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PERFORMANCE-BASED RETROFIT CONSIDERATIONS FOR PREFABRICATED BUILDINGS: A CASE STUDY OF ZAGREB, CROATIA

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ABSTRACT

The stakeholders in the AEC (Architecture-Engineering-Construction) community generally agree that the existing building stock plays a crucial role in the building-related energy consumption and emissions. In this context, prefabricated buildings (especially those constructed in the time-period between 1950 and 1980 in a number of East and Central European countries) require careful attention. In this context, the following observations are of relevance: (i) Prefabrication was utilized to industrially build a large number of widely identical buildings, and a major part of these buildings still exist with little to no modifications; (ii) In most cases, these buildings do not meets today's thermal and energy performance standards. As such, appropriate retrofit schemes could be applied several times, or in other words, retrofit planning efforts for this building typology can significantly reduce energy use and environmental emissions; (ii) Due to the prefabrication character, the complexity of these buildings' envelope details regularly is readily manageable. Thus, retrofit solutions for prefabricated buildings can be prefabricated as well; (iii) In many European cities, such buildings form a large fraction of available (social) housing units, and thus are an important resource, given the ongoing growth of the cities of the 21st century. Demolishing and replacing entire blocks of such buildings does not appear to be neither simple nor efficient, given the associated implications regarding cost and environmental impact. As a consequence, retrofitting seems as a more viable and logical choice for the future of 20th century prefabricated building stock.

In this contribution, we present method and results of a research effort pertaining to performance-based retrofit options of a prefabricated building typology from former Yugoslavia, which can be found not only in Zagreb, but also in other parts of the Balkan Peninsula. The effort involves the systematic deployment of parametric simulation runs toward the comprehensive investigation of the impact of different retrofit options. Thereby, multiple scales were taken into consideration, including both building components (i.e., thermal bridging effects of construction joints) and whole-building thermal performance..

INTRODUCTION

It is considered as general knowledge that buildings contribute to both worldwide CHG (green-house-gas) emissions and energy consumption. To change that, the building planning of new buildings regularly targets low- to zero emissions. However, due to low new building rates, the building stock has to be addressed as well. In many European countries an extensive stock of Pre-Wende (fall of the Soviet Union) built prefabricated buildings can be found. Such buildings are of particular interest for large scale retrofit measures, due to two reasons: On the one hand, the majority of these buildings were constructed by using a limited number of industrially mass produced building components (e.g. ceiling slabs, interior- and exterior walls). Such elements were combined in a limited number of variations, resulting in many similar buildings.

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Analogically, retrofit measures for such buildings can be conducted in a feasible and easy-to-applicate large-scale fashion, once the specific elements and constructions variants have been subjected to an extensive retrofit planning. On the other hand, prefabricated buildings often represent the backbone of large residential communities in many countries. A replacement with new buildings would require extensive large-scale construction work, encompass a large environmental impact compared to a retrofit, due to demolishing and new construction of buildings, and result in a lack of residential units until the new buildings have been finished. Moreover, many cities are growing, thus a redirection of construction efforts into to replacement of existing buildings would presumably aggravate the situation on the real estate market. Given the poor thermal quality of many of the older prefabricated buildings and the large extent of built volume of such construction, retrofit measures would be beneficial to a large number of inhabitants and show a significant impact on the absolute energy consumption of cities that encompass many prefabs.

A recently concluded master thesis [1] focused on retrofit methodologies for specific types of prefabricated houses that can be found in the former Yugoslavian countries, namely the Jugomont building type JU-61. Apartment blocks of this building type consist of modular spacial units (floor plan size 3.60 m x 4.80 m). To integrate the access openings into the residential units, connection walls could be shifted by one third of the length or width of the system. This allows for different unit sizes and a certain variation in construction. Figure 1 depicts a typical principal plan layout, while Figure 2 illustrates the building construction of JU-61 buildings in Novi-Zagreb in 1961. In a past study [2] the necessity of renovation of the JU-61 buildings was highlighted. Thereby, the repair of the metal cladding of the walls (these metal claddings resulted in the nickname "Tin Cans" for the buildings), the substitution of the windows, and the renewal of HVAC-systems have been mentioned as potential retrofit measures. An impact assessment of these measures, however, has not yet been conducted. The key objective of the recently concluded master thesis (and thus of this paper) was to further develop and present detailed retrofit options for the JU-61 building typology that improve the performance of the buildings without totally neglecting the appearance of the buildings, as they represent an important phase of the 20th century building history in the former YU-countries. These retrofit options are explored via utilization of state-of-the-art simulation tools on scales overall building simulation and numeric thermal bridge simulation.

