MŰEGYETEM 1782

**Sára Hrabovszky-Horváth**

# The climate strategy aspects of the energy efficient refurbishment of precast concrete buildings

Summary of
PhD dissertation

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2015

## I. The choice of the subject

Climate change is one of the greatest challenges in our times and the built environment has both an active and a passive role in this. Its energy consumption – and thus the emission of greenhouse gasses – is partially responsible for climate change, while at the same time it is exposed to its effects.

Many sources in the literature emphasize the need for a comprehensive **climate strategy**, addressing both the mitigation of greenhouse gas emissions due to human activity and the adaptation to the changing meteorological and environmental conditions [Láng et al, 2007], [IPCC, 2007]. With **mitigation** in mind we have to investigate how to reduce harmful emissions by both new and existing buildings throughout their entire lifecycle – from construction to operation and to demolition. The purpose of **adaptation** is the reduction of risks due to present and future climatic effects in a cost effective way.

The current residential dwelling stock is ca. 4 383 thousand units [KSH, 2012]. To renew this, it would take approximately 150 years even if we base our estimate on the building rates before the economic crisis (ca. 30 thousand dwelling units per year). But since this rate has dropped drastically since 2008 [KSH, 2014] the **refurbishment of the existing buildings** has an ever increasing importance.

Buildings built with **precast concrete building systems** following standardized planning represent a significant portion of our building stock. In Hungary altogether 510 000 dwelling units were created with the help of prefab factories from 1965 and ca. 13.8 % of the population is now living in such buildings [Birghoffer et al, 1994], therefore I have chosen this important segment of the building stock as a basis for my investigations.

## II. The goal of the research

The overall aim of my research is to give an estimate of the emission reduction potential that is achievable by the energy efficient refurbishment of precast concrete buildings and to identify the aspects that affect their vulnerability to climate change and the possible changes thereof due to this refurbishment.

The detailed goals of my research are:

- to prepare the **typology of the residential precast concrete buildings** to serve as a basis for the mitigation and adaptation calculations;
- to calculate **the mitigation potential** of energy efficient refurbishments of the precast concrete building stock;
- to analyse **the effects of the various input parameters** related to the global warming potential;
- to identify **the factors** that in a simplified building energy based life cycle assessment can provide an **estimate** of a detailed all-encompassing calculation's results of building constructions, regarding the construction, the refurbishment, the maintenance and the demolition phase;
- to develop a simple **decision support methodology** with the help of which one can determine the relative vulnerability of the country's precast concrete building stock regarding the three most important climatic factors: wind, precipitation and temperature change;
- to determine the technically relevant factors in the **climate vulnerability analysis** of existing unmodernised precast concrete buildings;

- to study the effects an **energy efficient refurbishment** has on the climatic vulnerability of precast concrete buildings.

## III. Methods of analysis and basic boundary conditions

To construct a typology suited for both the mitigation and adaptation calculations I had to rely on an abundance of sources: the available national statistics, the literature and my own Geographical Information Studies (GIS) of the micro districts or housing estates of Budapest. The final typology of the residential precast concrete buildings was created based on an **iterative technique**.

While studying the possibilities for mitigation I conducted **life cycle calculations** to model the different scenarios for the refurbishment of the various precast concrete building types and to determine what environmental impact reductions they could provide for the remaining building lifespan.

The basic assumptions of the life cycle calculations were:

- The base unit of my calculations, the so-called **functional equivalent,** is 1 m$^2$ of living space in a dwelling unit of a precast concrete building in Budapest, calculated for 5, 45 and 75 years.
- For my calculations I have **divided** the lifespan of the buildings **into 5 life cycle stages**: construction, maintenance, building energy refurbishment, operation, end of life (demolition).
- According to the relevant literature sources the expected **lifespan** for the reinforced concrete buildings is 80 years [Birghoffer et al, 1994], [Gilyén, 1982].
- Because the lifespan of this type of building is strongly influenced by the possible corrosion of the steel connectors in the panel joints [ÉMI, 2007], [Gilyén, 1982], [Hradil el al, 2014], and because some sources state that reinforced concrete surfaces protected from weathering can last 40-50 years longer [Bundesinstitut, 2009], an energy conscious refurbishment – mostly due to the external thermal insulation – can **increase the lifespan of the buildings by at least 25%.**
- Most of the investigated buildings operate with district-heating [Birghoffer et al, 1994], therefore I have collected the typical **energy-mix of** the Hungarian **district-heating systems**. As a baseline for the calculation of the Budapest based housing estates I have chosen the most common natural gas based combined cycle cogenerating power plant and its exergy based allocation.
- Based on the available plans I have determined the potential **solar collector** areas for the different building types and orientations and have made simple calculations of the usaful solar heat [Naplopó, 2008].
- The calculation of the **operational energy usage** was based on the current regulations methodology [TNM, 2006] augmented with the standard EN ISO 13790:2008 for the calculation of energy use for space heating [EN ISO, 2008]. As a baseline I have only considered the building dependent parameters of energy usage while the effects of the occupant behaviour (e.g. the different energy usage of household equipment) were neglected.
- The actual calculation were done with an Excel spreadsheet program I have developed using the Swiss Ecoinvent 2.0 **database** [ecoinvent, 2007].
- To evaluate the results I used the indicators significant for buildings: the non-renewable cumulative energy demand, the climate change potential, the ozone depletion potential, the acidification and the eutrophication.

