Methodology for assessment of resilience of multifamily residential houses in central Europe

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Abstract. In the context of changing climate and social development, new buildings need to be adapted to the conditions they face over their lifetime. The paper presents a newly developed methodology for evaluation of resilience of buildings, in relation to sustainability and energy-efficiency. The methodology is a multi-criteria point system where, for individual criteria, the building collects positive points. The resulting sum determines the rating, similar to existing multi-criteria building performance frameworks, such as SBToolCZ. The paper explains its function by means of one criteria.

1. Context and motivation
In the Czech Republic and neighbouring countries there is a growing demand for residential buildings. It is possible to design and construct them as innovative low-carbon residential buildings ready for global change. Current efforts and development of construction industry leads more and more to sustainability of the buildings and energy efficiency. At the same time, climate change brings more extreme weather, global warming and water shortages. This, together with higher and higher complexity of the buildings and other phenomena, threatens our high-performance super-sustainable buildings and endangers their durability, which is contrary to sustainability [1]. The term sustainability therefore should include building readiness for stress situations. This will often require solutions that can be either synergistic or antagonistic to the current definition of sustainable construction [2].

It turns out to be too demanding, expensive and unpractical to build buildings resistant to all unexpected events and disasters. So robust buildings are hard to adapt over time to changing demands, and in case of braking their resistance are hardly repairable. Instead of resistance, the resilience of buildings is being discussed more and more frequently nowadays [3]. The term resilience comes from Latin word resilio meaning "to bounce back" [4]. It came from the ecological science and in its original meaning it stood for the capacity of an ecosystem to absorb shocks and still maintain function [5][6]. From the ecological science, it spread to other disciplines and started to be used also in architecture. Meerow et al. [7] made a broad review of various papers and definitions and proposed an integrative definition of urban resilience:

Urban resilience refers to the ability of an urban system and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales-to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity.
In this paper, we consider resilience of a single building similarly: building resilience is the ability of a building and its systems to maintain or rapidly return to desired functions in the face of disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity. Difference between resistance and resilience is mainly in fact, that resilient building may not resist any disaster, and its function during stress situation can be decreased. However, it is easy to put the building back into operation, even after a stressful situation that would exceed the resistance of a resistant building (Figure 1).

The main objective of the present research was to develop for the assessment of resilience of residential buildings in the Central Europe. The main purpose of the methodology is to enable to set performance levels in terms of resilience for new multifamily residential buildings.

2. Methodology for assessment of resilience of residential buildings
The methodology was formed in the context of integrated design. Cooperation of a multidisciplinary team of specialists of various specializations was used.

2.1. Scientific method
The process of creating a whole methodology was based on the method of scientific knowledge synthesis, which was chosen as a main way of work. A large number of authors from various fields of construction science have undertaken a series of many discussion meetings that have managed the main direction of the methodology creation process.

The multidisciplinarity and size of the team ensures a comprehensive view and the use of synergies and the elimination of antagonisms of adaptation and mitigation measures, so that the preparation of a building for one type of threat did not cause it to be seriously susceptible to another one.

The method of the methodology itself is a multi-criteria point system where, for individual criteria, the building collects positive points. The resulting sum determines the rating, similar to existing multi-criteria building performance frameworks, such as SBToolCZ [9].

2.2. A workflow
Potential threats that current and future buildings will face were identified. These risks were then categorized according to the probability of their occurrence and the severity of their impact when they occur, in order to select from the long list of risks the items that need to be systematically addressed (such as flood, fire ...). Then a crisis scenario was developed for each threat, defining precisely how the building is at risk, in order to understand the situation in which the resilient building should be prepared.

According to the aforementioned crisis scenarios, a methodology for resilience assessment was then created. For each risk a criterion has been developed that evaluates the degree of preparedness of a

![Figure 1 - Difference between resistance and resilience](image)
building for a given threat. Finally, a catalogue of recommended solutions and solution combinations was created, as a guideline how to construct resilient buildings.

3. Resulting methodology

Four basic risk categories have emerged from the methodological process. Two categories are related with climate change. Firstly, the category of Climate Change Mitigation, which deals with contribution of the building to the climate change. Secondly the Climate Change Adaptation category, defining preparedness of the building to the upcoming climate change. Then also, anthropogenic threads have been found and socio-economic risks. The whole methodology consist of twenty criteria.

