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Possibilities for energy rehabilitation of typical single family house in Belgrade—Case study

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ABSTRACT

This paper presents a case study of refurbishment and energy efficiency upgrade of a family house in Belgrade, which can be considered, based on the National typology of residential buildings, to be one of the most common Serbian family housing types. Having in mind real life conditions regarding budget, occupant behavior, spatial comfort, functional and structural characteristics, this study discusses the envisioned levels of energy efficiency improvements as defined in the National typology and their correlation to the executed retrofit case. Focus of the work is primarily energy performance of the building and it has been evaluated based on the comparison of energy needed for heating between various scenario models calculated according to methodology in current Serbian regulations on energy efficiency of buildings. Functional, volumetric, site specific and structural characteristics relevant for building's energy performance are analyzed, summed up and discussed. Following the completion of the refurbishment, a post construction evaluation has been performed taking into account real energy performance (utility bills) and economic aspects of the intervention. Significance of the case study has been discussed in terms of impact of conducted retrofit case on the respective family housing building type as well as overall impact on whole building stock.

1. Introduction

Energy performance of the building sector has been significantly improved during past two decades, but it remains far below its real potential. To make the most of the benefits of energy efficiency in buildings, the biggest challenge is to accelerate and finance upfront investments and speed up the renovation rate of the existing stock from 1.4% – today's average – to above 2% annually [1]. Research of EU residential building stock [2] shows that environmental impact from new buildings is negligible compared to the impact from existing buildings (share is 1.2%). The exploitation phase of buildings, dominated by the energy demand for heating is by far the most important life cycle phase for both existing and new buildings. Analyzing the performance of the building stock it can be said that majority of the environmental impacts are related to single family houses, following their higher level of energy consumption (by m^2), compared to multi-family and high-rise, as direct consequence of building size and geometry [2]. Ambitious goals in energy savings, CO_2 emission reduction and increase in share of renewables [5] cannot be achieved without significant changes in polices, fostering the process of retrofitting the existing building stock. That is why incentives for increasing renovation rates, such as financial benefits or tax credits, are of particular interest [3,4].

Building typologies can be a useful instrument to facilitate the energy performance assessment of the existing building stock, as well as influence of various energy efficiency improvement measures, i.e. energy conservation measures (ECMs), providing a tool for estimating the impact of different retrofit scenarios [6]. Methodology for structuring and evaluation of Serbian residential building stock has been formulated in previous researches [7], and elaborated in detail during work on TABULA project[1]. Applied methodology has been appointed as one of two official European methodologies for building stock energy performance assessment, but the only one that contains all the data needed for the energy performance calculation [8]. Besides setting the methodology for deriving appropriate building typology, TABULA also defines

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[1] TABULA: Typology Approach for Building Stock Energy Assessment. Project co-funded by the Intelligent Energy Europe programme of the EU (2009–2012, predecessor of EPISCOPE). See episcope website as a portal: http://episcope.eu/welcome/.

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refurbishment strategies through two stage retrofit scenario, applying standard and ambitious ECMs. These include interventions on all elements of thermal envelope, as well as improvements of the heat supply and domestic hot water (DHW) system.

Based on the principles set within TABULA project, National typology of residential buildings in Serbia [9] has been developed. A matrix of typical model buildings has been formulated, supported by relevant statistical data on representation rates as well as respective building characteristics. In order to estimate the energy performance and impacts of retrofit scenarios, energy performance of each model building has been calculated in original and improved states, according to methodology defined in current Serbian regulations on energy efficiency of buildings [10,11], with the general calculation principles set in accordance to European standards and EN ISO 13790. This method provides data on possible levels of energy savings for each type after retrofits and estimation of particular as well as cumulative savings potential on the entire building stock level.

However, not all of the proposed elements of ECMs are always possible to be implemented in practice, due to the different circumstances, confirming the discrepancy between scientific and professional recommendations and real life individual refurbishment solutions [12]. In this paper, a case study that depicts the refurbishment and energy efficiency upgrade of a typical representative of Serbian family housing stock, based on National typology, is presented. When analyzing real buildings, the specific context and its impact on retrofit potential have to be taken into account [13]. In the process of formulation of different refurbishment scenarios for the real case one has to envision many specific restrictions coming from circumstances such as budget limitation, occupant needs, substandard functional and spatial characteristics, and to properly assess possible retrofit levels and energy savings. This approach enables us to test proposed measures and develop real case implementation recommendations that can improve the defined model exceeding the particular case.

