Buildings and climate change: impacts on roofs and vulnerability to wind storms

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Changes in climate have various implications for building design, construction and maintenance. In the framework of the CLAVIER project a case study has been implemented in Tatabánya to assess the structural impacts and vulnerability on the roof, particularly in point of the wind loads. A classification of building stocks were made in three main groups (dwellings; industrial/commercial buildings; public buildings) and 16 different types were defined representing almost the 90% of Hungarian building stock. The methodology of the assessment of the vulnerability: after estimating the sensitivity to meteorological conditions of each type of building attributed to roof covering material, building's age, roof area etc. we determine the exposure to the wind speed changed caused by the global warming. The indexes of building type's adaptive capacity depends on the attitude and socio-economic situation of house's owners related to mobility, risk prevention, potential to mitigate the damage costs etc. According to our results almost the half of the dwelling categories is attributed higher than average vulnerability. Obsolete block of flats (which are relatively prevalent in Tatabánya), churches and older, dilapidated public buildings are the most endangered. It is obvious that those areas where the block of flats from 1945's and the high-rise prefabricated housing blocks dominate are the most vulnerable. It is also notable, that more than the half of the population of the Tatabánya's inhabitants are living in most vulnerable settlements.
Keywords: climate change, vulnerability, buildings, wind speed

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Introduction

Changes in climate have various implications for the built environment: building design, construction and maintenance (CRISP, 2003; Medgyasszay et al, 2007). According to the existing literature (CIBSE, 2005) the possible impact of the climate change on the buildings may be grouped as: the direct impacts on structure (snow load, wind pressure, landslides, flood etc.), on building constructions (fastening systems, water management system, shading etc.), the implication for building materials (frost-resistance, UV-resistance, fadeless etc.) and the indirect impact on in-door climate (temperature, relative humidity etc.) also.

In the framework of the 3 year research CLAVIER project (Climate Change and Variability: Impacton Central and Eastern Europe) a case study has been implemented in Tatabánya to assess the structural impacts and vulnerability on the roof, particularly in point of the wind loads (Clavier, 2011). It should be emphasized that climate change may also affect building constructions of the roof (e.g. fastening of the roof covering elements, the rainwater drainage system) that need further researches.

Classification of the building stock

In order to be able to estimate the sensitivity of a settlement, in view of the results of climate change models, the whole building stock of Hungary were classified (typised). In the representative tipization there are 3 main groups: dwellings, industrial/agricultural/commercial buildings and public buildings. Altogether 16 different types were defined, from the small traditional family houses till modern office buildings and monuments, which represent almost 90% of Hungarian building stock (see examples at *Fig. 1-3.*). The different building types are characterized by different sensitivity values as well as different non climatic socio-economic drivers.

In this way if the composition of building stock (according to the types) and the future parameters of climate change of a settlement are known the overall vulnerability of a village or town may be estimated.

In the course of standardization the aim was to determine the significant characteristics of buildings in context of the wind load. These characteristics are: the height of the building, the shape and the angle of the roof and the covering of all the external structures (facade and roof).

The age of the building, the time of construction defines the used materials and structures, as well as the operative regulations used.

The selection of the studied area based on the following criteria:

- The building's composition of the area should represent the determined building types.
- The local climate of the selected area should be represented by rural circumstances (i.e. without urban heat island).
- A proper building statistics should be available from the case study area.

These criteria imply to select medium size town. Among them, Tatabánya was selected (the town is a member in Alliance

Fig. 1-2-3. Examples of the elements of the building stock: 'One-storied family house from 1945–1990'; 'Pre-war downtown tenement block' and 'High-rise prefabricated housing block'
1-2-3. ábra Példák a hazai épületállományra: az ún. „Kockaház", a „Belvárosi bérház" illetve a „Magas panelház"

of Climate-Friendly Municipal-Cities). Tatabánya located in Komárom-Esztergom County was a traditional industrial settlement before 1990. During the last decade, the town transformed to a typical multifunctional region centre, with various new and existing buildings and the building's composition of the town well represents the building' stock in Hungary.

Assessment of vulnerability

After the classification of building stock we defined the conceptual framework that creates the connection between the meteorology and the structural design. Finally the elements of Climate Impact and Vulnerability Assessment Scheme (CIVAS) methodology were identified the relevant to this Study. The CIVAS method starts with estimating the sensitivity to the climate change of each building type, than calculating the exposure and adaptive capacity of them. Finally on the basis of these indicators the vulnerability indexes were calculated by using the determined model (see *Fig. 4.*).

