

Energy Saving, Heritage Conserving Renovation Methods in Case of Historical Building Stock

Viktória Sugár, Zoltán Laczó, András Horkai, Gyula Kiss, Attila Talamon

Abstract—The majority of the building stock of Budapest inner districts was built around the turn of the 19th and 20th century. Although the structural stability of the buildings is not questioned, as the load bearing structures are in sufficient state, the secondary structures are aged, resulting unsatisfactory energetic state. The renovation of these historical buildings requires special methodology and technology: their ornamented facades and custom-made fenestration cannot be insulated or exchanged with conventional solutions without damaging the heritage values. The present paper aims to introduce and systematize the possible technological solutions for heritage respecting energy retrofit in case of a historical residential building stock. Through case study, the possible energy saving potential is also calculated using multiple renovation scenarios.

Keywords—Energy efficiency, heritage, historical building, renovation, technical solutions.

I. INTRODUCTION

THE buildings are responsible for more than 40% of the primary energy usage of the European Union. The energy usage of the buildings has been increasing constantly in the last 20 years [1]. Although the newly designed buildings must comply to very strict regulations concerning energy usage, the ratio of these modern structures is insignificant compared to the vast majority of ineffective buildings. As in Hungary, the exchange rate of the buildings (including demolitions and new constructions) is only 1.7% [2], the existing building stock should also be taken into account when considering energy efficiency of buildings.

Similar to other downtown areas in Europe, Budapest has an outstanding city center with historical buildings. The most characteristic building types of the inner districts were built around the turn of the 19th and 20th century [3].

Especially on the eastern side of River Danube, the so-called Pest, the significant part of the downtown building stock is in a run-down condition, causing unsatisfactory energy intake and insufficient life quality conditions for the residents. Also, as these districts are some of the most

populated areas of Budapest [4], the problems affect extensive number of people.

To protect the historical values, these buildings should be sustained instead of demolition, which complicates the question of energy efficiency retrofit: the historical buildings of Budapest have distinctive, sculptural façade and other architectural elements, which cannot be modernized by using the most common insulation technologies, also the renewable energy utilization has its own boundaries in case of dense urban fabric [5].

As part of a complex study concerning the building stock of Budapest, capital city of Hungary, the authors survey the energy saving possibilities in case of historical buildings by using heritage respecting modernization technologies.

II. PREVIOUS STUDIES

There have been studies dealing with rehabilitation possibilities in case of the turn of the century building stock. Pattantyús [6] in his collective study introduces the characteristic structures and their renovation methods in case of tenement houses of Hungary.

Szalay et al. [7] as well as Hunyadi and Becker [8] surveyed the energetics of the historical fenestration and offered solutions for heritage protecting renovations.

Csoknyai et al. [9] in the boundaries of Tabula Epsicope project [10] created a residential building typology for the Hungarian building stock, as well as offered solutions for energy saving renovation. The National Building Energetics Strategy also introduces a typology for the building stock and declares country level aims for energy saving [11].

The authors' previous paper [5] collected and assessed the rehabilitation limitations in detail in case of this particular building type.

III. CHARACTERISTIC HERITAGE BUILDING TYPE OF BUDAPEST

A. Building Stock Typology of Hungary

There had been attempts before to survey and create a typology of the Hungarian Building Stock. The National Building Energetics Strategy [11] defines 15 different residential building types. The downtown area buildings mainly belong to the type Nr. 10 of the typology.

The statistical characteristics of the group are the following: “built before 1945, brick or stone walls, more than ten flats in an apartment house. 15.3% of the buildings are in a run-down condition, 50.1% is satisfactory. Vast majority of them is situated in urban areas, 88.3% in Budapest” [11].

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The Tabula Episcopo international project [9], [10] is a similar system of grouping the national building stock. In this survey also, the types were defined by the age, function and size of the building. Characteristic building materials and engineering solutions were also assigned to each type based on statistical data. Similar to the National Building Energetics Strategy, the building stock in question was sorted into the group of traditional apartment house build before 1945.

B. Characteristic Layout of the Type

Fig. 1 shows an example of the aforementioned type. Usually, this type has been functioning as condominium with different size and variously equipped flats. The building is built around a courtyard. The street front wing is – as usual in this type – 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 is the main staircase. The flats on the upper stories can be entered from the hanging corridors running parallel the walls. This type 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.