**Scenarios:** the possible ways to refurbish existing (ca. 40 years old) precast concrete buildings were divided into three major categories:

- **No refurbishment (NR):** The building remains in its current state without any energy-conscious alterations with only the absolutely necessary maintenance and repair works being performed. At the end of the expected remaining 40 year lifespan the building is demolished, followed by the construction of a new energy-efficient replacement building.
- **Refurbishment (R):** A comprehensive energy-efficient refurbishment is performed, thus the operational energy need is reduced and the expected lifespan is increased (with approximately 20 years). Therefore the demolition and the construction of a new building are both postponed. The energy performance of buildings due to the renovation was calculated with four different sub-scenarios:
  - R1: a refurbishment complying with the current building energy regulation [TNM, 2006];
  - R2: a refurbishment complying with the stricter rules applicable for subsidised projects [TNM, 2006];
  - R3: the R2 scenario with an additional refurbishment of the heating system and the addition of solar collectors;
  - R4: a thorough refurbishment complying with the future near-zero energy requirements, basically R3 with the addition of heat recovery ventilation [Csoknyai et al, 2013].
- **Demolition and construction of a new building (NB):** The building is demolished right away and is replaced by a new but same sized and shaped one with a lower energy consumption, which is constructed from materials and constructions most common in contemporary residential buildings and equipped with a natural-gas based heating system. The energy performance of the new building was calculated with two different sub-scenarios:
  - NB1: a building complying with the stricter rules applicable for subsidized projects after 2015 [TNM, 2006];
  - NB2: a building complying with the future near-zero energy requirements [Csoknyai et al, 2013].

After analysing the individual building types I have totalized the results and **have determined the total mitigation potential achievable with the refurbishment of the Kelenföld housing estate** (Kelenföldi lakótelep). According to my one-site surveys I have determined that roughly 30% of the building stock (based on floor area) already belongs to the R1 category (refurbished according to the current regulations) and therefore was not considered for further energy-efficient refurbishments in the calculations.

I have compared the results of simplified building energy based life cycle assessments' with the results of holistic (encompassing all known and relevant parameters) calculations. I have introduced the concept of a **holistic factor** and determined its value for the investigated building types to make it possible to estimate the result of a holistic calculation based only on a much simpler energy based calculation. With the help of this factor it should be possible to conduct a preliminary environmental study during the design process as soon as the parameters necessary for a building energy calculation become available (before the more detailed parameters necessary for a holistic calculation are known). During the calculations I investigated the same scenarios as described earlier and I have performed the following steps:

1.) step: building energy based life cycle assessment: calculations based solely on the constructions forming the external heated envelope of the building with the surface areas calculated according to their internal dimensions; the calculation of the heat transfer coefficients was based only on the existing structure and on the new layers with a significant thermal resistance (i.e. thermal insulations).
2.) step: the 1.) step but calculated with all the layers (including all of the complementing layers, fixtures, etc.).
3.) step: calculation with a holistic model of the construction layers: the structures surface areas calculated according to their external dimensions.
4.) step: the 3.) step with further holistic additions: thermal insulation of projections to reduce thermal bridging (e.g. at balconies and parapet walls), complying with fire safety regulations.
5.) step: the 4.) step with the addition of internal constructions: the holistic assessment includes the calculation of the internal constructions (e.g. slabs, partition walls, doors) and the constructions outside the heated envelope (e.g. cellars, unheated ground floors) as well.

I have performed a **sensitivity analysis** to evaluate the following parameters' effect on the results:

- The increase of the remaining building lifespan;
- The frequency of the maintenance works;
- The composition of the district heating energy-mix.

While studying the adaptation ability I have investigated the vulnerability of the building stock to the effects of the changing climatic conditions, primarily by analysing **extreme meteorological events** (windstorms, heavy rainfall events and heat waves). Vulnerability, according to the definition of the IPCC, is the degree to which a system is sensitive to the adverse impacts of climate change (sensitivity), and its ability to endure these impacts (adaptation capacity). Furthermore vulnerability is also dependant on the form climate change takes, its degree, speed and the building's exposure to the external effects climate change is amplifying (exposure) [IPCC, 2007].

