Resilient and Environmentally Efficient Residential Buildings - Assessment Method and Interim Outcomes

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Abstract. Historically, the fire-safety orders restricted the use of majority of the nature-based low impact materials in town buildings. Houses therefore became rigid and resilient. Today, we need to return to those materials, but the tradition and public opinion are preventing changes in building habits. This paper describes the work done within a research project, which aims to define a resilient and low impact residential building. The main goal of the research is a development of an assessment method that evaluates the building’s ability to withstand or easily overcome most important threats which may occur in the Central European area. The research team’s objective was to identify the risks, define the crisis scenarios and to provide an exemplary solution that will ensure the necessary resilience of a model building. The method includes environmental criteria with benchmarks set up to fulfil the requirements of the Paris Agreement. This leads the building design towards the low-impact materials and technologies and towards resilience at the same time. The research team developed an assessment method including 20 criteria. A set of buildings has been evaluated and favourable technical solutions have been developed. Based on the results, a design of a model building was carried out. New equipment and technologies were implemented: removable green facade, natural ventilation with solar chimneys, or a hybrid control system managing renewable sources in the building. The next step should be a test of the technology or the overall design in real conditions. The project outcomes show the possibility of reaching a sufficiently solid and robust design of a low-rise apartment building while following a sustainable design approach at the same time.

1. Introduction

The building sector in Czechia continues in a tradition that can be tracked back to history. The fire-safety orders then restricted the use of majority of the nature-based low impact materials in town buildings [1]. Houses therefore became resilient from the fire-safety point of view. It means, in the historical prospective, that the built environment became more resistant to the fire danger. Refurbishments of buildings affected by fire became possible.

Resilience, which can be defined as an ability to withstand shocks and maintain function, is now widely discussed again. The Sustainable Development Goals (SDGs) [2] point out the most important threats our civilization is facing nowadays. The main stresses that the buildings can and should either withstand or mitigate are SDG 7 – Affordable and Clean Energy and SDG 12 – Responsible Consumption and Production. Climate Action (SDG 13) creates the main boundary condition for the future development. Resilience is an inevitable quality; it is increasing the effectiveness of the material consumption by rising building’s life time and broadening the possible utilization of the building.
In the past three years of our research project, we have been examining most important threats, stresses and disturbances to residential buildings and have been searching for technical solution that will bring higher resilience to buildings with low environmental impact. The paper describes the work done within the project and the interim results.

2. Methods

The two main goals of the research are firstly, a development of an assessment method, that evaluates the building’s ability to withstand or easily overcome the most important threats; and secondly, a development of a set of good examples of technical solutions that will bring the desired building qualities. In the first step, the goal of a multidisciplinary research team was to identify the threats, define the crisis scenarios and to provide an exemplary solution that will ensure the necessary resilience of a model building. The method included also environmental criteria with benchmarks set up to fulfil the requirements of the Paris Agreement [3] normalized to specific model building and its users. This leads the building design towards the low-impact materials and technologies and towards resilience at the same time. This is necessary for moving towards to “Climate Action” SDG.

The research team has found, that even though the threats to buildings can be identified globally, the relevance of their occurrence is strongly site-dependent. For instance, the Australian building Resilience Rating Tool [6] or Australian Resilience Measurement Scheme [7] share the criteria with the developed Central Europe-based method only partly. The criteria were sorted out to four main groups. The Climate Change Mitigation group contains three of them; the Adaptation of the Building to Climate Change group includes eight criteria; Impact of Human Activity on the Quality of Use of the Building contains four; and last five criteria belong to Socio-Economic Issues group. The assessment method in this paper used the complete array of 20 criteria that should be weighted specifically for each building. The reader can find more information on the particular assessment method in [4] and [5], where it was earlier described in detail. The principle is similar to an international sustainability assessment tool SBTool [8], where the maximum is also 10 points per criteria. Zero-point gain corresponds to the standard object solution; most objects solved without emphasis on resilience should get zero points.

3. Results and Discussion

3.1. Assessment Results

The research team performed an overall evaluation of a usual, already built reference building. Based on the result, the method was further adjusted, and the process was repeated. In the next step, a set of five residential buildings has been evaluated and favorable technical solutions were developed and tested.