The final evaluation does not, unlike the SBToolCZ methodology, lead to a single aggregate result that would express the overall resilience of the building, but presenting a set of 20 results. Other threats are relevant to each specific building, so it is not possible to adjust the weights of individual criteria. Each criterion results in Positive Credits on a scale 0-10, the higher the result is, the better. In addition to the list of all criteria, one sub-criterion is presented to illustrate and understand the nature of the method.

3.1. Content of methodology

Content of the methodology, separated into four chapters is presented in Table 1.

| Climate change mitigation | Adaptation of the building to climate change | Impact of human activity on the quality of use of the building | Socio-economic issues |
|---------------------------|---------------------------------------------|---------------------------------------------------------------|----------------------|
| + Building contribution to climate change. | + Torrential rainstorms. + Flooding. + Summer overheat risk. + Extreme climate manifestations. + Drought. + External fire. + Infrastructure damage. + Urban heat islands. | + Traffic noise + Technology and production noise. + High concentrations of dust particles in ambient air. + Insufficient internal fire resistance. | + Reducing housing quality. + Population aging. + Energy poverty. + Crime and social unrest. + Unreliability or excessive complexity of used solution. |
| + Building energy demand. | | | |
| + Unpreparedness to new forms of unpretentious transportation. | | | |

3.2. Example of one sub-criterion: Operating reliability

The “Operating reliability” is a single part of wider criterion called “Unreliability or excessive complexity of used solution”. The presented example represents only one part, because the whole criterion consists of three separated problems: Simplicity of building process, Operating reliability and Degree of user simplicity.

3.2.1. Context of operating reliability

The current trend in the construction of energy-efficient houses increases the amount of installed building equipment. In addition to traditional heating and sanitary facilities, nowadays also air-conditioning, outdoor blinds with motor drives, complex building management systems, security systems, solar and photovoltaic panels and other equipment are commonly found in buildings. All of these devices require not only proper installation, but also regular maintenance and brings additional risk of failure.

The failure of different devices causes complications of different severity. While the failure of heating in winter, or the failure of a ventilation system in a house without openable windows, is fatal to
the building operation and may cause uninhabitability, the failure of a single drive of outdoor blinds reduces comfort but does not prevent the building from being used. Even a minor failure, however, worsens the reliability of the building, and its risk is reflected in the assessment.

Operational reliability can be achieved in multiple ways. The traditional technical way is the duplication of systems, the cascading folding of components, and thus the addition of other, back-up equipment. This leads to a higher degree of reliability (if one device fails, a 100% substitution turns on), but also to a higher building complexity and a higher probability of a single failure. The failure then does not have a fatal impact, but still needs to be fixed and the building may appear to be poorly reliable or too complex for the owner.

Another way is to apply passive solutions instead of 100% backups. For example, air-conditioning for balanced ventilation can be backed up by natural window ventilation. The backup solution is then less comfortable and more energy-intensive, it brings the risk of penetration of outdoor dust and noise into the interior in the short term, but it does not significantly increase the complexity of the building, while the main function (ventilation) is not completely lost during the stress situation.

3.2.2. Indicator and assessment of operating reliability.

The indicator of operating reliability is a number of active elements in the building management system. For individual sub-systems of building technical equipment, the level of operational reliability is determined separately per chapters, by assigning auxiliary points (AP) for each of the provided functions. The chapters are namely:

- **Sanitary** (Table 2): Installation of water and sewer systems can do without active elements, but sometimes may contain active elements with a major failure effect.
- **Heating and DHW preparation** (Table 3): Heating of buildings typically contains a number of elements at risk of failure. Heating failure can mean the loss of the building’s inhabitability if it occurs in the winter and its extent is that the building freezes.
- **Ventilation** (Table 4): Apartment buildings are usually not equipped with central air-conditioning, installations of residential air-conditioning or vacuum ventilation prevail. Decentral units contain more active elements, but with smaller impact of malfunction and better reparability.
- **Other appliances** (Table 5) includes other active devices in the building that are not included in previous categories.

The evaluation is always carried out for the whole building or its part serving as an apartment building (if a significant part of the building has a different purpose). For most of the chapters, the number of Auxiliary Points varies depending on whether the technology is backed up. As a backed up are considered those technologies, where the failure of one element does not disable the entire function. For example, in malfunction of single gas-boiler from a multi-boiler cascade means, that the overall power of whole cascade is lower (so the temperature of DHW may decrease), but the heating still works, so the boiler is considered as backed. As backed up are considered also systems where the backup solution is passive. For example: natural ventilation is a backup solution for mechanical ventilation as described in chapter 3.2.1.