In my **vulnerability study** I have used the methodology described in "Climate Impact and Vulnerability Assessment Scheme" [Pálvölgyi-Hunyadi, 2008]. Based on this I have developed a qualitative **decision support methodology** with the help of which one can determine the relative vulnerability of precast concrete buildings from a housing estate, or even from the entire country, regarding the three most important climatic factors: wind, precipitation and temperature change.

The proposed **bottom-up approach**'s basic element is the building itself. The indicators for the meteorological exposure, sensitivity and adaptation capacity of the precast concrete building types in their original state were determined based on the international literature and the database of an insurance company I gained access to. Additionally, I investigated how these parameters (and therefore the vulnerability) change **as an effect of an energy-efficient refurbishment**. This study was conducted for the **larger housing estates of Budapest**.

Because we only have predictions regarding the expected future intensity of extreme weather events, and these are widely debated, I could not perform concrete sizing calculations for individual building constructions. Therefore I resolved to investigate the vulnerability against the current climate and to **approximate the future vulnerability by extrapolating** according to the modelled tendencies.

**The steps of the vulnerability calculation:**

- During a **sensitivity calculation** the first step is to study the standards and regulations about the sizing against a specific meteorological load in question, and then to analyse the national and international literature and available databases. Based on this work the building types are categorized into classes from 1 to 5, and then the sensitivity of the entire housing estate is estimated by summarizing the results.
- The indicators for the **exposure** are determined with the help of current meteorological data and relevant estimates about the future. Based on the available data the housing estates of Budapest were classified into exposure classes of 1 to 5.
- The **adaptive capacity** is the systems reaction to future circumstances. Based on the literature I have taken the following parameters into consideration: socio-economic situation of the owners and their age. Based on this the housing estates of Budapest were classified into adaptive capacity classes of 1 to 5.
- The **vulnerability** was finally calculated based on the sensitivity, exposure and adaptive capacity classes as a result of which the housing estates of Budapest were classified into vulnerability classes of 1 to 5.

It is important to stress that the individual parameters were calculated separately for the three main climatic components (wind, precipitation and temperature). The classification (for each climatic component separately) was done proportionally to the individual parameters value, therefore they are only applicable to the comparison of precast concrete building or whole housing estates.

## IV. The scientific results of the dissertation

***0. principal result:***

***Based on current building rates of residential buildings it would take approximately 150 to 200 years to renew the existing dwelling stock, therefore in addition to the construction of new buildings we must put special emphasis on the refurbishment of existing ones. Steps should be taken by considering both main aspects of climate strategy: mitigation and adaptation.***

***1. principal result:*** *[Hrabovszky-Horváth, Szalay, 2014]*

*By studying the residential building stock I have determined that considering mitigation and adaptation the following factors have to be taken into consideration when typifying the precast concrete buildings: layout, number of levels, time of construction, type of panel joints, type of windows, roof shape and construction and finally the heating system.*

***Based on national statistics, a literature review, the available type plans and the Geographical Information Systems (GIS) study of larger (more than 800 dwelling units) housing estates of Budapest I created a typology of residential precast concrete buildings with the help of an iterative technique. With the help of this technique I have differentiated 14 different types.***

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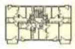
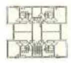
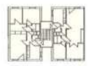
|---|---|---|---|---|---|---|---|
| Picture |  |  |  |  |  |  |  |
| Floorplan |  |  |  |  |  |  |  |
| **Code of building** | **3FOG - hőhidas** | **3FOG** | **KY** | **6FOG** | **TB 51** | **GYŐR 6/73** | **H0** |
| Housing factory | BHK. 1. | BHK. 1. | BHK.2. | BHK. 1. | Békéscsaba HGY | Győr HGY | BHK.3 |
| Year of construction | 1960 - 1967 | 1967 - 1974 | 1967 - 1974 | 1967 - 1974 | 1974 - 1982 | 1974 - 1982 | 1974 - 1982 |
| Number of heated storeys | 10 | 10 | 11 | 10 | 5 | 5 | 5 |
| Height of building (m) | 29,50 | 28,90 | 33,30 | 29,75 | 16,40 | 17,30 | 15,00 |
| **Floor area ($m^2$)** | **13 812,7** | **12 787,2** | **11 642,4** | **19 292,0** | **4 528,9** | **4 211,3** | **2 660,2** |
| Number of sections | 3 | 3 | 4 | 5 | 2 | 3 | 3 |
| Number of flats | 180 | 180 | 176 | 300 | 30 | 63 | 30 |
| Wall panels: level of thermal bridging | extreme high | high | high | high | high | high | high |
| Windows | wooden | wooden | wooden | wooden | wooden | wooden | wooden |
| Shape of roof | flat roof, ventilated | flat roof, ventilated | flat roof, ventilated | flat roof, ventilated | flat roof | flat roof, ventilated | flat roof |
| Heating system | double pipe system | double pipe system | double pipe system | double pipe system | single pipe sys., flow-through | single pipe sys., cross conn. | single pipe sys., flow-through |