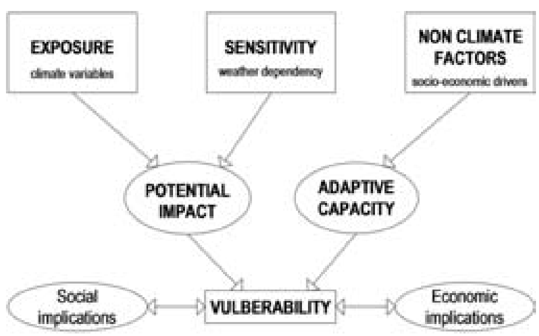

Fig. 4. Application of CIVAS methodology in Buildings Case Study of the CLAVIER project
4. ábra A CIVAS módszer, a CLAVIER projekt Épített Környezet fejezetében

Sensitivity to meteorological conditions

As it was shown the identification of sensitivity is a central element to assess vulnerability. In present case study the wind-related sensitivity is defined as what extent the wind pressure affects the structure of the roof. The meteo-sensitivities are generally attributed to roof covering material, building's age, roof area etc., and determined by expert judgments based on experiences gained in planning, maintenance and insurance activities. This examination was very complex; several aspects should be taken into consideration, with different weights.

The wind related sensitivity depends on many factors, for example the structure and the size of the roof, the type of roof covering (covered by small elements or felts), and the buildings and plants close to the roof structure. The age of the building is one of the most important factors during the vulnerability examinations of roof structures, as the date of the construction determines which standards and regulations were in force, which technologies were used by the designers the builders. Since the 1960ies, the roof structures have been built in weak quality. Its main reason was that formerly the roofs were designed by experimental methods, and these mainly more robust structures could bear severe meteorological events. Since the introduction of structure and measure standards the designers have had to fulfil the minimum requirements, thus in generally say, the roof structures built before the 1960ies are more robust than those were built after this date. This phenomenon – which can be very strange for non-professionals – is well described in the international scientific sources (Roaf et al, 2005).

The sensitivity of the buildings is also influenced by the difference between the financial value of the case of damage and the original value of the building. In this respect, the function of the buildings is also an important factor during the sensitivity examinations. In case of historic buildings the damage is incalculable, thus, these protected buildings (such as ancient public and residential buildings and churches) can be defined as strongly sensitive.

The sensitivity values were identified on a five grade scale by experts' judgments. The highest score is assigned to the situation that is most hazardous for roof damages, and the lowest score denotes the hazardless case. Since the sensitivities are strongly depend on building types, the sensitivity values were determined for each building's type, separately.

Summarizing the results of our examinations the most sensitive buildings in Hungary – besides the historic buildings – are the so called 'cubic houses' which were built after the Second World War, namely the one-storied, square-planned, houses with tent-shaped roof and an area of about 80–100 m^2 (see Fig. 1.). The public buildings built before 1945, the traditional residential houses and the multi-storied 'cubic houses', which were built after the 1960ies, are slightly less sensible. The smaller or huge industrial buildings, halls, trade buildings and modern office buildings are the less sensible to the wind (the result are shown in *Fig. 5.*).

Exposure to climate change

The identification of exposure indicators were derived by the relevant standards. The first step was the examination of the wind-related standards and then the definition of the exposure indicators, according to the meteorological calculations. In order to know the reactions of the load bearing structures of buildings to the wind it is important to overview the regulations concerning the structural design, both the current European Standard (Eurocode 1–4, 2004) and the former National Standard (MSz, 1986).

According to Eurocode, the basic value of an action (or impact) is the characteristic value, having annual probabilities of exceedence of 2% (this is equivalent to a mean return period of 50 years.). The design value of an action is calculated from the characteristic value (using e.g. the combination factors, the partial factors etc.). Therefore the characteristic value creates the connection between the meteorology and the structural design.

The characteristic wind speed in different building types was divided into four clusters: low buildings (the characteristic daily mean wind speed cws = 8 m/s at height h = 8 m), family buildings and commercial centres (cws = 12 m/s at h = 9 m), moderate high buildings (cws = 11 m/s at h = 17 m) and high buildings (cws = 12,5 m/s at h = 27 m).

The exposure indicators are the increase in number of days between 1971–2000 and 2021–2050 when daily mean wind speed exceed critical threshold values according to the clusters. These indicators were calculated from the error-corrected Regional Model REMO (version 5.7, 0.22° × 0.22° grid spacing) IPCC A1B-scenario simulations for the decades from 1971–1980 to 2041–2050.

