Potential for energy savings in Czech residential building stock by application of a prefabricated mass retrofitting system

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Abstract. Buildings are responsible for a significant share of EU energy consumption. To improve energy efficiency of the building stock, it is needed to significantly increase renovation rates. To overcome actual barriers related to this problem, such as partial and non-systematic renovations, lasting unrest during renovation or time-consuming wet processes, an industrialized construction system using prefabricated modular elements seems to be a possible way. Such system for mass energy retrofitting of residential buildings in Central Europe was developed in H2020 project MORE-CONNECT. The work presented in this article aimed to roughly estimate potential yearly energy savings by applying this new modular retrofitting system on one typology segment of the Czech residential building stock: non-renovated multifamily residential buildings built between 1946 and 1960 with total gross floor area covering over 7 million square meters.

The main objective of the research presented in this paper was to make a hypothetic rough estimation of potential yearly energy savings by applying the new modular retrofitting system on a target typology of the Czech residential building stock. According to the calculations, application of proposed retrofitting system on the chosen building type would reduce the total energy consumption in Czech residential buildings by 2.9 % and by 1.8 % compared to energy consumption in all Czech buildings.

1. Introduction

1.1. Need for improved renovation rates in EU building stock
As the European Commission states, “Buildings are responsible for approximately 40 % of energy consumption and 36 % of CO₂ emissions in the EU. Currently, about 35 % of the EU’s buildings are over 50 years old and almost 75 % of the building stock is energy inefficient, while only 0.4–1.2 % (depending on the country) of the building stock is renovated each year. Therefore, more renovation of existing buildings has the potential to lead to significant energy savings – potentially reducing the EU’s total energy consumption by 5–6 % and lowering CO₂ emissions by about 5 %. “ [1] Thus, finding new ways for unleashing the potential of deep energy retrofitting of the existing building stock is a major concern.

1.2. Barriers
Directorate-General for Internal Policies of the European Parliament in its study on boosting building renovation [2] identified five categories of barriers to renovation: awareness; process; regulatory; financial; and technical.
Since in Czechia there are ongoing public subsidies for renovation and energy savings campaigns, the last barrier – technical – was determined as the crucial one to boost the building renovation in short time period. A technical solution that would overcome disadvantages of present practice was needed.

The technical barriers are in the report further split into three sub-categories: lack of technical solutions; cost of technical solutions; lack of knowledge of the construction professionals. A potential response to these barriers was identified in creating a new retrofitting system that would engage industrialized production of elements at improved level of automation for a specific sub-group of the existing building stock due for retrofitting in the coming years.

1.3. European and Czech residential buildings stock
According to Buildings Performance Institute Europe BPIE [3] in 2011, residential buildings represented 75 % of the EU building stock. At least 80 % of residential buildings were older than 20 years and it seems that residential sector represents a major proportion of the energy-saving potential.

For Czechia, there is available an analysis of the national residential building stock [4] published by the Czech NGO Chance for Buildings. The report indicates that the group of single-family houses built before 1990 (built in poor energy standard) approximately accounts for a total gross floor area of at least 179.3 M m². For the multifamily residential buildings, the study presents 104.5 M m² in buildings built before 1980. Building stock built between 1946 and 1960 covers approx. 15.7 M m² according to the study, which represents 10.0 % of the total gross floor area in Czech multifamily residential buildings (as of 2011).

In another report on building stock renovation strategies [5], Chance for Buildings presents outcomes of a complex modelling of the Czech building stock that the total national energy consumption in buildings in 2016 was 349 PJ, of which residential buildings accounted for 224 PJ and non-residential buildings 125 PJ. The modelled energy consumption included the same consumption categories as energy performance certificates (heating, cooling, ventilation, air conditioning, hot water preparation, lighting, and auxiliary energy).

1.4. Modular retrofitting system for residential buildings as potential tool for significant energy savings in the Czech residential building stock
The EU project MORE-CONNECT [6–8] developed a new modular system for deep energy retrofitting of residential buildings in Central Europe to various energy levels including net zero energy level. The system is based on timber frame panels with thermal insulation for external insulation of façades and roofs and it integrates HVAC, monitoring and renewable energy systems in one package [9].

1.5. Objectives
The main objective of the research presented in this paper was to make a hypothetic rough estimation of potential yearly energy savings by applying the new modular retrofitting system on one typology segment of the Czech residential building stock. The question of interest was, whether it the energy saving potential is significant (i.e. at least 5 % of the final energy consumption of the Czech national building stock), or rather negligible (i.e. bellow 1 % of the final energy consumption of the Czech national building stock). When it turns to be significant, then it would be worthy to seek for policy support to make it happen. On the other hand, when it turns out to be negligible, it would not be worth further investigation.