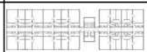
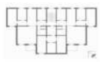
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Picture |  |  |  |  |  |  |  |
| Floorplan |  |  |  |  |  |  |  |
| **Code of building** | **K-I** | **A10** | **KB-512** | **KF10** | **P100** | **4M** | **1301** |
| Housing factory | BHK. 2 | BHK. 1. | Békéscsaba HGY | BHK 2. | BHK. 3. | BHK. 3. | BHK.3. |
| Year of construction | 1974 - 1982 | 1974 - 1982 | 1974 - 1982 | 1974 - 1982 | 1974 - 1982 | 1982 - 1992 | 1982 - 1992 |
| Number of heated storeys | 11 | 10 | 10 | 11 | 15 | 5 | 10 |
| Height of building (m) | 33,00 | 33,48 | 32,40 | 32,80 | 47,10 | 15,00 | 26,00 |
| **Floor area ($m^2$)** | **7 691,2** | **6 770,8** | **5 040,6** | **4 083,6** | **9 753,1** | **1 134,2** | **8 974,9** |
| Number of sections | 1 | 1 | 2 | 1 | 1 | 1 | 2 |
| Number of flats | 132 | 100 | 80 | 66 | 165 | 15 | 120 |
| Wall panels: thermal bridge in the panels | high | high | high | high | high | moderate | moderate |
| Windows | wooden | wooden | wooden | wooden | wooden | modernized wooden | modernized wooden |
| Shape of roof | flat roof | flat roof, ventilated | flat roof | flat roof | flat roof | pitched roof | pitched roof |
| Heating system | double pipe system | single pipe sys., flow-through | single pipe sys., flow-through | single pipe sys., flow-through | single pipe sys., flow-through | single pipe sys., cross conn. | single pipe sys., cross conn. |

Figure 1: Typology of the residential precast concrete building stock

***2. principal result:*** *[Hrabovszky-Horváth, Szalay, 2014] [Hrabovszky-Horváth et al, 2013a] [Hrabovszky-Horváth, Szalay, 2012] [Horváth, 2012]*

***By performing life cycle assessment calculations on the residential precast concrete building types I have proven, that for the investigated 75 year period a comprehensive refurbishment results in less harmful emission than the buildings demolition and replacement. The investigated impact categories were: the climate change potential, the acidification, the ozone depletion potential and eutrophication.***

*I have concluded, that for all the investigated building types the comprehensive refurbishment, or "R4" scenario, results in the largest reduction in environmental loads for the next 75 years in all the investigated categories. With the "comprehensive refurbishment" by 2060 we can reach a 63-71 % decrease regarding climate change potential and by 2090 a 30-37% reduction in $CO_2$eq emissions compared to the "no refurbishment" scenario.*

*I have reached similar conclusion with the other indicators as well: by 2060 we can achieve a 50-57% $SO_2$eq reduction regarding acidification, a 38-60% reduction in CFC-11eq emissions regarding ozone depletion potential and a 52-57% $PO_4$eq emission reduction in eutrophication.*

The results for the different refurbishment scenarios for the most-significant building type are presented in figure 2:

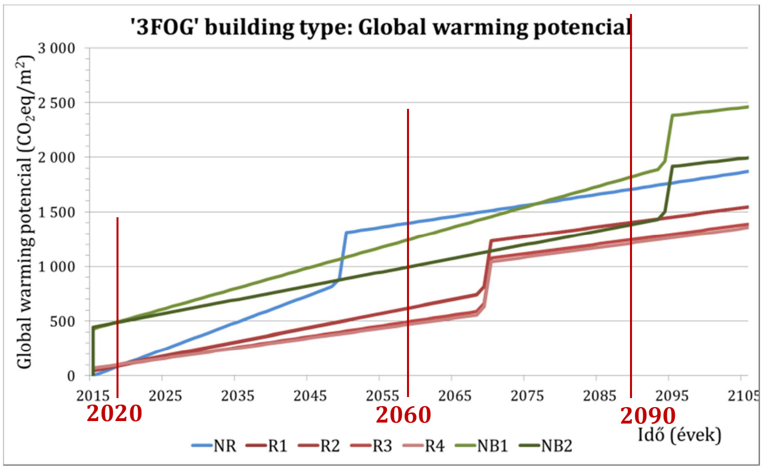



Figure 2: the 3FOG building type, climate change potential and the evaluation dates (2020, 2060 and 2090)