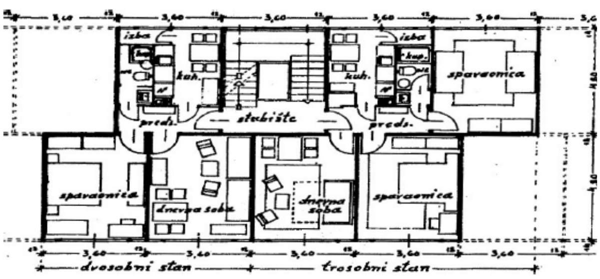

Figure 1. Typical plan layout of a JU-61 prefabricated, residential building

Figure 2. Construction site of JU-61 buildings in Remetinački Gaj, Novi-Zagreb [Private archive of architect Bogdan Budimirov]

METHODOLOGY

To explore the impact of different retrofit variations, building performance simulation has been deployed. To assess the impact of different retrofit options, overall building performance simulation with EnergyPlus [3] has been utilized (via OpenStudio [4], while the impact of thermal bridges has been evaluated with the numeric thermal bridge simulation tool AnTherm [5].

Sample building and key simulation input data. A sample building from the JU-61 buildings of the settlement Remetinački Gaj was chosen as virtual case study building. Figure 3 to 5 illustrate this building's current shape (and some of the damages that can be found). The specific building features 5 floors and a total height of 16.8 m. The building houses 35 residential units (net area 1814 m²) and has a total gross building area of 2675 m². The major facades are oriented to West and East. The vertical bearing structure of the building is constituted by a system of reinforced concrete columns (2.6m x 0.12m x 0.12 m) and panels (1.2 m x 2.6 m x 0,12 m). Horizontal load bearing elements are 12 cm strong concrete panels of 3.6 x 1.2 m. The panels, which form the exterior walls and room-partitioning elements, feature thicknesses of 20, 16, or 5 cm. Figure 6 and 7 illustrate the non-loadbearing façade panel and a load bearing façade panel construction of the building, as originally illustrated in the prefab-concrete handbook published by Duro Peulic [5]. Table 1 illustrates the thermal properties of key elements of the building.

Figure 3. Typical plan layout of a JU-61 prefabricated, residential building

Figure 4. Typical plan layout of a JU-61 prefabricated, residential building

Figure 5. Typical plan layout of a JU-61 prefabricated, residential building

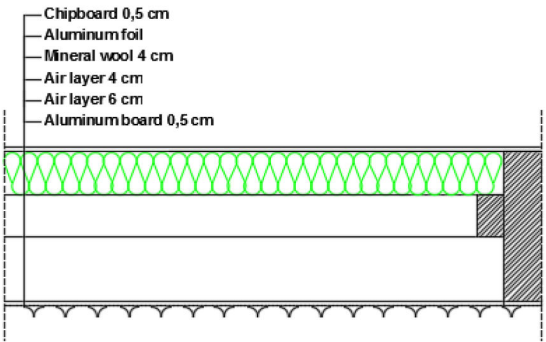

Figure 6. non-load bearing exterior wall of the JU-61 building type.

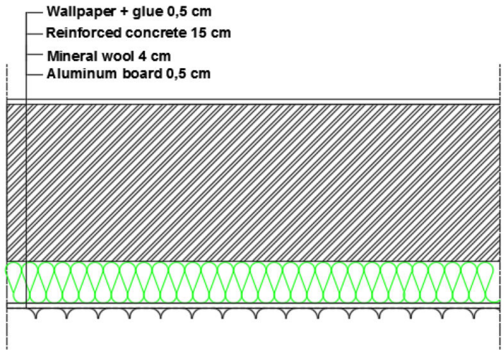

Figure 7. load bearing exterior wall of the JU-61 building type.

Table 1. Thermal properties of the case study building's constitutive elements

Building construction	Thickness [mm]	U-Value [W.m^{-2}.K^{-1}]	Heat flow direction	Min. req. U-value(Croatian legislation) [W.m^{-2}.K^{-1}]
Groundfloor exterior Wall	150	3.46	(unheated)	-
Ground floor	420	2.15	(unheated)	-
Parapett	150	0.76	Horizontal	0.3
Exterior Façade	150	0.69	Horizontal	0.3
Exterior Façade (Sides)	200	0.98	Horizontal	0.3
Groundfloor Slab	190	0.72	Downward	0.4
Floor Slab	150	2.49	(heated/heated)	0.6
Interior Wall (to unheated)	130	2.83	Horizontal	0.4
Window glazing	3	5.9	Horizontal	1.1
Window Frame – wood	7	2.2	Horizontal	-
Window Frame – Aluminium	7	3.2	Horizontal	-
Steel Doors	80	5.97	Horizontal	2
Flat Roof	270	1.4	upward	0.25