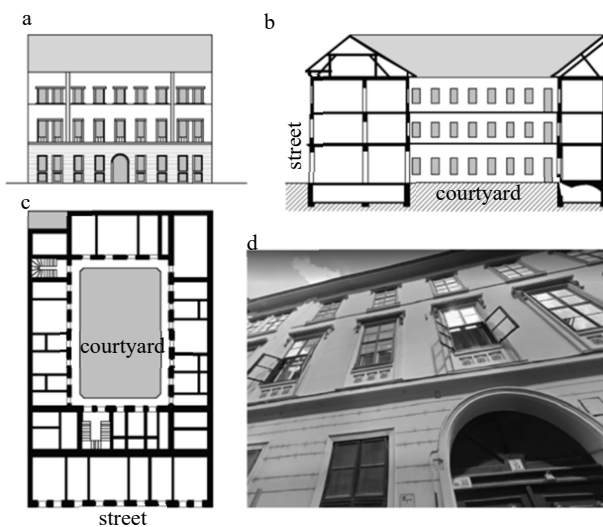


Fig. 1 Characteristic multi-apartment residential building in Budapest. (a) Street front façade. (b) Cross section, (c) First floor plan, (d) Façade detail with historical style elements

C. Characteristic Building Structures of the Type

The buildings are constructed using similar structures and materials due to the strict regulations of the 19th century, which prescribed detailed requirements for quality. As a result, the primary load bearing structures are in fairly good shape; however, the secondary structures (for example fenestration as they have a shorter lifespan) are aged.

The load bearing brick walls support mostly Prussian vault slabs, which are constructed of steel beams and narrow brick

vaults in-between. The closing slab is usually full timber. The roof of the street front wing is pitched roof, the courtyard wings are covered by lean-to roofs, supported by firewalls.

The hanging corridors are cantilever structures, supported by stone or in latter examples steel beams [6]. The windows are mostly box-type made of wood. Apart from the warped fenestration, the high amount of cantilever ledges and beams on the façade increase the heat loss.

IV. MONUMENT PROTECTION BOUNDARIES IN HUNGARY

Before attempting to collect the possible solutions, some highlight of the monument protection guidelines in Hungary should be mentioned.

The monument protection of the area contains three levels: individual monument protection, local level protection, conservation area, and monument neighborhood. The local level protection is under the judgement of the local government, while the individual protection is prescribed by government: the listed or protected historical building is registered and declared protected by law.

The limitations concerning the protected buildings are the following: it is prescribed to reinstall the previously removed but identified parts. Every change may be performed in such a manner and extent, which does not affect or endanger the 'set of values' (the 'set of values' contain: mass, space relations, ratios, symbolic content, façade design, etc.). The protected buildings should be preserved physically. The activities concerning construction should always be dependent on professional researches. The historical values concerning building structure and material should be explored and documented.

In case of repairs or modernization of a part, the preservation of the original or existing part should be primary aim. A protected building cannot be demolished under any circumstances [12].

Although most of the above building type is not secured by law, the protection of the set of values can be taken as a guideline: sustaining the appearance, especially the façade and the ratios of space contributes to uphold the unique cityscape of Budapest.

V. ARCHITECTURAL INTERVENTIONS FOR ENERGY EFFICIENCY

The possible energy efficiency measures for buildings can be grouped into two main types: architectural interventions and engineering modernization (based on building energetics and their calculation methodology in the European Union and Hungary [13]).

Under architectural intervention, the two main techniques are: A.: changes in geometry, and B.: changes in material or structure. With these measures, the energy demand of a building can be reduced.

After reducing the energy demand, the engineering modernization for heating, cooling should also be considered, if possible, supported by renewable energy production. By using the aforementioned steps, a complex energy efficiency modernization can be designed for each building.

In the current paper, the authors are introducing solutions for the architectural interventions.

A. Changes in Geometry for Energy Demand Reduction

To reduce the energy demand, the following architectural interventions can be utilized (examples on Fig. 2):

- reducing the heated volume,
- reducing the enveloping surface area per heated volume (A/V) ratio (for example covering the inner courtyard),
- repositioning (grouping) of heated rooms,
- increasing solar gains by new openings.

In case of historical buildings, however, not all the above measures can be used, as mentioned above: reduction of heated volume could be achieved by demolishing wings, an also construction new openings on the façade would change the set of values. The repositioning of functions or for example covering the courtyard to decrease A/V can be an option.