Summarizing the results of this step the number of days per year when critical daily mean wind speed exceed calculated critical threshold value is the highest (39 day) in case of 3rd cluster, the moderate-high buildings, including block of flats from 1945's, traditional public building, the modern housing estates and the modern office buildings. The exposure indicator is similar of the high buildings in 4th cluster (all the results are shown in *Fig. 5.*).

Adaptive capacity

The identification of adaptive capacity is an important element to assess vulnerability. In present case study the indexes of building type's adaptive capacity depends on the attitude and socio-economic situation of house's owners related to mobility, risk prevention, potential to mitigate the damage costs etc. The adaptive capacity indicator was also identified on a five grade scale by experts judgments based on experiences of Tatabánya Major Office.

When determining adaptive capacity the social and the financial background of the residents or the owners of the building were explored in the representative area, the town of Tatabánya. Adaptive capacity is mainly determined by the attitudes of the residents/owners of the building, for example, has the residents insurance for the building, by which the damages of the structure, walls, roofs, doors and windows can be refunded, or not. The 'damage prevention capacity' of the building is depending on the financial situation of the owners, that means, the permanent repair, reconstructions and renovations are taken regularly, or not. In case of block of flats (with more owners) a special hindering factor is the number of the owners, because the decision making process connected to the building can be difficult and slow. The adaptive capacity of the buildings can be improved by the use of national and/or EU financed sources for the reconstruction.

According to our aspects, those types of buildings have the highest adaptive capacity level, where the owners of the building have financial interest to the permanent functioning of the building; thus, the small or large industrial buildings, and the newly built office buildings are in the first place. When the residential buildings are taken into consideration, the residential houses built in the past decades and the buildings of housing estates are in the best group according to adaptive capacity. Unfortunately, in the town of Tatabánya, the 80% of the inhabitants live in buildings with low adaptive capacity values (mainly in older housing estates and residential buildings with more owners, where the owners do not have any insurance on the building). The public buildings and historical buildings – mainly because of the poor financial background and the problems of decision-making process – are among building types with medium adaptive capacity level (the results are shown in *Fig. 5.*).

Assessment of the vulnerability

On the basis of the exposure, sensitivity and adaptive capacity indicators presented above, the vulnerability indicators were calculated by using of CIVAS model. The basic assumptions are as the follows:

- The changes in exposure (i.e. the estimated climate change manifested in exposure indicators) are statistically significant.
- The sensitivity and adaptive capacity indicators are supposed to be invariant for the time period. In other words, the sensitivity values are the same for the baseline and future periods, which means that the technological development in building's constructions is neglected. It also means that the socio-economic circumstances are unchanged.
- It is assumed that building's roof damages are only caused by wind.

After the calculations of exposure (ΔE), adaptive capacity (A) and sensitivity (S) we can determine the vulnerability (V) of the different types of buildings by a simple algorithm:

$$V_i = \Delta E_i \cdot S_i \cdot (6 - A_i)$$

According to our examinations we can determine, that the following types of buildings can be rated as the most vulnerable: blocks of flats, built after the Second World War in the socialist period; the traditional public buildings, built before the First and Second World War; historical buildings and churches. In the second, group there are the ten-storied panel houses and the tenements built before 1945, mainly in the centre of city. In the medium group, there are the modern housing estates and blocks of flats, and the four-storied blocks of flats. In the group

Types	Exposure (days)	Sensitivity	Adaptive capacity	Vulnerability
block of flats from 1945's	39	↑↑↑	★★	●●●●❺
traditional public building	39	↑↑↑↑	★★★	●●●●❺
church	31	↑↑↑↑↑	★★★	●●●●❺
pre-war downtown tenement block	31	↑↑	★	●●●❹○
high-rise prefabricated housing block	31	↑↑↑	★★	●●●❹○
modern housing estate	39	↑↑↑	★★★★	●●❸○○
small prefabricated housing block	9	↑↑↑	★★	●●❸○○
traditional family house from early 1900's	4	↑↑↑↑	★★	●❷○○○
one-storied family house from 1945–1990	4	↑↑↑↑↑	★★	●❷○○○
public building from 1945's	9	↑↑↑	★★★	●❷○○○
multi-storied family house from 1960–1990	4	↑↑↑↑	★★★★	❶○○○○
modern family house (from 1990's)	4	↑↑	★★★★★	❶○○○○
small industrial building	39	↑	★★★★★	❶○○○○
large industrial building	39	↑	★★★★★	❶○○○○
commercial centres	4	↑	★★★★	❶○○○○
modern office building	39	↑	★★★★★	❶○○○○

Fig. 5. Exposure, sensitivity, adaptive capacity and vulnerability in various building types in Tatabánya
5. ábra A tatabányai épületek kitettsége, érzékenysége, alkalmazkodó képessége és sérülékenysége

of less vulnerability, there are the family residences and the public buildings built after the wars. Although the industrial buildings and the modern office buildings have high exposure values, but they have low sensitivity values and good adaptive capacity, therefore their vulnerability is at minimum level.

