Energy Saving and Climate Adaptation of Buildings: A Paradox?

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Abstract. The European climate policy goals include (a) reducing energy consumption and avoiding the emission of climate-affecting gases as well as (b) adapting to existing and expected climate change. The synergetic implementation of both goals forms a central challenge particularly for the building stock. There is evidence that damage to buildings due to extreme weather events (e.g. heavy rain, fluvial flooding, hail, summer heat) steadily increase. Therefore, several national strategies and action plans in European member states formulate requirements for climate-adapted modernisation and retrofitting of existing residential buildings. The paper explores the conflicts between the two named goals at the building level, since building energy saving measures are unfortunately not in any case consistent with the goal of increased climate adaptation, as they undesirably increase the vulnerability of buildings. For this purpose, the paper first deals with the structural design of selected building types, which have been refurbished in order to optimize their energy efficiency. Second, it analyses and evaluates the physical vulnerability of existing buildings against extreme weather events. Then, the paper proposes some practical options on how to achieve the two goals effectively. Finally, some implications for future research and practice are discussed.

1. Introduction

On the one hand: Whilst natural fluctuations in climatic systems are expected, there is scientific consensus that human activities, and in particular the burning of fossil fuels, agricultural practices and land use change, are influencing the Earth’s climate. Over the last 100 years the Earth has warmed at a faster rate than at any other time over the last 1,000 years with an average rise in global surface temperatures. It is predicted that this rate of warming will accelerate over the early part of the twenty-first century. A special report from the Intergovernmental Panel on Climate Change (IPPC) indicates that warming reached approximately 1 K (±0.2 K likely range) above pre-industrial levels in 2017 [1]. Over the next decades an average temperature rise of 0.2 K (±0.1 K) per decade is expected with continental land masses warming more quickly than the sea [1]. Changes beyond this depend mainly on actions to reduce carbon emissions in the interim.

Given this uncertainty, scenarios have been developed by the IPCC to help understand how the global average temperature may change based on our actions to reduce climate change. But under each scenario, and in every part of the world, the temperature is set to rise, and climate patterns will change. Therefore, a major objective in European policymaking is to strengthen the efforts to limit climate change.
Indeed, the United Nations Office for Disaster Risk Reduction (UNISDR) estimates that around 87 percent of disasters are now climate related – up from around 50 percent two decades ago [2]. Whilst it is difficult to ascribe any particular weather event or disaster as being due to climate change. It has been recently estimated as ‘very likely’ that global anthropogenic greenhouse gas (GHG) emissions increased substantially the probability of hazardous natural events, like heavy rain, flooding, hail and summer heat. Therefore, European climate policy fosters climate change mitigation measures.

On the other hand: Whilst the impacts of climate change will vary, it is likely that there will be net annual costs that will increase over time for the repair of damage caused by natural hazards. Damage reports (e.g. [3]) show that with over 700 climate related loss events, 2017 ranks among the top five years in terms of number of events. The reports provide again a convincing argument for the need to build more resilient buildings that are better adapted to uncertain climatic extremes and their related risks. This means that building planners need to ensure that buildings respond appropriate to the changing climate in order to minimize negative impacts (damage) and financial implications.

The reinsurance group Munich Re offers an analysis tool (NatCatSERVICE) to users as an information service on natural catastrophes. For instance, Figure 1 shows the high number of flood events in Europe between 1980 and 2017. Floods are throughout Europe the most common and most destructive natural hazards. The 5th Assessment Report from the IPCC states a high level of confidence that Northern Europe will be gradually subjected particularly to increased pluvial flood risk as precipitation patterns intensify [4]. It is evident that the likely increase of the frequency and intensity of weather events, due to climate change, as well as the rising vulnerability of assets at risk raise the environmental impacts on housing. Particularly pluvial flood events have gained high attention that are triggered by convective storm events and result in severe inundation. For these reasons, European climate policy goals include both

- reducing buildings energy consumptions and avoiding the emissions of climate-affecting gases and
- adapting buildings to existing and expected climate change.

![Figure 1: Number of flood / flash flood events in Europe between 1980 and 2017. Source: NatCatService Munich Re (includes copyrighted material of Munich Re and its licensors)](image)

The paper elucidates that for many buildings it is a major challenge to tackle both goals in a balanced way. The authors see great efforts to implement energy saving measures at the scale of individual buildings. But we also see a rising susceptibility of assets at risks. Therefore, this article faces a paradox, an apparently self-contradictory statement: how to implement measures for energy saving without
increasing the buildings vulnerability against natural hazards? The purpose of this paper is to look briefly at the hypothesis that the synergetic implementation of energy saving and climate adaptation measures establish a central challenge particularly for the building stock.