***<u>3. principal result:</u>*** *[Hrabovszky-Horváth, Szalay, 2014]*

***Summarizing the results of the individual building types I have demonstrated that by a comprehensive refurbishment of the Kelenföld housing estate's buildings (only those currently still in their original state) we can achieve a reduction of climate change potential of 8% by 2020, 57% by 2060 and 25% by 2090 compared to a no refurbishment scenario.***

*According to an one-site survey I have determined that roughly 30% of the building stock (based on floor area) was already refurbished to a level complying with current building energy regulations (scenario R1) and therefore was not considered for further refurbishments in the calculations.*

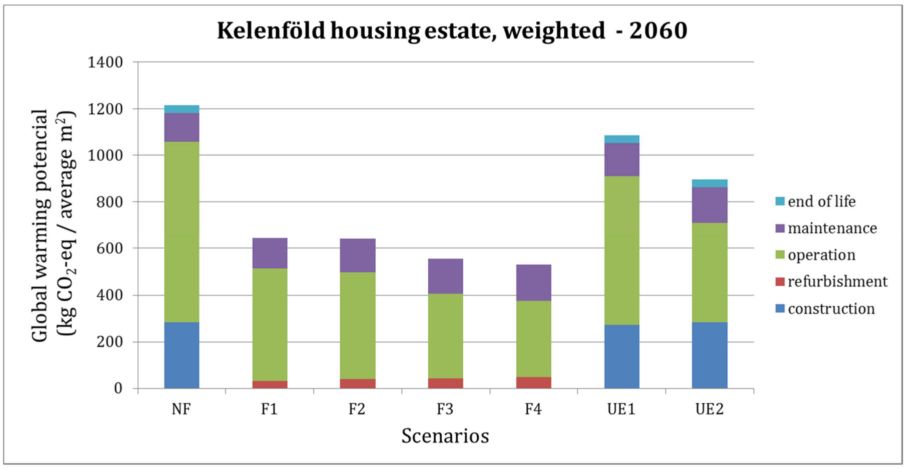



Figure 3: A comparison of the Kelenföld housing estate's climate change potential according to the different refurbishment scenarios by 2060, projected on 1 m² of general floor area

***<u>4. principal result:</u>*** *[Hrabovszky-Horváth et al, 2013a]*

***I have developed a simplified calculation method with the help of which one can estimate the total holistic life cycle assessment results of precast concrete buildings refurbishments by performing only a simple life cycle calculation. I have introduced the concept of a holistic factor that represents the ratio of results from a simple building energy based life cycle calculation and a holistic calculation.***

*The depth of a life cycle calculation depends on the goal and scope of the investigation. I determined the value of the holistic factor (for each building type) for two fundamental tasks: firstly to determine the building energy quality of the proposed refurbishment, and secondly to aid the decision between a refurbishment and a demolition.*

***Regarding the climate change effects I have determined, that when with an existing precast concrete building our goal is***

***4.a. the evaluation of a proposed refurbishment regarding its building energy quality:***

***then in case of a refurbishment complying with the current building energy regulations (R1) we can use a holistic factor of 1.67 and in case of a comprehensive building energy refurbishment (R4) a factor of 1.54 to estimate the holistic result from a simplified building energy based life cycle analysis.***

***4.b. to decide between a possible refurbishment or demolition and replacement:***

***it is necessary to take the internal construction into consideration as well, therefore in case of a refurbishment complying with the current building energy regulations (R1) we can use a holistic factor of 3.34 and in case of a comprehensive building energy refurbishment (R4) a factor of 2.70 to estimate the holistic result from a simplified building energy based life cycle analysis.***

***The holistic factor is the unweighted average of the results obtained for the different building types in the typology. The spread of the obtained results is caused by the different surface-to-volume ratios, the different year of their construction resulting difference in their remaining lifespans.***

Figure 4. below shows the differences between the different calculation steps (calculation depths) for scenario R4, grouped by the year of the individual building's construction (1965, 1970, 1975, 1980 and 1985) and further grouped by the individual building's surface-to-volume ratio.