### Table 2 – Resilience of sanitary systems

| Used sanitary technology                                      | AP       |
|---------------------------------------------------------------|----------|
|                                                              | Backed up| Not backed up|
| Pump for drinking water supply                                | 4        | 8           |
| Pump for service water supply                                 | 1        | 2           |
| Pump to boost drinking water pressure for part of the building| 2        | 4           |
| Pump to boost service water pressure for part of the building | 1        | 2           |
| Drinking water treatment plant of drinking water filters including passive filters | 2        | 4           |
Service water treatment plant of drinking water filters including passive filters 1 2
Sewage pumping station for the whole building 4 8
Sewage pumping station for the basement below the bottom of the sewer 2 4
Wastewater treatment plant 2 4
Pump for draining purified waste water 2 4

Table 3 – Resilience of heating systems

| Used technology of domestic heating and DHW | AP | Backed up | Not backed up |
|--------------------------------------------|----|-----------|----------------|
| Central heating source (and DHW)           | 1  | 8         |
| Central direct-heated water storage tank   | 3  | 6         |
| Transmission station of central heat supply| 1  | 2         |
| Solar assistance in hot water preparation  | 1  | 2         |
| Another additional central heat source     | 1  | 2         |
| Circulation loop on hot water distribution | 1  | 2         |
| Multiple in-flat decentral heat sources for heating (and DHW) | 2  | 4         |
| Decentral DHW preparation in-flat          | 1  | 2         |

Table 4 – Resilience of ventilation systems

| Used technology for ventilation | AP | Backed up | Not backed up |
|---------------------------------|----|-----------|----------------|
| Central air handling unit for multiple apartments | 4  | 8         |
| Shared exhaust fans on backbone pipes | 4  | 8         |
| Multiple single-apartment air handling units | 1  | 2         |
| Local units for balanced room ventilation | 2  | 4         |
| Local exhaust ventilation fans   | 1  | 2         |

Table 5 – Resilience of other appliances

| Used technology for other appliances | AP |
|-------------------------------------|----|
| Electrically powered blinds on windows | 2 |
| Elevator                            | 1  |
| Central station of fire extinguishing system | 2 |
| Central station of Electronic Fire Signalisation | 2 |
| Security system control panel       | 2  |
| BMS central station                 | 2  |
| Battery storage                     | 2  |
| PV panels                           | 2  |
| House communicators                 | 2  |
| Router for LAN                      | 2  |
| Other active elements in the building excluding the normal wiring | 2 per element |

Table 6 – Resilience of heating systems

| AP  | KB |
|-----|----|
| 25 or more | 0 |
| 20      | 1  |
| 16      | 2  |
| 13      | 3  |
| 10      | 4  |
| 8       | 5  |
| 6       | 6  |
| 5       | 7  |
| 4       | 8  |
| 3       | 9  |
| < 3     | 10 |
The resulting number of AP’s is the sum of partial point profits for each table row. If none of the cited technologies are installed in the building, the number of APs is zero for given chapter. Then, total number of Auxiliary Points is calculated as a sum of AP’s from all chapters. The final degree of resilience in context of given criterion is expressed by number of positive credits (KB). The number of credits is obtained from the Auxiliary Points according to Table 6. Intermediate values are interpolated linearly. The higher the KB is, the better is resilience in the terms of operational reliability.

4. Summary

The paper presents the developed methodology and explains its function by means of one criteria. The criterion "Operating Reliability" determines how to evaluate that ability of a building, based on the number of active elements of building services, that are potential sources of failure. The criteria take into account that the failure of the various elements can be of varying severity, to capture effect of different severity between failure of drinking water pump and house communicator. The methodology provides a holistic view of resilience and facilitates the use of synergy and the elimination of antagonisms of adaptation and mitigation measures to improve the quality of building design. The methodology is currently applied to a serial multifamily building in the Czech Republic, as part of the process of parameter tuning. This work fills the gap of a missing guideline for the construction of sustainable buildings prepared for the climate change.

Acknowledgement

This work has been supported by the Technology Agency of the Czech Republic, project No. TH02030797 and the Ministry of Education, Youth and Sports within National Sustainability Programme I, project No. LO1605

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