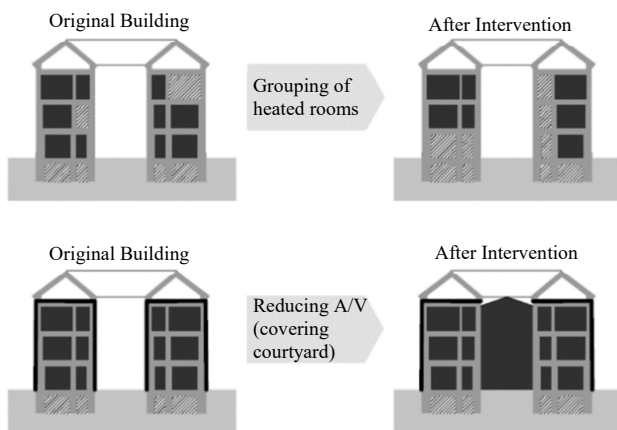


Fig. 2 Architectural intervention examples in case of historical buildings of Budapest (black color represents the heated volume)

B. Changes in Structure and Material for Energy Demand Reduction – Introducing Previous Study

The energy efficiency modernization of structures and materials can be reached by reducing their thermal transmission coefficient (U) values (increasing the heat insulation characteristic of the structure). The changes should be applied for all the structures enveloping the heated volume.

There are previous studies regarding U value reduction:

Csoknyai et al. [9] with their residential building typology introduce energetic modernization scenarios: Two different renovation scenarios were created, based on valid national Decrees either offers increased energy saving potential (Table I, standard refurbishment, ambitious refurbishment). Table I shows the typical structures and the modernization suggestions for each.

With the above architectural, and additional engineering modernization steps (modernization of heating and hot water supply system), the case study building of the Tabula was able to reach high energy saving values: the total primary energy demand for heating and domestic hot water decreased by 51% in case of standard, and 61% in case of ambitious

refurbishment. The carbon-dioxide emission for heating and domestic hot water is also decreased by 50% and 60% [9].

By keeping in mind that the Tabula project is an outstanding work of professionals, the authors would like to point out the following: Although the project declares that in case renovating monuments and protected buildings, the monumental set of values should not be damaged, and also, the characteristics of the historical building should always be taken into account, these scenarios do not give special instructions for heritage respecting solutions (only listing standard solutions for energy efficiency).

The suggestions of Table I in real life photos show that these standard solutions in case of historical buildings are damaging the values (especially in case of façade insulation and fenestration exchange). Fig. 3 shows the old, wooden window changed to a new, plastic one, while the original ratios and look were mainly neglected.

Fig. 4 shows a once historical building after application of external insulation, and compared to it, a façade of a same age building: the standard insulation sheets clearly damaging the appearance of the building.



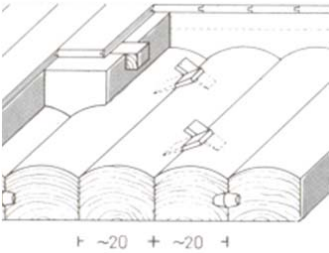
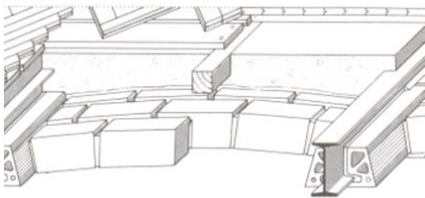
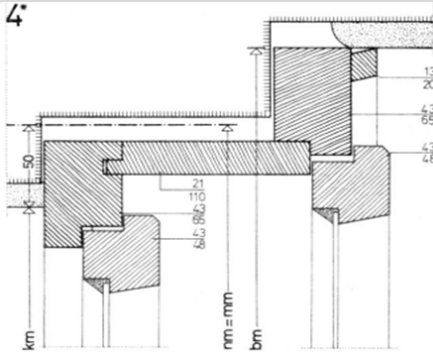
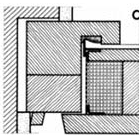
Fig. 3 Disagreeable modernization of a window by neglecting historical values (photo of Attila Zsoldos BSc Architect student)



Fig. 4 Traditional building with original decoration, and a same age building with external insulation on a historical building,

As a conclusion, the above building type has high potential of energy saving; however, the historical values and uniqueness of the buildings should also be considered in case of energy saving modernization. In the following, the authors aim to collect and systemize the possible solutions for energy saving, but also heritage protecting technical solutions.