2. Retrofits of existing residential buildings

The European Commission (EC) states that buildings are responsible for approximately 40 percent of energy consumption and 36 percent of CO₂ emissions in the EU. Currently, about 35 percent of the EU’s buildings are over 50 years old and almost 75 percent of the building stock is energy inefficient, while only 0.4 to 1.2 percent (depending on the country) of the building stock is renovated each year. The given numbers confirm that the European building sector, being the largest single energy consumer in the EU, has vast potential for energy efficiency gains. Thus, this article elaborates conflicts between energy saving and climate adaptation measures of existing buildings more than on new builds. The main EU policy is the Energy Performance of Buildings Directive (EPBD) promoting the improvement of the energy performance of buildings within the EU [5].

The IPCC as well as other authors (e.g. [6]) argue that retrofits are key to an energy efficient and low-emission building stock. It is evident that older buildings adhere to outdated standards and have often higher energy intensities than new constructions. The EC assumes that more renovation of existing buildings has the potential to lead to significant energy savings – potentially reducing the EU’s total energy consumption by 5 to 6 percent and lowering CO₂ emissions by about 5 percent [7]. Measures to lower the levels of energy consumption focus on all relevant building components:

- Building constructions, e.g. thermal insulation of building envelopes, elements of the roof, windows and doors,
- Building technologies and equipment, e.g. energy efficient heating, ventilation and air conditioning (HVAC),
- Smart building management solutions that encourage more automation and control systems to make them operate more efficiently.

New developments in building codes gradually increase the requirements of the energy performance of buildings that supposed to lead to significant primary energy reductions all over Europe [6]. Reviews of several studies of individual buildings indicate that retrofits generally entail high investment costs, but they also generate large annual energy cost savings and so are often attractive from a purely economic point of view. Following these retrofit studies in [6] the achieved reductions in total energy use for detached single-family homes reach up to 75 percent. In multi-family housing (such as apartment blocks), a number of projects have achieved reductions in space heating requirements by 80 to 90 percent, approaching, in many cases, the passive house standard for new buildings.

In Germany the Energy Saving Ordinance (EnEV) sets compulsory regulations for energy-efficient building and refurbishment. The ordinance is a central instrument within German energy and climate protection policies. The EnEV came into force in 2002 and replaced the Thermal Insulation Ordinance (1995) and the Heating Systems Ordinance (1998). The purposes are, first, the transposition of the amended EPBD (2018/844) into German law and, second, the further development of the energy performance requirements in consequence of the Federal Government’s policies.

The EnEV sets energy performance requirements, quantified through the annual demand of primary energy, for both new builds and the refurbishment of existing buildings. Following the EnEV, new buildings must not exceed the annual primary energy requirement of a corresponding reference building and must be realised in such a way that the cladding and the systems engineering comply with prescribed minimum standards. Where changes are made to existing buildings the affected component must meet minimum energy requirements. The last amendment of the EnEV got into force in 2014 and again tightened the regulations for new buildings in 2016 (Table 1). In order to reach the targets of the annual primary energy requirements the ordinance defines structural and heating system standards and specifies the energy efficiency.
The EnEV established minimum standards for both the thermal insulation of building envelopes and for the energy efficiency of heating systems. For example, each renovated part of the surface has to meet the defined energy standards. Any alterations to outer shell components, which belong to heated or cooled space, have to meet the requirements concerning the resulting heat transmission coefficient for existing buildings in case of major renovations. This does not apply in cases of internal insulation or when the coverage of the measure does not exceed 10 percent of the total surface covered by this kind of shell component on the whole building.

Table 1. Amendments of Germany’s Energy Saving Ordinance (EnEV).

| EnEV | Valid          | Comments                                                                                                                                 |
|------|---------------|----------------------------------------------------------------------------------------------------------------------------------------|
| 2002 | 01.02.2002 – 30.09.2007 | First version. Each following one has been a combination of (a) fine-tuning of existing regulations and broadening their scope and (b) raising standards and introducing completely new regulations. |
| 2007 | 01.10.2007 – 30.09.2009 | EnEV 2007 simply restated many of the 2002 regulations without change, while at the same time extending energy-efficiency requirements to non-residential buildings, establishing “energy performance certificates” to rate the energy consumption of existing buildings and specifying inspection and evaluation procedures for thermal insulation, heating and air conditioning systems. |
| 2009 | 01.10.2009 – 30.04.2014 | The aim of the 2009 regulations was to reduce energy, heat and warm-water consumption in buildings by around 30 %. For example, the maximum permitted primary energy demand for new-builds and renovated existing buildings was cut by an average of 30 %, with a further 30 % cut planned for 2012. Heat insulation standards for building envelopes were raised by 15 %. |
| 2014 | Since 01.05.2014 | The EnEV 2014 sets new emissions and energy-efficiency targets, including the aim of carbon-neutral buildings by 2050. EnEV 2014 redefined the energy ratings for buildings and specified that the primary energy consumption of new-builds would have to be cut by another 25 % from 2016. The role of the energy certificates was also strengthened, so that they contain more detailed information on heating systems, energy sources, actual energy consumption and year of construction. In addition, oil and gas boilers that are more than 30 years old and provide central heating in apartment buildings need to be replaced. |

Not all new and renovated buildings have to meet the requirements set out in the Energy Saving Ordinance. Exceptions exist e.g. for listed buildings, as long as an exception has been granted by the competent national authority.