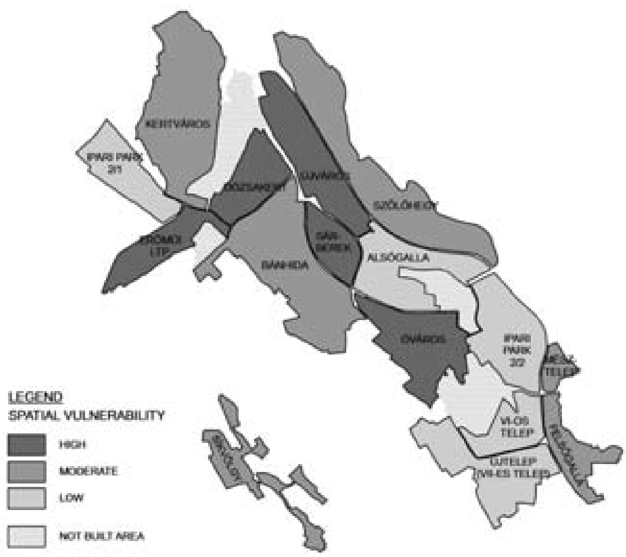

Fig. 6. Spatial vulnerability of building's roof to climate change in Tatabánya
6. ábra Tatabánya területi sérülékenysége (a klímaváltozás és a tetők viszonyát tekintve)

Summarizing the types of building in Tatabánya according to regional aspects, the vulnerability map of the town was formed (see *Fig. 6.*). The most vulnerable areas are the following: Dózsakert, Újváros (New Town) and the Erőmű (Power Station) housing estate, because in these areas the most vulnerable types of buildings can be found, mainly the 'socialist' blocks of flats and the small and large panel houses. The area of the Óváros (Old Town) is also very vulnerable, because of the big housing estates built in the socialist period.

When examining the population of Tatabánya, we can see that more than the half of the population (54,5%) lives in the most vulnerable areas, and their greatest share lives in blocks of flats, panel houses and four-storied houses. Areas with medium vulnerability values are the area of Kertváros and Bánhida, where most of the buildings (50–60%) are family residences, but the share of panel blocks is also important (20–25%). In the other areas with medium vulnerability values are mainly family residences, which vulnerability is low. 10% of the population live in the areas with low vulnerability values; they are mainly family residence belts (VI. and VII. colonies and Alsógalla) and industrial areas.

The major conclusions are as the follows:

- The most vulnerable building's types have been identified as most critical components of the city's building stock and mapped on Tatabánya's urban district.
- It can be shown that almost the half of the dwelling categories is attributed higher than average vulnerability.
- Obsolete block of flats (which are relatively prevalent in Tatabánya), churches and older, dilapidated public buildings are the most endangered.
- It is obvious that those areas where the block of flats from 1945's and the high-rise prefabricated housing blocks dominate are the most vulnerable. It is also notable, that almost 25% of the Tatabánya's inhabitants are living in most vulnerable settlements.

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Klímaváltozás és az épületeink: a tetőt érő hatások és a széllel szembeni sérülékenység

A klímaváltozás jelentős hatással bír az épített környezetünkre: az épületek tervezésére, az építésére illetve a fenntartásukra egyaránt. A CLAVIER projekt keretében egy módszertant dolgoztunk ki, melynek segítségével a tetőszerkezeteket érő hatások és azok széllel szembeni sérülékenysége meghatározható, s mindezt Tatabányán elvégeztük.
Az épületállományt a tipizálás során három nagy csoportba osztottuk (lakóépületek; ipari/kereskedelmi épületek, ill. középületek) és összesen 16 típusépületet határoztunk meg, melyek a hazai épületállomány közel 90%-át lefedik.
Az érzékenység vizsgálat első lépése, hogy mérnöki közelítéssel meghatároztuk az épülettípusok érzékenységét az időjárási körülményekre, majd meghatároztuk az épületek kitettségét, a globális felmelegedés által okozott szélsebesség növekedésnek. Végül az alkalmazkodóképesség meghatározása során az épületben lakók vagy azt használók ill. tulajdonosok szociális körülményeit és anyagi lehetőségeit tártuk fel: ezt leginkább az épületben élők/tulajdonosok szemlélete, gondolkodásmódja befolyásolja (épületbiztosítás, karbantartási gyakoriság, igényelhető támogatások stb.).
Az összegzés alapján megállapíthatjuk, hogy a lakóépületeink közel fele az átlagosnál sérülékenyebb és a legsérülékenyebb csoportba tartozó épületeink a II. világháború utáni években épült manapság „szocreál” blokkos társasházak, a háborúk előtt épült hagyományos középületeink és a műemlék épületek, templomok. A települések azon területei a legsérülékenyebbek, ahol a fent említett “szocreál” blokkos épületek, illetve a magas panelházak dominálnak, s a tatabányai lakosság több mint fele (54,5%) a jelentősen sérülékeny területen lakik.
Kulcsszavak: klímaváltozás, sérülékenység, épületek, szélteher