TABLE I
CHARACTERISTIC STRUCTURES AND THEIR RENOVATION POSSIBILITIES OFFERED BY TABULA TYPOLOGY [9]

Elements of the building envelope		U (W/m ² K)
Wall		
	Existing state	
	plaster (1.5cm); brick wall (51cm); plaster (1.5cm)	1.1
	Standard refurbishment	
	Additional 5 cm external insulation	0.46
	Ambitious refurbishment	
	Additional 16 cm external insulation	0.2
Attic slab		
	Existing state	
	Wooden slab: clay (6cm); wooden beams (20cm); reed (1.5 cm); plaster (2cm)	0.64
	Standard refurbishment	
	Additional 12 cm external insulation on top of existing structure	0.23
	Ambitious refurbishment	
	Additional 28 cm external insulation on top of existing structure	0.12
Cellar ceiling		
	Existing state	
	Prussian vault: ceramic tiles (2 cm). concrete (5 cm). boiler slag infill (15 cm). brick vault between steel beams (12 cm)	0.97
	Standard refurbishment	
	Additional 10 cm insulation on the underside	0.35
	Ambitious refurbishment	
	Additional 20 cm insulation on the underside	0.21
Window		
	Existing state	
	Box-type wooden window with single glazing	3
	Standard refurbishment	
	Window with double-glazing. low-e coating and argon gas filling	1.6
	Ambitious refurbishment	
	Window with triple-glazing. low-e coating and argon gas filling	1
Door		
	Existing state	
	Old wooden door	3.5
	Standard refurbishment	
	New door	1.8
	Ambitious refurbishment	
	New door	1.3

C. Changes in Structure and Material for Energy Demand Reduction –Solutions compatible with Heritage Protection Aspects

Apart from the above, there are several options for enveloping surface insulation. Fig. 5 shows the possible insulated surfaces of the given type in case of heritage

respecting modernization.

Outside insulation of the façade (A): As mentioned before, this standard solution should be avoided due to the damage in the façade ornaments. There are, however, cases when it can be utilized. For example, in case of inner, usually less elaborate facades and firewalls, it can be reasonable.

Demolishing and later rebuilding the decoration elements using plastic replacements is also possible however, not always feasible, also not complying with the monument protection guidelines (in case of small amount or simple decoration, it can be an option). Also, in case of covering the courtyard with additional glass roof, the insulated surfaces could also be reduced in the courtyard.

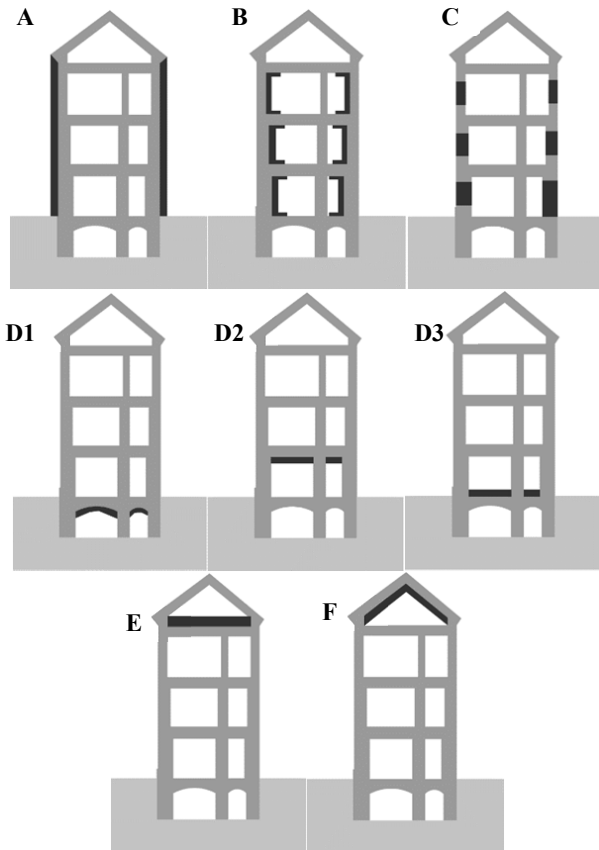


Fig. 5 Heat insulation possibilities on enveloping structures in case of heritage respecting modernization A: Outside insulation of the facade, B: Inside insulation of the facade, C: Window renovation, D: Bottom slab insulation; D1: Underside insulation of cellar vault, D2: Underside insulation in case of arcade, D3: Floor insulation, E: Closing slab insulation under pitched roof, F: Pitched roof insulation

Inside insulation of the façade (B) [14]: 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:

1. Vapor-tight material (Fig. 6): 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)
2. Insulation plates with vapor-tight surface (Fig. 7): for

example, built of expanded polystyrene with sheetrock.