As proof of compliance with these regulations, the legislators require an Energy Performance Certificate to be issued for the refurbished building. Besides the regulations for the thermal insulation of the building envelope, including the external walls, the roof as well as the windows and doors, the EnEV also addresses the replacement of old boilers. However, it is always advisable to proof the difference between the energetic status before and after the retrofit in order to guaranty a sufficient amortization of costs.

Individual buildings as well as building energy codes should be more robustly designed to ensure that the buildings will be appropriate for future climate scenarios with temperatures and extreme weather events (and possible energy service interruptions) that in previous decades would have been unthinkable.

3. Natural hazard: pluvial flooding

The European territory is not equally threatened by natural hazards. Its natural, particular meteorological and geological diversity results in complex, characteristic hazard patterns. In many regions meteorological hazards are strongly represented. Floods are basically ubiquitous in all populated riverines areas and along the coastlines. There are several kinds of flooding, and each one bears a different impact in terms of how it occurs, the damage it causes, and how it is forecasted. River and coastal floods with
their related risks are well established topics in international flood risk management research and practice. However, pluvial flooding refers to flood events that are caused by extreme rainfall.

Pluvial floods occur on a much smaller spatial scale without any direct relation to the main river network. They depend strongly upon the micro topography and the drainage pathways. The possible role of the sewer capacity has led to the use of the term ‘sewer flood’ as a synonym. Although this would be appropriate for urban areas and drainage systems consisting only of sewers. Urban water management practice has now broadened using a combination of grey and green infrastructure for sustainable stormwater drainage [7]. The onset of this flood type can occur within a couple of minutes to a few hours of rainfall. The resulting floods are shaped by a rapid rise in water level and highly turbulent conditions at outflows or manholes. The impacts on housing include the inundation of basements and ground floors of buildings. The inundation can result in severe damage (Figure 2).

4. Physical flood vulnerability
The methodology for analysing the physical flood vulnerability of properties uses a synthetic approach for the determination of flood damage to buildings that has already been described and exemplified in [8]. Based on the specific physical flood vulnerability of building types, the costs for repairing flood impacts are calculated and visualised employing synthetic depth-damage functions (Figure 3). Depth-damage functions correlate flood repair costs to the specified inundation levels. Flood repair costs are related to the building footprint that is defined as the area underneath the horizontal projection of the roof. The authors have used either quality-assured damage appraisals or detailed cost determinations of long-term and technically correct repairs to validate the synthetic depth-damage functions that we have developed for numerous building types in study areas in Germany.

Figure 2. Selected flood damage to buildings.

Figure 3. Example of a synthetic depth-damage function for a selected building type. The abscissa presents the magnitude (water depth above ground floor in metre) and the ordinate shows the impacts (costs for flood damage repair in Euro per square metre ground floor).
5. Reference building
The vulnerability of buildings can be investigated on the basis of a spatial structural classification of the fabric of settlement. Buildings, as an element of urban structure types are classified in terms of building type: firstly by categories such as residential or non-residential, and secondly in terms of the characteristic age of the given building stock (cf. [9]). There are significant links between the date when a building is erected and its physical structure ([10]). Since the construction method and physical design, as well as building services and the use-related properties of a building provide important insight into its vulnerability to environmental causes, the structural analysis of building types is a fundamental stage in vulnerability assessment.

This paper describes a multi-family residential building, which was built in 1909 in the area of Dresden. The building has a total of 11 apartments distributed on four floors. The outer walls are made of brickwork and currently have no additional external thermal coating. The wall thickness is about 54 cm on the ground and first floors and about 41 cm on the second and third floors. The facade design of the multi-family residential building can be allocated to the period of the “Reform architecture” in Dresden. The main design elements of the façade are the jambs (sandstone) of the doors and the windows, as well as other decorative elements made of sandstone and plastering.

In 2017 the building owner decided to refurbish the façade of the building. The building is not registered in the list for protection of valuable monuments of the city of Dresden. Hence, the refurbishment has to follow the energy performance requirements of the EnEV.