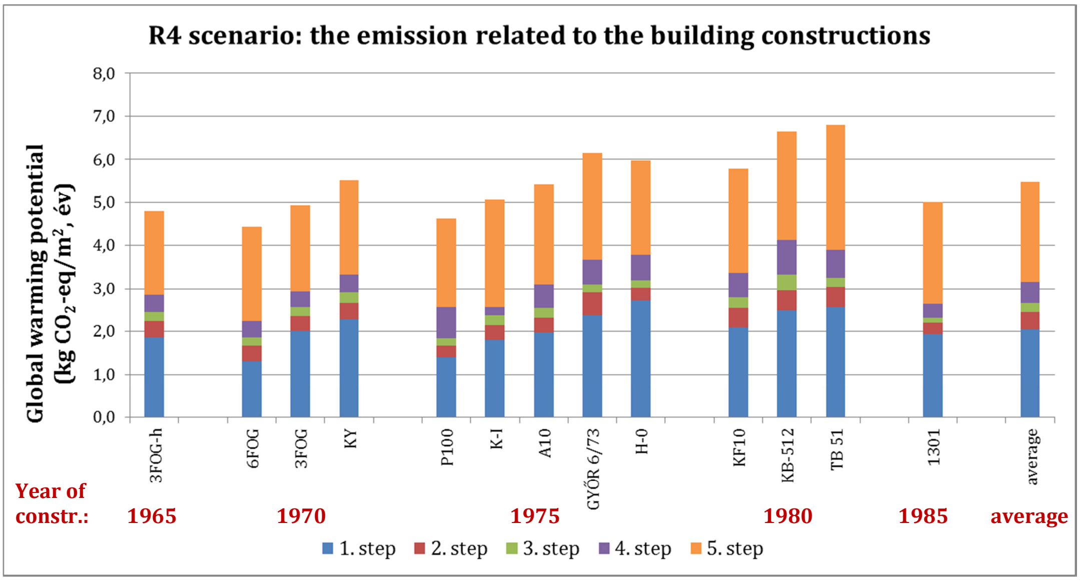



Figure 4: The emissions pertaining to the building constructions in the case of scenario R4: grouped by the year of construction and further grouped by the surface-to-volume ratio

***<u>5. principal result:</u>*** *[Hrabovszky-Horváth et al, 2013a]*
*I performed a sensitivity analysis to the most typical building type in order to investigate the effect of the following parameters concerning the global warming potential:*

***5.a. The increase of building lifespan after refurbishment***

*In the base scenario the total lifespan of the buildings was assumed to be 80 years, but as a result of the refurbishment this was increased by 25% (20 years) in the other scenarios. I have investigated the effect this lifespan increase has on the results by adding two additional data points: 10 and 30 years. In the new building scenario I did not assume any further refurbishments regarding building energy consumption.*

***With the help of the sensitivity analysis I showed, that the scale of the lifespan increase – in the investigated 75 year span – has no significant effect on the results. The comprehensive refurbishment scenario always produces lower environmental impacts than a demolition and the construction of a replacement building in case of global warming potential.***

I investigated the scenario previously found to be the most favourable: the comprehensive refurbishment (R4) by comparing it to the new building 2 (NB 2) scenario. The results are shown on figure 5. below.

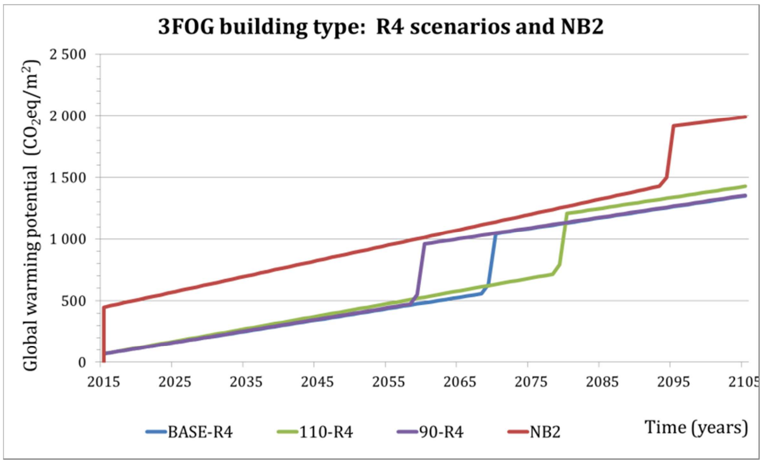



Figure 5: the 3FOG building type's climate change potential due to R4 and NB2 scenarios

***5.b. Frequency of maintenance works***

***By analysing all the constructions of all the building types I have showed, that if we assume a 20% decrease in the constructions' expected lifespan and thereby an increase in the frequency of the maintenance works this would result in an increase in the maintenance related climate change inducing emissions of 13-21% by 2060 and 8-11% by 2090 in case of global warming potential caused by maintenance. If we decrease the frequency of maintenance works we can only achieve a 1-2 % reduction in the same emissions by 2060 and 2-3% by 2090 compared to the base scenario.***