3. Mounted structure with vapor-restraining surface (Fig. 8): for example, standard insulation material between wooden frame covered by vapor-restraining foil and sheetrock. Assembled on site, it is easily customizable for every surface; however, the foil is easily damaged.
4. Materials enabling vapor diffusion (Fig. 9): as these particular materials are containing capillaries, they can uphold a balanced vapor quantity with the heated room, thus trepidation does not occur.

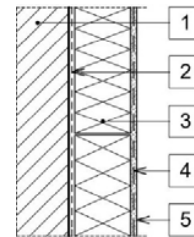


Fig. 6 Vapor-tight material inner surface insulation. 1: wall; 2: base layer; 3: foam glass board; 4: base for mortar; 5: mortar [14]

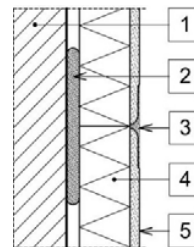


Fig. 7 Insulation plate with vapor-tight surface. 1: wall; 2: glue; 3: joint-strengthening; 4+5: insulation with sheetrock [14]

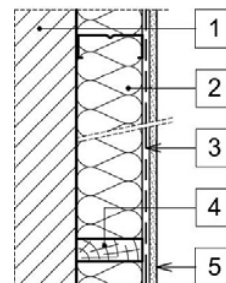


Fig. 8 Mounted structure with vapor-restraining surface. 1: wall; 2: insulation; 3: vapor-restraining foil; 4: wooden frame; 5: sheetrock [14]

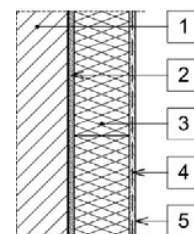


Fig. 9 Materials enabling vapor diffusion. 1: wall; 2: base layer; 3: insulation; 4: strengthening net; 5: mortar [14]

Window renovation (C): As 40-50% of the façade is glazed surface in case of 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. Either layers are opening inside, into the room (see Table I window picture). 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 (Fig. 10) to level out the uneven surfaces, the thermal transmittance value (U , W/m^2K) can already be decreased from $2.23 W/m^2K$ to $2.12 W/m^2K$ [7].

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 are thin, hard coated structures, some especially used for historical renovations [8]. With this solution, the U value becomes 1.54

W/m^2K instead of the original $2.23 W/m^2K$.

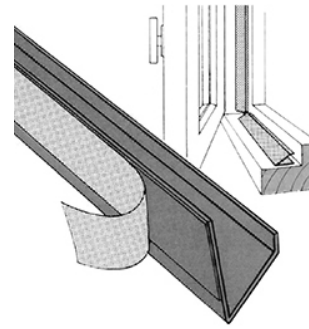


Fig. 10 Plastic filling for U value decrease [16]

In case of 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 [8]. The U value can be decreased to $1.45 W/m^2K$.

The combination of the above can decrease the U value to $1.13 W/m^2K$, which already complies to today's requirements ($U_{max}=1.15 W/m^2K$).

The full exchange of the original structure, as shown in Table II, does not provide outstandingly better values. However, because of the long repay time and precipitation problems, it is unadvised. Table II also shows the summarized values of the above technologies.