Simulation-evaluated improvement scenarios on overall building level

A model of the building as it is was generated and subjected to simulation. Subsequently, different improvement scenarios (IS) were envisioned and simulated as well. Note that IS_01 scenarios reach the same U-Value, but use different materials/constructions. Table 2 provides an overview about the evaluated scenarios. Figure 8 and 9 show the SketchUp/OpenStudio model used for the simulation.

Table 2. Basic table style.

Abbreviation	Scenario	Description & used input data
Basecase	Building as it is.	• Thermal properties see Table 1.
IS_01_a	Improved façade type A	• Exterior Façade: 10 cm PUR foam panels and 5 cm of mineral wall implemented in the exterior wall (U_{new}= 0.157 $W.m^{-2}.K^{-1}$) • Exterior Façade, Side: 15cm Mineralwool (U_{new}= 0.224 $W.m^{-2}.K^{-1}$ • Window & Door exchange: (apartment windows: U_{wind} = 1.06 $W.m^{-2}.K^{-1}$, unh.corridor windows: U_{wind} = 1.546 $W.m^{-2}.K^{-1}$, Exterior doors: U_{wind} = 1.275 $W.m^{-2}.K^{-1}$ • Ground floor walls insulated (U_{GFwall} = 0.222 $W.m^{-2}.K^{-1}$ • Change of ventilation rate to 0.5 h^{-1}
IS_01_b	Improved façade type B	• Renewal of front façade with aereted concrete blocks (U_{new}= 0.157 $W.m^{-2}.K^{-1}$) • Exterior Façade, Side: 15cm ETICS system (U_{new}= 0.224 $W.m^{-2}.K^{-1}$ • Window & Door exchange: (apartment windows: U_{wind} = 1.06 $W.m^{-2}.K^{-1}$, unh.corridor windows: U_{wind} = 1.546 $W.m^{-2}.K^{-1}$, Exterior doors: U_{wind} = 1.275 $W.m^{-2}.K^{-1}$ • Ground floor walls insulated (U_{GFwall} = 0.222 $W.m^{-2}.K^{-1}$ • Change of ventilation rate to 0.5 h^{-1}
IS_02	Improved Roof and Basement Ceiling	• New roof construction (U_{roof}= 0.221 $W.m^{-2}.K^{-1}$) • New floor constructions ($U_{floor2\ unheated}$= 0.246 $W.m^{-2}.K^{-1}$, Appartment floors: $U_{apartment}$= 0.562 $W.m^{-2}.K^{-1}$,) • Change of ventilation rate to 0.5 h^{-1}
IS_03_a	IS_01_a + IS_02	Combination of measures of IS_01_a and IS_02
IS_03_b	IS_01_b+IS_02	Combination of measures of IS_01_b and IS_02

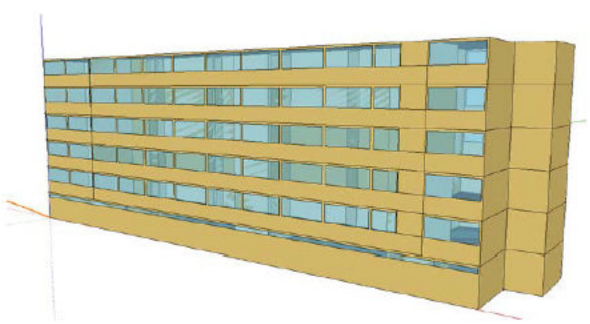

Figure 8. SketchUp/Open-Studio model

Figure 9. SketchUp/Open-Studio model

Numeric thermal bridge simulation

Based on the improvement scenarios for the overall building, major construction joints have been subjected to numeric thermal bridge simulation with the tool AnTherm. This has been done to see, if the retrofit efforts would potentially cause any unwanted thermal bridge effects. Figure 10 and 11 show the simulation models of the upper window/wall connection with both used wall systems (IS_01_a and IS_01_b). Input data parameters, if not known, have been assumed with typical values for the corresponding materials.

Cost efficiency analysis.

In addition to the simulation efforts, a cost efficiency analysis has been conducted.