2. Methods
To estimate the potential yearly energy savings, description of the building typology of concern had to be made at first. Second, a brief summary of the developed retrofitting system with key parameters was composed. Third, a case study of a typical multifamily residential building suitable for application of the new retrofitting system was made. Fourth, the results were roughly extrapolated to the suitable building stock using estimated savings in specific yearly energy consumption and the estimated floor area available for retrofitting.

2.1. Building typology of concern
The system developed in the MORE-CONNECT project was intended primarily for multifamily residential buildings typical for the post-war era. After 1945, there was a huge demand for new flats. At the same moment, left-oriented and since 1948 communist governments ruled the country having socially oriented agenda with the aim to secure jobs and flats for the people. A typical building of that era, that dominated the category of new multifamily residential building until 1960’s, was a simple building of up to four floors, with flats of minimum floor area, massive structural external walls made of bricks of typical thickness of 45 cm, pitched roof with ceramic tiles on timber rafters with free loft area, typically with cellars partially underground (see CZ.N.AB.03 in Figure 1). After 1960, a new type of massive prefabrication stepped in and replaced the brick-and-mortar buildings by concrete slab housing, typical in Eastern part of Europe (CZ.N.AB.04 and CZ.N.AB.05 in Figure 1).

Both these typologies together present a major group in Czech building stock. The newer concrete slab houses were examined by Estonian partners of the MORE-CONNECT project, this paper deals with the multifamily residential buildings built before 1960 (CZ.N.AB.03). Their building typology has a high potential for application of precast modular retrofitting solution because of its energy inefficiency; simple design with low architectural quality; or high number of similar building with unified design. It also carries further challenges concerning low quality of after-war materials and thus its structures.

![Figure 1](image-url). Overview of Czech residential building typologies with a highlighted typology of concern. Figure taken from TABULA report [10].

2.2. New system for modular retrofitting of post-war residential buildings
To provide desired rapid refurbishment to the building owners and users, the new system was designed to integrate as much functions as possible. Complete building refurbishment thus uses number of structural prefabricated modules (wall, roof, basement module, balcony) and technological modules (ventilation module, engine room etc.). These modules get combined and connected to the existing building using tailor-made steel anchors. The main load-bearing core of the structural modules was created by timber frame and strengthened with fibre boards. Interior side of the modules is designed to fit tightly to the uneven original façade surfaces. The system is variable; the total U-values of the refurbished envelope can vary within wide range of values. The core is fitted with main layer of thermal insulation and the module is finished with external thermal insulation of variable thickness with final façade layer. Where needed, the thermal bridges are minimized using aerogel. Windows equipped with electric window blinds are part of the module. The system also enables extension of the unit’s floor area by attaching an additional balcony.

Structural elements are fitted with all necessary technologies: HVAC providing air ventilation with heat recovery, hydraulic heating pipes, electric window blinds to control overheating. In the Czech case, the engine room would be installed in one of the empty rooms in the building basement. There were developed inter-modular connectors that enable connection of the integrated sensors for monitoring indoor air humidity, temperature, or moisture content with control system and equipping each apartment with new Wi-Fi routers. The indoor environment in apartment can be controlled by app on smart phone or tablet. Further technical information is available in [9].

Complete solution is protected by national utility model.

2.3. Case study of a typical representative of the typology

2.3.1. Description of the building. As a reference building, a post-war residential block in Milevsko, Czechia, built in 1958 was chosen. The building by its typology and material basis represents a significant part of the residential housing stock of Czechia suitable for retrofitting. This particular building, used as social housing, has 24 studios (living/sleeping room, kitchen, bathroom), 31 m² each, in three stories (see Figure 2).

![Figure 2](image-url)

Figure 2. The building type from the case study in Milevsko, Czechia.