***5.c. The district-heating energy-mix***

*As a baseline I performed the calculation with a natural-gas based cogeneration district-heating system and for the sensitivity analysis I investigated three further domestic energy-mixes: natural gas based heat-only boiler stations, cogeneration district-heating systems based on a combination of natural gas and biomass and finally cogeneration based on natural* *gas and biogas. In case of cogeneration plants I used exergy allocation to determine the heating energy.*

***I have shown, that if in addition to performing comprehensive refurbishments on our existing stock of precast concrete buildings we also change our current district-heating systems from a solely natural-gas base to one based on cogeneration and the utilization of gas and biomass in combination, by 2060 we can achieve a further 5% reduction in the $CO_2$ eq. emissions, or 36% with a solely biogas based system. In the absence of necessary data this calculation does not include the emissions of building the necessary infrastructure.***

*Despite the favourable results due to the limitations of the domestic biomass potential it is not recommended to use a biomass based district-heating system in large cities such as Budapest.*

*In Budapest heat-only boiler stations are quite widespread, but the environmental impact of such a system is 115% higher than that of a comparable cogeneration based one, therefore it is highly recommended to transfer to cogeneration wherever possible.*

***6. principal result**: [Hrabovszky-Horváth, 2014] [Hrabovszky-Horváth et al, 2013b] [Horváth, Pálvölgyi, 2012] [Horváth, 2012]*
*According to the relevant literature a buildings vulnerability to climate change can be assessed based on its meteorological exposure, its sensitivity and its adaptation capacity.*

***I have developed a decision support methodology, with the help of which one can estimate the relative vulnerability of precast concrete buildings and entire housing estates to the three most important climatic factors: wind, precipitation and temperature change. Based on the buildings sensitivity, its location dependant exposure and its inhabitants adaptation capacity I have ranked the main precast concrete building types of Budapest into classes from 1 to 5 and used this data to determine their overall vulnerability.***

*The developed methodology and the utilised sensitivity parameters could be expanded to other types of buildings and other housing estates as well.*

***By analysing the literature and the relevant design standards I have concluded, that the following technical parameters have to be determined in order to analyse a precast concrete building's sensitivity to:***

***6.a. Windstorms***

> ***The building's sensitivity is mainly determined by its height. Another characteristic parameter is the roofing material which is strongly connected to the roof's shape.***

***6.b. Heavy precipitation***

> ***The type of the façade panel joints (which typically is in strong correlation with the year of construction) and the height of the building are the two main parameters here. I took these into consideration with a greater emphasis, but the roof's shape is another factor influencing the amount of water impacting the facades which is worth mentioning.***

***6.c. Temperature increase***

> ***The most important parameter influencing the sensitivity of precast concrete buildings in their original state is the possibility for cross ventilation, most notably the position of windows on the facades. Other, altough slightly less important***

***parameters are the shape and construction type of the roof, as well as the immediate environment of the building.***

According to my calculations based on the technique described above:

- with regards to **windstorms** two housing estates in Budapest show significant sensitivity: the Óbudai and the Békásmegyeri housing estates.
- with regards to **heavy precipitation** one location, the Újpalotai housing estate, has an extremely high sensitivity, while Kispest, Kőbánya újhegy and Óbuda are also high sensitive.
- with regards to the **increased number of heat waves** the most sensitive housing estates in Budapest are Újpalota and Óbuda (see figure 6.).