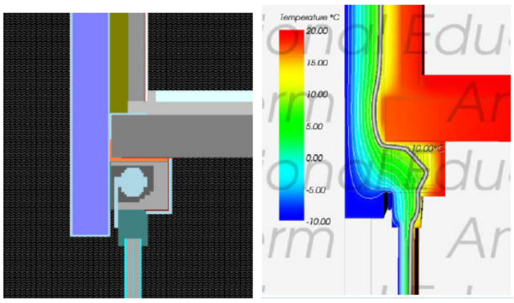

Figure 10. Wall/Window connection detail of system A (IS_01_a) and simulation result

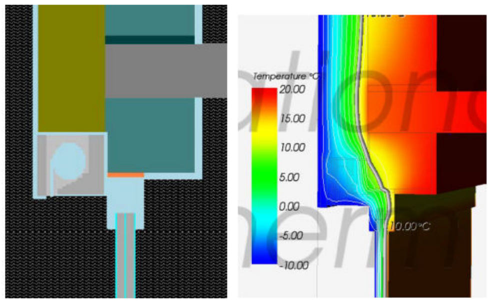

Figure 11. Wall/Window connection detail of system B (IS_01_b)

RESULTS AND DISCUSSION

Overall building's performance assessment.
Table 3 provides an overview about the results of the simulation efforts regarding heating and cooling demand.

Table 3. Results overview about the overall building

Scenario	Heating Demand [kWh.m^{-2}.a^{-1}]	Cooling Demand [kWh.m^{-2}.a^{-1}]	Heating load reduction [%]	Cooling load reduction [%]
Basecase	136.28	21.92	-	-
IS_01_a	74.93	15.97	45%	27%
IS_01_b	76.03	15.72	44%	28%
IS_02	113.32	20.72	17%	5%
IS_03_a	57.39	15.33	58%	30%
IS_03_b	58.44	14.68	57%	33%

The results indicate that in absolute numbers there is little difference between the scenarios IS_01_a and IS_01_b. The minor differences derivate from different heat storage capacity of the used materials (the operational regimes regarding ventilation and shading deployment were identical). However, both of these scenarios already offer a significant reduction of both the heating and cooling demand (up to 45% for the heating demand and up to 28% for the cooling demand). The scenario IS_02, which leaves the walls untouched, but focuses on horizontal elements, does not perform as good as the wall-affecting scenarios. The combination of the wall-affecting scenarios with the roof- and slab-retrofit shows by far the best performances: Up to 58% reduction for the heating demand and up to 33% for the cooling demand.

Thermal bridge assessment.
In general it can be said that the assessed details all can be constructively optimized so that the minimum criteria for condensation avoidance can be fulfilled. In case of the two construction joints shown above (Fig 10. & 11.), f_{Rsi}-values of 0.73 (System A; Fig 10) and 0.77 (System B; Fig 11) could be reached. The minimum thresholds for these f_{Rsi}-values are defined by around 0.70 and 0.71 in corresponding standards [6][7].

Cost benefit analysis.
The five retrofit scenarios have been in detail assessed regarding the required cost and work effort, and their potential savings in operating the buildings. Thereby, IS_02 turned out to be the retrofit scenario with the lowest investment and cost return period. However, as indicated in the results of the overall building's performance assessment, this retrofit concept provides only little reduction of heating and cooling loads. The net present value (NPV) of this scenario is the only non-negative NPV, which means that this retrofit measure is the only one that is feasible from a money-only perspective. However, that might be subject to

change, if energy prices and interest rates will change in future. Table 4 provides an overview about the cost, savings, and return period.

Table 4. Results overview about the overall building

Scenario	Investment Cost per m² [€.m-2]	Annual savings [€.m^{-2}.a^{-1}]	Return period (a)	Net present value [€]
Basecase	-	-	-	-
IS_01_a	113.8	6.7	17	-21.8
IS_01_b	105.6	6.6	16	-15.3
IS_02	29.6	2.5	12	4.2
IS_03_a	143.3	8.6	17	-25.5
IS_03_b	135.2	8.5	16	-18.9

CONCLUSIONS & FUTURE RESEARCH

The present contribution illustrated potential retrofit measures for the “tin can” Jugomont JU-61 buildings, which can be commonly found in post-Yugoslavia countries. Given the shear amount of these buildings, it seems reasonable to think about thermal retrofit of such buildings. While the economic analysis showed some challenges regarding return-of-investement / net present value, the energy and thermal bridge analysis showed that such retrofit could be feasible. The present analysis did not include social aspects of retrofit or improved indoor comfort in the buildings, but it can be expected that these domains benefit from a retrofit as well. A detailed analysis of these aspects should become a top aim of future research efforts. The research presented in this paper can be fully accessed via [1].

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