Each flat has two windows oriented either to the east or to the west. Technical and housing facilities and cellars are put in the basement, which is partially underground. Entrance to the building is from the north, leading to the wide central hall with north-south orientation. At the southern façade, central hall is ended with a loggia. The building has a gable roof (33°), attic space is currently unused. Building has longitudinal wall structural system made of bricks (450 mm), ceilings are made of reinforced concrete. Façades are plastered, original windows and exterior doors have been replaced with insulating double-glazed ones with plastic frame.
2.3.2. **Retrofitting strategy.** The general strategy came out from the analysis of typical representatives of the select typology, their technical shape and needs, and from the SWOT analysis of typical common retrofitting interventions offered on the market nowadays. The limitations given by the building typology are given by the fact that the major part of the building envelope is at the same moment the load bearing structure – typically the masonry walls of 450–600 mm form the supporting structure for the concrete floor structures. Therefore, there is no option for their replacement, the only way is to make an addition upon the existing walls. There is also planned an additional layer of thermal insulation to be placed in the attic and the floor above the cellar will be insulated as well. A mechanical ventilation system with heat recovery supplies fresh air into each of living rooms and can also provide space heating. The air ducts are integrated in the wall panels together with sensors for controlling the indoor environment in each apartment.

2.3.3. **Simulation outcomes.** For the case study building, a set of computational simulations has been performed both for the state before renovation and for the renovated building. Results of these simulations have been used for estimation of energy savings presented in this section.

Before renovation, calculated total energy consumption accounted to 308–318 kWh/(m²·a), energy consumption for heating was 230–237 kWh/(m²·a) (depending on a heat source – district heating system and natural gas boiler were considered as initial state). The report [10] indicates for the given typology typical specific energy consumption for heating 222 kWh/(m²·a), which is in line with our case study.

Common retrofitting practice is wall insulation with ETICS supplemented with insulation of attic and the floor above the cellar, and windows replacement. However, as can be seen from the report [11], the renovation employing the MORE-CONNECT system provides a solution of a higher standard with comparable costs. Therefore, a potential of energy savings presented further in the text is based on the MORE-CONNECT solution.

Depending on a renovation level and a possible heat source replacement (see [11] for details, results presented there expressed in primary energy and GW²), total energy consumption can decrease up to 33–90 kWh/(m²·a) (89–71% savings), which corresponds to specific energy consumption for heating between 25–41 kWh/(m²·a) (89–82% savings). Thanks to mechanical ventilation, U-values at a passive standard level (mean U-value is 0.25 W/(m²·K)), and generally deep energy retrofitting, this surpasses the predictions reported in [10] where typical energy need for heating after application of progressive measures reaches 63 kWh/(m²·a). Expressed as specific energy saving potential, retrofitting using MORE-CONNECT solution can save 251 kWh/(m²·a) from total energy consumption in average (up to 285 kWh/(m²·a) at maximum).

2.4. **Extrapolation to the building stock**

For further calculations, the total gross floor area of the Czech multi-family residential building stock built between 1946 and 1960 of approx. 15,657,000 m² [4] was used as a basis. The developed solution has limitation given by the national fire safety regulations, which forbid combustible products to be used in the envelopes of buildings with fire height above 12.0 m (i.e. distance between first and the upmost flooring). This regulation reduces the applicable gross floor area to 10,926,000 m² of buildings up to four floors. As mentioned in the introduction, 35 % of the Czech residential buildings have already been retrofitted, so the remaining gross floor area available for retrofitting has to be reduced to 7,101,900 m².

3. **Results**

The result of the rough estimation comes from a simplistic multiplication of the gross floor area available for retrofitting by the specific energy saving potential coming from the case study. The resulting hypothetical energy consumption saving potential (when the proposed system gets applied to all suitable multifamily residential buildings in Czechia) is 1,783 GWh/a. The figure represents 1.8 % saving on the total national energy consumption in buildings and 2.9 % of total national energy consumption in residential buildings (compared to 2016 baseline).
4. Discussion

4.1. Limitations of the study
There are many sources of uncertainties in the study. Firstly, it is based just on one case study, which cannot be taken as representation of the whole residential building stock. At the same moment, the statistics behind the figures on the Czech building stock are potentially inaccurate.

On the other hand, the purpose of the study was only to tell globally whether the potential energy savings from the proposed mass retrofitting would be significant or negligible.

4.2. Conclusion
The result of the calculation showed, that the potential for savings in the energy consumption of the residential buildings is 1,783 GWh/a, which represents 1.8% saving on the total national energy consumption in buildings and 2.9%, of total national energy consumption in residential buildings (compared to 2016 baseline). The result is not significant, but not negligible. A bold policy action on the national scale would not be justified, on the other hand, it is worth trying to discuss with the policy makers inclusion of the support of this type of energy renovation into the national subsidy schemes for energy savings in buildings and to look for suitable industrial partners for market uptake.

Acknowledgments
This work has been supported by the Ministry of Education, Youth and Sports within National Sustainability Programme I, project No. LO1605 and within project INTER-EXCELLENCE No. LTT19022.

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