TABLE II
SUMMARY OF TECHNOLOGIES AND THEIR U VALUES [7], [8]

Name of Technology	Original U value [W/m^2K]	New U value [W/m^2K]	Change in U [%]	Repay (years approximately)
Fitting, plastic filling	2.23	2.14	5%	3
Fitting and one-layer Low-E glass change	2.23	1.54	31%	6
New insulated wings on the inner layer	2.23	1.45	35%	9
Full exchange to plastic or wooden premanufactured structure	2.23	1.14	49%	25
New insulated wings on the inner layer, Low-E glass change on outer layer	2.23	1.13	51%	13

Bottom slab insulation (D1, D2, D3): Most commonly these buildings have cellars (especially the ones built after 1838, where the new regulations prescribed the cellars after the Great Flood of River Danube, which destroyed most of the building stock [15]). As the average cellar is vaulted, bendable insulation can be installed (for example rock or glass wool), but otherwise standard technologies can be utilized (D1). In case of flat slab, the averagely used solutions are: polystyrene or wood-wool plates. The solution is the same in case of the arcade slab of the gate (D2). An alternative solution for the not heated cellar insulation is to renovate the structure from the upper side: install insulation into the floor structure from the ground floor side (D3). In this case, the most commonly wooden parquet should be ripped up, which is not an ideal solution. It is unavoidable, however, in the case where there is no cellar, and the floor layers are on the soil.

Closing slab insulation under the pitched roof (E): As the building types nearly in all cases have empty 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 should be chosen (for example rock or glass wool).

Pitched roof insulation (F): In case of built-in attic, the commonly used solution is rock or glass wool filling between and underside the rafter. In the case of building in the winter, heat loss is not the main concern. The summer overheating caused by the insufficient thermal mass is much bigger problem.

VI. CASE STUDY CALCULATION

Our case study calculation contains the data of a typical multi-story, historical tenement house described above (III.B.). The calculations were carried out in Winwatt [17] software, which is compatible to the Hungarian, thus European Union standard energy efficiency and building energetics calculation methodology.

As first step, the case study building's present energy usage (Scenario 00) was calculated, then renovation scenarios and

their combinations were calculated and surveyed (Table III).

Scenario 01 is equivalent to the ambitious refurbishment scenario offered by Tabula project [10], described above (V.B.). The engineering solution here is to exchange the heating system to condensing boiler. This scenario utilizes standard insulation technologies not considering heritage and other boundaries.

Scenario 02 was created based on Scenario 01, however heritage and other boundaries were considered in case of structures affecting appearance. In these cases, new technologies were chosen from above (V.C.). Here, the engineering solution contains heat pump.

The structural variations and engineering variations were

also combined with each other.

The solutions of Scenarios are summarized in Table III.

As a modification of the above scenarios, we calculated the effect of covering the inner courtyard also (as shown on Fig. 2), thus decreasing the enveloping area but increasing the heated volume. Thus, the above scenarios have two versions: original geometry and modified geometry.

Table IV shows the results of the calculations. The name of the combinations indicates the used scenarios: the first number indicates the scenario of the structural upgrade, the second shows the scenario of engineering upgrade. Thus, for example 1_2 means Scenario 1 of structure (Tabula solution) combined with Scenario 2 of engineering (heritage respecting solution).

TABLE III
SUMMARY OF THE SCENARIOS USED FOR CASE STUDY CALCULATION

Scenario name	Scenario 0 (Present state, see Table I)	Scenario 1 (Tabula solution, see Table I)	Scenario 2 (Heritage and boundaries respecting solution)
Structural variations	Brick wall with mortar on both sides	Outside insulation 16 cm EPS	Inside insulation 16 cm wood-wool on frame (Fig. 8)
	Brick wall (firewall)		Outside insulation 16 cm
	Windows (box-style)	Change of window to modern structure	Renovation of window, new insulated wings on the inner layer, Low-E glass change on outer layer (Table II)
	Closing slab full beam Cellar slab Prussian vault		Outside insulation 28 cm Underside insulation 20 cm
Scenario name	Scenario 0 (Present state, see Table I)	Scenario 1 (Tabula solution, see Table I)	Scenario 2 (Heritage and boundaries respecting solution)
Engineering variations	Heating system: traditional convector	Condensing boiler	Heat pump

TABLE IV
SUMMARY RESULTS AND THE SCENARIOS AND THEIR COMBINATIONS USED FOR CASE STUDY CALCULATION

Name of combination	Explanation of combination	Total energy usage, Esum [kWh/m2a]	Change compared to original [%]	Label (AA++ - JJ)	Total energy usage, Esum with change of geometry [kWh/m2a]	Change compared to original [%]	Label (AA++ - JJ)
0_0	original structure. original engineering	275.38	0.0	GG	249.24	0.0	FF
0_1	original structure. Tabula engineering	198.82	-27.8	EE	179.56	-28.0	EE
1_0	Tabula structure. original engineering	186.74	-32.2	EE	196.15	-21.3	EE
2_0	heritage respecting structure. original engineering	186.29	-32.4	EE	196.15	-21.3	EE
0_2	original structure. heritage respecting engineering	168.7	-38.7	EE	151.4	-39.3	DD
1_1	Tabula structure. Tabula engineering	134.87	-51.0	DD	141.26	-43.3	DD
2_2	Heritage respecting structure. heritage respecting engineering	109.83	-60.1	CC	116.32	-53.3	CC