The model building was designed in two new variants, an affordable Variant A, fulfilling the environmental requirements for low cost; and a comfortable Variant B, providing unaltered comfort to the user even during a shock occurrence. In design variants, different building equipment, layouts and technologies were used. The results are stated in Table 1.

| Criteria Group                                      | Reference | Variant A | Variant B  |
|-----------------------------------------------------|-----------|-----------|------------|
| Climate change mitigation;                          | 0 out of 30| 7.0 out of 30| 15.6 out of 30|
| Adaptation of the Building to Climate Change        | 15.9 out of 80| 50.2 out of 80| 70.2 out of 80|
| Impact of Human Activity on the Quality of Use of the Building | 1 out of 40 | 11.9 out of 40 | 18.4 out of 40 |
| Socio-Economic Issues                               | 12.2 out of 50 | 24.4 out of 50 | 33.7 out of 50 |
| **Total Result**                                    | **29.1 out of 200** | **93.5 out of 200** | **137.9 out of 200** |
It can be seen from Table 1, that even after the application of the technical measures, the newly designed building failed to achieve a high point gain in the Climate Change Mitigation criteria group. This is partly due to the strict setting of environmental objectives, but it rather shows the necessity of a different building design and deeper environmental optimization of the structures and services.

3.2. Technical Results
Beside the theoretical development of the assessment method, the team focused on transferring the method guidelines into real object design. New additional technologies or changes in layout of the buildings were included in the design to improve overall result of the building. Some of these technologies are listed below.

3.2.1. Example of a Technical Outcome: Horizontally Replaceable Modular Façade. For the Variant B, a new building envelope system with integrated greenery has been developed. It consists of non-load-bearing timber-based panels with integrated technologies (e.g. air-conditioning, facade sprinkling equipment, façade vegetation).

The panels are hung on reinforced concrete load-bearing skeleton from the second floor up. The solution enables a rapid replacement of the façade panels or possible improvement of the envelope properties to meet the changing requirements. The modules can be changed independently on each other so that the damaged parts of façade can be replaced without affecting the building operation in its other parts.

The panel consists of two functional parts, double-skin cladding construction with low environmental impact and a plant growing system. The prefabricated double-skinned wood-based construction consists of the main support wooden frame with OSB boards both sides and filled with blown wood fibre insulation. This structure is further provided with a partially prefabricated interior plasterboard made of cement fibre boards and exterior cladding.

Figure 1: Replaceable prefabricated envelope with integrated greenery

Figure 1 shows a perspective view of the component composition and its disintegration into fully prefabricated and partially prefabricated elements. Partially prefabricated elements (interior plasterboard and a part of the thermal insulation of the wall; horizontal water distribution, flower boxes) have predefined dimensions and are mounted to the fully prefabricated part of the workpiece so that they secure the connection to the anchor system and cover the technical joints.

This type of façade positively affects results in the criteria “Extreme summer and winter temperatures” by providing shading system and “Heat islands” by utilizing the greenery on its external surface. The “Effects of external fire”, “Effects of indoor fire”, “Noise from transportation”, “Noise from external technological sources” were taken in account and the structure provides the necessary fire protection and acoustic resistance. The goals of “Low architectural and operating quality, low
variability” were met by providing the possibility of individual architectural design and easy future replacement. Result in “Energy poverty” criteria was also improved by a decent design avoiding unnecessary heat loses or gains with mean thermal resistance level $R_{\text{mean}} = 8.34 \text{ K.W}^{-1}\text{.m}^2$.

3.2.2. Further Technical Outcomes. Beside the presented modular façade system, number of other technologies was accommodated in the model building, but the detailed information cannot fit in this paper. The indoor air quality was improved using a hybrid ventilation system including multi-solar chimneys. The energy system of the building combines diverse energy sources. Therefore, a new control system optimized to run a cogeneration unit along with building integrated photovoltaic power plant has been designed.

The architectural solution of the building’s interior (floor plan) also had to be changed to provide a flexible as well as an affordable living space for the future building users. The load bearing structure was changed to hybrid wood-concrete system.

4. Conclusions

The design positively affects the building’s resilience and by that decreases both the present and future environmental impact of the building. A complete technical solution will be publicly available at the end of the project, but the method provides a good information about the success of the process.

There are new technologies that have been developed and accommodated in the design of the model building, an example of modular, replaceable building envelope has been introduced in the paper. The next step should be testing of the technology or the overall design in real conditions. The project outcomes show the possibility of reaching a sufficiently solid and robust design of a low-rise apartment building while following a sustainable design approach at the same time.

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