The owner wanted to save the appearance of the building. Therefore, the designers generate two different refurbishment alternatives: alternative 1 is following strictly the requirements of the EnEV 2014. Alternative 2 is aligned to preserve largely the appearance of the building. Subsequent the two different alternatives are delineated:

- First, following the requirements of the EnEV 2014 a minimum insulation thickness of about 14 cm (\( \lambda = 0.035 \text{ W/(mK)} \)) would result for the applied thermal insulation composite system. This is associated with increasing costs through additional construction works, such as adjustments in the area of the window and door walls, the eaves and cornices. Moreover, the appearance of the building will be changed hardly because of the removal of all typical stylistic elements such as ornaments and sandstone details.
- Second, the aligned refurbishment persecutes a conservation and restoration of main parts of the plaster façade and installing only a reduced thickness of thermal insulation on subordinated façade. A disadvantage of this alternative 2 is the incomplete achievement of the required level according to EnEV 2014.

Table 2 compares the estimated costs for the two different refurbishment alternatives.
Table 2. Comparative cost estimation for the refurbishment alternatives.

| Costs | Alternative 1 | Alternative 2 |
|-------|---------------|---------------|
| Sum   | € 245,000     | € 142,000     |

On the basis of the constructional boundary conditions, the designers determined the specific heating demand for the existing not refurbished building: about 104 kWh/(m²a), taking into account this heating demand and the costs for the energy source (natural gas ~0.065 €/kWh) the annual heating costs are around € 7,000 in total. The reduction of heating energy for the two different refurbishment alternatives is shown in the table 3 below.

Table 3. Economic comparison of two different refurbishment alternatives.

|                       | Annual thermal heat reduction | Heating costs [€/year] | Savings [€/year] |
|-----------------------|------------------------------|------------------------|-----------------|
| Not refurbished building | -                            | 7,000                  | -               |
| Alternative 1         | 49.5 %                       | 3,530                  | 3,470           |
| Alternative 2         | 20.2 %                       | 5,590                  | 1,410           |

The comparison of the two refurbishment alternatives shows on the one hand that alternative 1 is saving additional annual € 2,060. On the other hand, there is a production cost difference between the refurbishment alternatives of about € 103,000.

The additional costs of alternative 1 “mounting an external thermal insulation composite system (ETICS)” in comparison to alternative 2 “aligned refurbishment” are balanced only after an expected useful life of about 50 years. It must be pointed out that this calculation does not take into account impacts of interest or costs for regular maintenance. It should also be noted that a period of 50 years clearly exceeds the predicted lifetime of composite thermal insulation systems (20 to 25 years).

From an economic point of view, it is not sensible to renovate the existing building by taking into account… the component-related minimum requirements in accordance with EnEV 2014 compared to the aligned refurbishment with less thermal insulation measures does not make sense.

6. Discussion and conclusion

Figure 5 provides an example of three depth-damage functions showing the accumulated damage to the reference building that would occur if flood water reaches different depths. In addition to the yellow-coloured graph for the original state (traditional plaster façade), Figure 5 presents depth-damage functions considering the refurbishment alternatives 1 and 2. Alternative 1, represented by the orange-coloured graph, indicates the flood vulnerability of the reference building complying the standards of the EnEV 2014 for the thermal insulation of the building envelope. Alternative 2, represented by the grey-coloured graph, covers an ETICS only on subordinated façades.

It is apparent that the costs of flood repair increase for both refurbishment alternatives. In case of flooding the building envelope is exposed to water at least for a short duration. Even if no water seeps through the building envelope, moisture potentially penetrates the external masonry walls respectively the ETICS. The effort for the required flood repair is higher than for both alternatives, because there is a high probability that the ETICS lose their structural integrity in case of inundation. The shifting depth-damage functions (in figure 5) indicates the expected efforts. In the presented example, the direct costs of flood repair are increased approximately by 25 percent (alternative 1) and 10 percent (alternative 2) for water depths up to 1 m.

It became evident that these energy saving measures raise the physical flood vulnerability of that building. Another example for building constructions and building materials, which represent that...
conflict, are floor constructions consisting of floating screed and thermal insulation. Large insulation thicknesses lead to critical buoyancy forces that can uplift the floor construction in case of flooding.

The enhancement of the energy performance is gaining greater importance on the individual building scale in order to reduce buildings energy consumptions and avoiding the emissions of climate-affecting gases. However, some of these measures have a negative effect on the vulnerability. They lead to an increasing potential of direct tangible damage to properties at risk.

Further research and development of practice should break the presented issue out of a narrow niche and transfer it to a mainstream issue. Ultimately, it should be noted that the presented methodology as such is not confined to pluvial flooding. The methodology can be applied to other hazardous flood events or heat waves.

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