Fig. 11 shows the results of Table IV on diagram which includes the total energy usage of the building in case of the above variations, either in case of original (darker shade) and changed geometry (lighter shade).

The original state (0_0) of the building with either geometry variation uses the largest quantity of energy. In this case, the covered courtyard as a modification decreases the energy usage in response to the change of A/V ratio. Variation 2_2 is the most energy saving solution, offering 60.1% saving of energy in case of original structure and 53.3% in case of covered courtyard. Also, the CO₂ emission of the building decreases by 60t/year in with these scenarios.

In case of combination 1_0 and 2_0 the enveloping structures had been upgraded, which is resulting a significant

decrease of energy intake; however, in these cases the geometry modification increases the energy intake. The explanation of this is the following: the heated volume is increased slightly, but these two scenarios are not containing the engineering modernization, the engineering is the original, not effective convector heating, which increases the energy usage compared to the non-changed geometry. Also, in case of 1_1 and 2_2, the covered courtyard does not decrease the energy intake, the increased heated volume has more effect on energy intake than the decreased enveloping surface ratio.

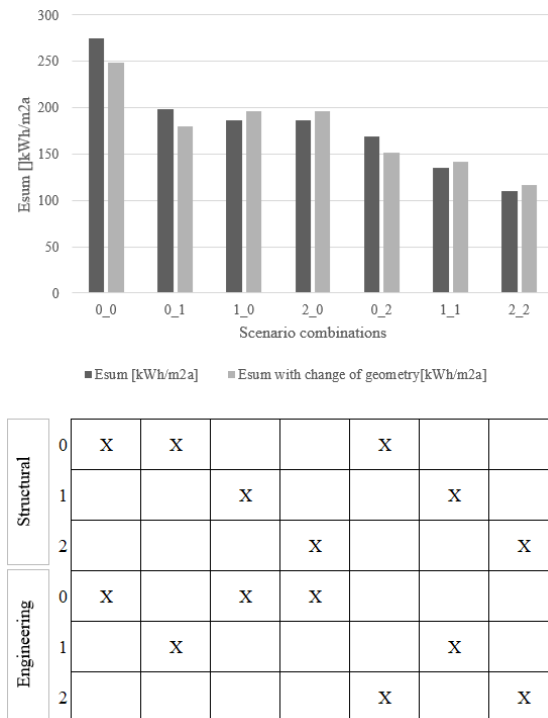


Fig. 11 Results of case study building renovation scenarios

VII. CONCLUSION

The energy usage of the existing building stock is an important question due to the large quantity of inefficient buildings. There are various solutions to decrease the energy demand: the structures enveloping the heated volume can be upgraded, and the geometry of the building (A/V ratio) can be changed.

There are standard solutions (mainly insulation) to upgrade the thermal transmittance of the structures; however, the values of the given building type should always be considered before deciding on the technology of retrofit. Especially in case of historical buildings affecting the cityscape, the standard solution should be revised from value protection point of view.

There is a considerable energy saving potential in the older building stock. Previous studies show that 50-60% energy saving can be reached in case of energy retrofit. These scenarios however do not contain heritage respecting viewpoint.

In the case studies, the energy savings were calculated by using standard and heritage respecting solutions both. By using heritage respecting technical solutions, the same or even better energy saving can be reached compared to standard solutions.

It can be concluded that in case of the typical Budapest historical tenement house built around courtyard due to its already compact structure, the change of geometry is not always resulting energy saving.

The high energy saving potential of the building type was verified via case study calculations, reaching 60% saving in

best case scenario.

Based on the above, the characteristic historical building stock of Budapest should be considered for energy retrofit due to the high energy saving potential, which can be reached by considering the historical values also. The large scale renovation of these buildings thus would result high energy saving and considerable increase in quality of life of residents also.

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