The analysis methodology is based on comparison between retrofit scenarios defined in the National typology (for the model building) and the actually conducted refurbishment of the sample building. Only energy needed for heating is investigated, so the retrofit scenarios take into account only ECMs affecting building geometry and thermal envelope. Energy performance of the conducted refurbishment has been calculated for two scenarios, with variations in management of heated area. Since this is one of the important parameters that is influencing heating energy consumption [14] and also the one often varied during the exploitation phase of building, its influence on energy performance and relation to some basic geometric and structural characteristics of building in analyzed scenarios is investigated. Calculated energy performance is then compared to actual energy consumption of the investigated sample building (based on utility bills) in order to validate the theoretical results for the real usage scenario. Three retrofit scenarios are compared in terms of economic evaluation of the refurbishment action based on the relation between investment, energy savings and payback period. Finally, conclusions driven from these analyses are discussed in terms of impact on retrofit of the respective family housing stock and effects on overall reduction of the heating energy consumption for the entire building stock.

2. Theory

2.1. Reference building

2.1.1. Characteristics of the building type—Model building

The reference building that represents type **E1**, according to National typology of residential buildings in Serbia, is a free-standing single family house, built in the 1970s. This building type accounts for almost 20% of entire housing stock by the number of buildings and total energy consumption for heating, as shown Fig. 1. It also represents almost 22% of family housing stock [15], being the second most frequent type.

Large number of dwellings and total living space area, as well as continuous inhabitation of this type of houses, through several generations, emphasizes the importance and necessity of their refurbishment. This activity enables the raising of overall living conditions, with positive impact on energy performance lowering the ever raising heating bills. Generally, this type of houses are predominantly heated by individual systems or single heating sources, creating direct relation between real consumption and billing, unlike houses connected to district heating systems that are still being charged on listed heated area. This presents a sound ground for implementation of retrofit measures because results are immediately visible both in the performance and economic sense. Thus, the aim of the refurbishment should not only be achievement of certain energy rating, but significant improvement in thermal comfort and reduction of heating consumption and arising expenses [16].

This building type is characterized by compact shape, rectangular floor plan, unheated basement and attic storey, with relatively moderate percentage of façade openings. Characteristics of thermal envelope, as well as basic data about building geometry for a model building of this building type are summed up in Table 1.

2.1.2. Characteristics of the sample building

The sample building can be described as a real representative of the model building for building type E1. It is located in Belgrade residential suburban area, built in the beginning of 1970s, as a detached house with two separate living units. Initially it consisted of two identical single family living units, of 140 m^2 living area each, with unheated basement and attic. The subject of this study is the unit located on the southern side of the house, with two facades facing the streets (Fig. 2a). Partial alterations have been conducted in the 1990s, through addition of new volumes in the longitudinal direction towards the backyard. Although the main, longer facade has favorable, southern orientation, which results in higher solar gains, due to its unshielded corner position it is also characterized with higher ventilation losses. Thermal imaging (Fig. 2b) shows even distribution of heat losses through the wall area, except in the zones of vertical and horizontal concrete reinforcements, which show significant linear losses. Heating sources, in the form of radiators behind the parapet wall, can be easily spotted indicating inadequate performance of the external wall (solid brick wall of 38 cm and 25 cm thickness, and sandwich wall with 5 cm of mineral wool in the added volume).

The added living space, materialized in notably different manner, is currently not being used, resulting in the fact that only 69% of available living space is heated (Fig. 3).

This characteristic is in accordance with research findings regarding management of heating area in Serbian family houses that are showing large discrepancy between constructed living area and heated area. This degradation of spatial comfort is directly related to heating costs that are consequence of poor energy performance. Only 30% of houses heat more than 70% of living area, while in 25% heated area is less than 25 m^2 [15]. This heating regime is affecting the overall thermal performance, altering the surface to volume ratio and surface ratio towards external and non heated spaces, resulting in thermal parameters significantly different than initial ones. Also, we have to stress the important role of building occupants is in process of adaptation of their house size according to their particular needs, which in the case of under-occupancy usually limits the number of heated rooms in winter [14]. However, under-occupancy is neither the only nor the main reason for this