Köszöntő Dr. Balázs György 85. születésnapja tiszteletére

Dr. Balázs György professor emeritus, Széchenyi-díjas nemrégiben ünnepelte 85. születésnapját. A tiszteletére rendezett ünnepségen a Szilikátipari Tudományos Egyesület részéről Asztalos István főtitkár köszöntötte a Professzor Urat.

Miközben készültem a mai napra, azon törtem a fejemet, mivel is tudnám köszöntőmet ez alkalomhoz illővé tenni? Elővettem legfontosabb művedet, a Beton és Vasbeton hat kötetét (amely nekem megvan, mert a hetediket még sajnos nem szereztem be) és megnéztem kiknek is ajánlottad ezeket a műveket? Átnézve az ajánlásokat úgy találtam, hogy ezekben benne van mindaz, amit ma itt érdemes elmondani, ezért engedtessék meg nekem, hogy ezeket idézzem.

Az I. kötetet, amely az Alapismeretek története alcímet viseli kedves feleségednek ajánlottad, aki megértéssel fogadta, hogy rajta kívül még egy szerelmed volt: a tudomány és az oktatás.

A II. kötetet, amelynek a Mélyépítési Beton- és Vasbeton Szerkezetek Története az alcíme, kedves szüleidnek, Gimes Lajos tanítódnak, és Rábaszentandrás szülőfaludnak ajánlottad, mert ott tanították meg Neked a fizikai munka szeretetét, a tanulni vágyást, az emberek tiszteletét, a töretlen optimizmust és a becsületességre törekvést.

A III. kötetet, amely a magasépítési beton- és vasbetonszerkezetek történetéről szól, a Pápai Református Kollégiumnak ajánlottad, ahol az alapismereteken kívül a hazaszeretetet, a közösség szolgálatának örömét, az eszmék szabad áramlásának tiszteletben tartását, a küzdeni tudást az igazságért, egymás meggyőzését vitában, valamint a hagyományok tiszteletben tartását és ápolását tanították meg Neked.

A IV. kötetet, amely az oktatás történetét foglalja össze, Dr. Mihailich Győző Kossuth-díjas egyetemi tanárnak ajánlottad, aki első tanszékvezetőd is volt és aki megtanította Neked a munkatársak iránti megértést, amely egyben határozott vezetéssel is párosul.

Az V. kötetet, amely a kutatás történetének első részét, a tudományos diákkörök, valamint a beton és vasbeton kutatását tartalmazza egy idézettel ajánlottad az olvasók figyelmébe, amely Schimanek Emil rektor 1923. évi tanévnyitó beszédéből való: „Mert bármennyire értékesek magasabb ideális szempontból azok a tudományos elméletek, amelyek a természet törvényeinek megismerésére irányulnak, kétségtelen, hogy az emberiség haladása, kultúrfejlődése a törvények gyakorlati értékesítésén, a technikai tudományok haladásán épül fel.”

És végül, de nem utolsó sorban a VI. kötetet, amely a kutatás történetének második része, és amely a kutatás támogatását, a tudományos ismeretterjesztést és tudományos képzést ismerteti, továbbá rövid életrajzokat közöl azokról, akik a betonért, vasbetonért sokat tettek egy Pascal idézettel ajánlottad: „A jövő talpköve a múlt. Az előre látó ember néz legtöbbet hátra.”

Kedves Professzor Úr!

Születésnapod alkalmából szeretném tolmácsolni a Szilikátipari Tudományos Egyesület jókívánságait, további jó erőt, munkabírást és egészséget kívánva! Isten éltessen még sokáig!

Asztalos István
főtitkár