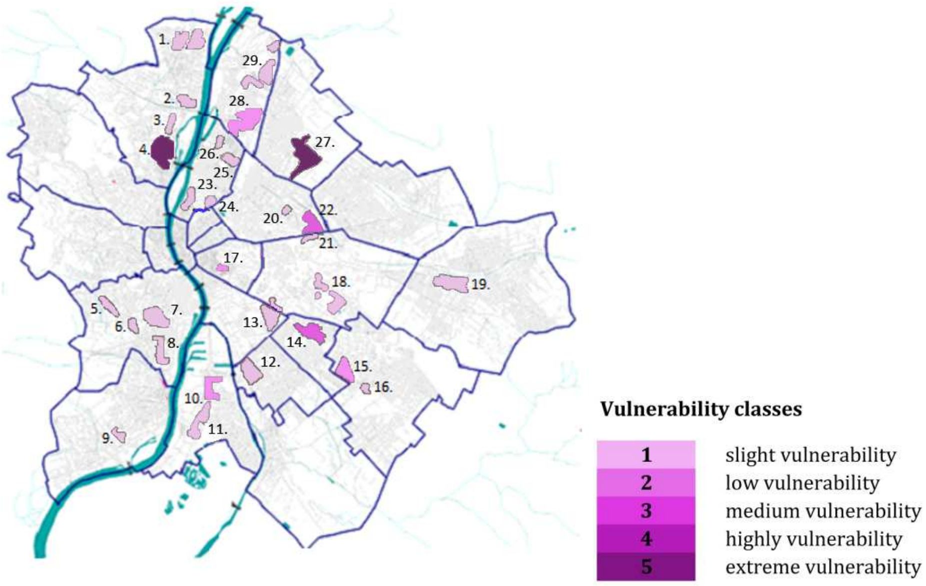



Figure 6: The temperature increase caused vulnerability of the major housing estates of Budapest

***<u>7. principal result:</u>*** *[Hrabovszky-Horváth, 2014] [Hrabovszky-Horváth et al, 2013b]*
***I investigated how the sensitivity of precast concrete buildings change as a result of major building energy centered refurbishments:***

***7.a. Against windstorms***

***External thermal insulation of facades, external shading devices as well as solar collectors and solar panels increase the building's sensitivity against windstorms.***

***7.b. Against heavy precipitation***

***The sensitivity of precast concrete buildings against heavy precipitation is decreased as a result of building energy refurbishments.***

***7.c. Against temperature increases***

***The sensitivity of housing estates against temperature increases is heavily affected by the 'complexity' of the refurbishment. If the windows are replaced and an external shading is installed the sensitivity is decreased. However, if only thermal insulation is added the sensitivity is increased, provided that the occupants' behaviour remains unchanged.***

## V. The possible application of the results and further work

The results of my research and my calculations can form as a scientific basis for national or regional **climate strategy decisions** related to both mitigation and adaptation. It is suggested to take into consideration a strategy that increases the adaptive capacity besides the mitigation of greenhouse gases during the design of the refurbishment of existing buildings.

The **typology of residential precast concrete buildings** I have presented can serve as a basis for calculations unrelated to this work, e.g. to support decision making regarding the future strategy of district-heating systems.

My results about energy saving and the **reduction of greenhouse-gas emissions** can serve as a basis for future subsidy tenders.

The **holistic factor** I have introduced can promote the spread of life cycle assessments among architects. With the help of this factor it should be possible to conduct a preliminary environmental study during the design process as soon as the parameters necessary for a building energy calculation become available (before the more detailed parameters necessary for a holistic calculation are known).

The **vulnerability analysis methodology** I have developed could also be expanded easily to other building types and could serve insurance companies in the assessment of risk-categories.

### Further research work

Regarding the mitigation potential of building refurbishments it would be desirable to develop a method that takes the **future effects of climate change** into account **during life cycle assessment.** Particularly focus on the temperature increase since that could potentially impact the energy consumption a great deal therefore their greenhouse gas emissions.

A further line of future research concerning the mitigation potential would be **the expansion of the holistic factor** to other building types.

Regarding adaptation it would be worthwhile to **analyse the precipitation, wind speed and temperature measurements of the last decades** in cooperation with the National Weather Service (OMSZ). This would enable a detailed study of the most important sizing standards, their core coefficients and perhaps lead to their revision or the unification of different calculation methods.

I also propose to further investigate the extreme case, when **more than one climatic effect** acts simultaneously on a building – most importantly precipitation and wind – amplifying each-others effects and resulting in a further increase of the building's sensitivity.

The developed a simple **decision support methodology for vulnerability assessments** for precast concrete buildings could also be **expanded to other building types**.

## VI. Acknowledgements

I would like to say thanks to all those who have supported me during my research. First to my supervisor Dr Zsuzsanna Szalay for her patience and guidance, to my consultants Dr Bálint Petró and Dr Tamás Pálvölgyi for their useful advice, to the head of the Department of Building Constructions Dr Gábor Becker for the possibility and to all those who have participated in the PhD seminars and provided me with their critical observations and advice, mostly to Dr Gergely Dobszay, Géza Kapovits, Dániel Bakonyi, Zoltán Páricsy and Dr Lajos Takács.

I thank Dr András Zöld, Dr Tamás Csoknyai and Miklós Horváth for their professional help.

I would also like to thank Balázs Némethi (FŐTÁV Zrt.), Csaba Demeter (Miskolci Hőszolgáltató Kft), Miklós Gyenesi (Pannon Hőerőmű Zrt) and the ALLIANZ Hungária Zrt as well as the CARPATCLIM project for the data and help I have received.

I also owe thanks to the HORBER Mérnökiroda Kft's associates for their help.

Last but not least I thank my family for their support and infinite patience.

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