantity with the heated room, thus trepidation does not occur.

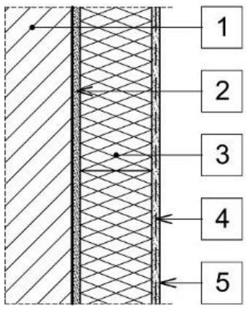


Figure 78: Materials enabling vapor diffusion. 1: wall; 2: base layer; 3: insulation; 4: strengthening net; 5: mortar

7.6.3 Fenestration renovation (Becker & Hunyadi, 2011) (Szalay, et al., 2016):

As 40–50% of the façade is glazed surface for this type, the energetic state of the fenestration is an important question. Apart from the box-type window structure mentioned before, the traditional shading solutions are remarkable. Unfortunately, nowadays the residents tend to remove the old wooden shadings oblivious of its positive effect if energetics.

As mentioned before, the most characteristic window structure is box-type: The two layers of casement are built in the frame. Both layers open inside, into the room. Unfortunately, the advantages of this two-layered structure are often neglected: most commonly they are disassembled and exchanged for plastic fenestration when renovation occurs.

There are several solutions, however, already in practice, which are not requiring the destruction of the original window. First and foremost, as these wooden-glass structures are average 120-year-old windows, their connection points are mostly displaced, the wings are warped. By correcting the warping and using for example plastic strips to level out the uneven surfaces, the thermal transmittance value (U, W/m^{2}K) can already be decreased from 2.23 W/m^{2}K to 2.12 W/m^{2}K.

It is also possible to exchange the glass of one or both layers to Low Emission glass, which is nearly an undetectable change in the appearance. The Low-E glasses (Figure 79) are thin, hard coated structures, some especially used for historical renovations. With this solution, the U value becomes 1.54 W/m^{2}K instead of the original 2.23 W/m^{2}K.

During larger interventions, full wings can be changed to new structures. To protect the outside façade appearance, the inner wing is proposed to be changed. It is also the better solution from building physics point of view. The U value can be decreased to 1.45 W/m^{2}K. The combination of the above can decrease the U value to 1.13 W/m^{2}K, which already complies to today's requirements (U_{max} = 1.15 W/m^{2}K).

The full exchange of the original structure does not provide outstandingly better values. However, because of the long repay time and precipitation problems, it is unadvised.

Table 16, shows the summarized values of the above technologies.

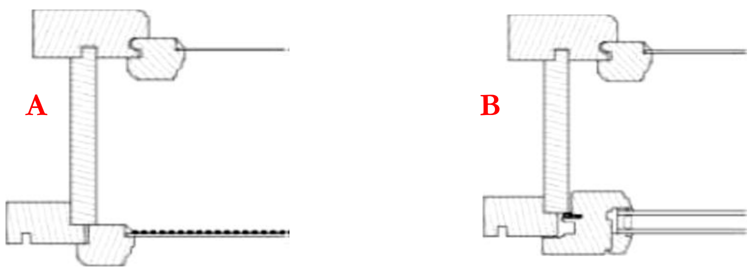


Figure 79: Two heritage respecting solutions used in the calculations for fenestration renovation. A: Low-E glass on the inner layer. B: exchange of the inner layer to new wing with highly insulating glass (Becker & Hunyadi, 2011)

Table 16: Heritage respecting technical solutions and their energy data (Szalay, et al., 2016)

Name of Technology	Original U value [W/m²K]	New U value [W/m²K]	Change in U [%]	Repay (years approximately)
Fitting, plastic filling	2.23	2.14	5%	3
Fitting and one-layer Low-E glass change		1.54	31%	6
New insulated wings on the inner layer		1.45	35%	9
Full exchange to plastic or wooden premanufactured structure		1.14	49%	25
New insulated wings on the inner layer, Low-E glass change on outer layer		1.13	51%	13

7.6.4 Bottom slab insulation

Most commonly these buildings have cellars (ones built after 1838 certainly, because the new regulations prescribed the cellars after the Great Flood of River Danube, which destroyed most of the building stock (Edvi, 2005)).

As the average cellar is vaulted, bendable insulation can be installed (Figure 80). In this case also, mineral wool is applicable. There are preformed bended products foam made of polyurethane and polystyrene, but here also, the high concentration of vapour in the air and in the structures can cause problems if we use materials with closed system. For the current calculations, the Rockwool Fixrock product data were used.

Concerning cellars, vapour is a constant problem. There are various technical solutions for supplementary water insulation, but these tend to be very expensive. Injecting the wall and using electro kinetic wall drying is a possible solution for building parts only approachable from indoor.

Figure 80: Indoor insulation and renovation of a cellar with vault (StelBuild, 2019)

7.6.5 Roof insulation

In the case of closing slab insulation under the pitched roof without attic rooms, the solution is not problematic. As the vapor exiting the rooms under can cause precipitation damage, a vapor open solution for should be chosen (for example rock or glass wool). For the current study the Rockwool Multirock data was used.

If the attic is to be utilized, the commonly used solution is rock or glass wool filling between and underside the rafter (Rockwool Deltarock data were used in the calculations)

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