A strategic approach for existing buildings to withstand climate change

Rasmussen, Torben Valdbjørn

Published in:
Open House International

Publication date:
2012

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

Users may download and print one copy of any publication from the public portal for the purpose of private study or research.

Users may not further distribute the material or use it for any profit-making activity or commercial gain

Users may freely distribute the URL identifying the publication in the public portal.

Take down policy
If you believe that this document breaches copyright please contact us at vbn@aub.aau.dk providing details, and we will remove access to the work immediately and investigate your claim.
INTRODUCTION

Climate change and measures to mitigate its effects are issues of high priority in industrial countries including Denmark. In spite of efforts to develop a broad strategic approach to climate change, adaptation of existing buildings does not appear to be a high priority.

In 2005, the Danish Government presented an action plan that aimed to promote significant results in the energy field. This action plan has already and will continue to have an impact on Danish energy-saving initiatives in the years to come (Ministry of Transport and Energy 2005). The action plan includes an outline of the Danish energy sector in the years leading up to 2025. One subject in the strategy is the climate policy related to the Kyoto Protocol (UN 1998), which was enforced on February 16, 2005. Industrialised countries signatory to the Protocol were obliged to limit their emissions of greenhouse gases between 2008 and 2012. As part of the internal obligations within the European Union (EU), Denmark was required to reduce its emissions by 21% compared with 1990 emissions (Olesen et al. 2004). Furthermore, the draft action plan contains energy-saving initiatives prescribing that consumer energy consumption should be reduced by an average of 1% per annum from 2006 to 2012.

The effort of elaborating a new climate policy agreement failed at the Conference of the Parties (COP) meetings number 15 (COP15), 16 (COP16) and 17 (COP17), held in Copenhagen, Mexico City and Durban, in December 2009, 2010 and 2011, respectively. It was intended to succeed the Kyoto Protocol (UN 1998) by introducing obligations to limit emissions of greenhouse gases after 2012. At COP17 it was stated that from 2012 only the member states of the European Union will succeed the Kyoto Protocol including new Kyoto-obligations to limit emissions of greenhouse gases. However, the Parties agreed on the development of a new global climate agreement that must include all countries with the largest emissions of greenhouse gases. The new global climate agreement needs to be agreed on in 2015 and come into force in 2020. At COP 15, a Green Fund was agreed and at COP17 the fund was designed, with the purpose of aiding underdeveloped countries in meeting the challenges of climate change.

Keywords: Climate Change, Impact, Effects, Strategy, Buildings.
The European Union continues agreed independently on their climate visions (CEU 2009). The ambition was global and aimed to limit global warming to a maximum of 2°C and reduce 1990 emissions of greenhouse gases by a total of 80-95% in industrial countries by 2050. As a consequence, the Danish Commission on Climate Change Policy presented their ambitions in 2010. These ambitions outline Danish energy-saving initiatives, energy supply investments, energy distribution and a slow-down of climate change in the years leading up to 2050 (Danish Commission on Climate Change Policy 2009). Three main issues related to the built environment, outlined in the plan, are:

(i) Changing the energy supply to be independent of fossil fuels by 2050. Today 80% of the energy demand in Denmark relies on fossil fuels like oil, coal and gas.

(ii) Mitigating the effects of climate change by implementing a large reduction of the emissions of greenhouse gases. Emissions from a large number of agents needs to be included i.e. fossil fuels and carbon dioxide from i.e. farming, industrial processes, solvents, methane and nitrous oxide from plastics in waste and sewage along with industrial gases as hydro fluorocarbon gases, sulphur hexafluoride gases and perfluoro-compound gases.

(iii) Adaptation of the built environment to the future climate.

In Danish society, buildings have a replacement value of approximately €1,600 to €1,850 billion. The value is determined in 2010 for the whole country based on built-up area (Statistics Denmark 2010) with a mean value of 2,400 €/m². The value of infrastructure such as roads, rails, bridges, embankments, harbours and sewers are not taken into account. The floor area of new buildings constructed each year makes up about 1% of the total floor area of buildings. It is crucial to preserve the value of the building stock, and it is therefore important to adapt the building stock to the challenges of the future climate.

As buildings play a vital economic and social role in society and are vulnerable to climate change an effort to preserve their satisfactory performance and value are needed. The paper suggests and outlines actions needed for developing a broad strategic approach for existing buildings to withstand climate change. As effects of climate change are a serious challenge for the design and upgrading of buildings, adaptation must include key requirements dictated by the effects of climate change, that for the time being are uncertain and evaluated differently in different countries.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>A2</th>
<th>B2</th>
<th>EU2C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+0.6</td>
<td>+1.4</td>
<td>+3.1</td>
</tr>
<tr>
<td>Annual average temperature [°C]</td>
<td>+0.6</td>
<td>+1.4</td>
<td>+3.1</td>
</tr>
<tr>
<td>Average winter temperature [°C]</td>
<td>+0.5</td>
<td>+1.3</td>
<td>+2.8</td>
</tr>
<tr>
<td>Average summer temperature [°C]</td>
<td>+8</td>
<td>+19</td>
<td>+43</td>
</tr>
<tr>
<td>Annual rainfall [%]</td>
<td>+3</td>
<td>+7</td>
<td>+15</td>
</tr>
<tr>
<td>Winter rainfall [%]</td>
<td>+3</td>
<td>+7</td>
<td>+15</td>
</tr>
<tr>
<td>Maximum daily rainfall [%]</td>
<td>+4</td>
<td>+10</td>
<td>+21</td>
</tr>
<tr>
<td>Sea, change in:</td>
<td>0.45-1.05</td>
<td>0.45-1.05</td>
<td>0.45-1.05</td>
</tr>
<tr>
<td>Average wind speed [%]</td>
<td>+1</td>
<td>+2</td>
<td>+4</td>
</tr>
<tr>
<td>Maximum wind speed [%]</td>
<td>+2</td>
<td>+5</td>
<td>+10</td>
</tr>
<tr>
<td>Maximum sea level [m]</td>
<td>+0.45-1.05</td>
<td>+0.45-1.05</td>
<td>+0.45-1.05</td>
</tr>
</tbody>
</table>

Note: Scenario A2 assumes a world with little global economic integration and a slow development and distribution of effective technological solutions that can reduce the emissions of greenhouse gases. Furthermore, it is assumed that population growth will continue to be high (Nakicenovic et al. 2000, Danmarks Meteorologiske Institut 2010).

Scenario B2 assumes, like scenario A2, a world with little global economic integration and a slow development and distribution of effective technological solutions that can reduce the emissions of greenhouse gases. Scenario B2 considers a situation with more reduced emissions of greenhouse gases than scenario A2 as a result of moderate population growth and more environmentally conscious consumers (Nakicenovic et al. 2000, Danmarks Meteorologiske Institut 2010).

Scenario EU2C assumes a world-wide implementation of a large reduction of the emissions of greenhouse gases. Industrial countries reduce their emissions of greenhouse gases by 80-95% by 2050 compared with 1990 emissions. Consequently global warming will be limited to a maximum of 2°C (Nakicenovic et al. 2000, Danmarks Meteorologiske Institut 2010).

Table 1: Projected climate change based on A2, B2 and EU2C scenarios.
The adaptation needed in the built environment is closely related to the projected climate impacts. Available emission scenarios A2 and B2 (Nakićenović et al. 2000, DMI 2005), as well as EU2C (Danish Government 2008) were used as a basis for the Danish strategy for adapting to a changing climate (Danish Government 2008), as they are considered the most likely in Denmark. The scenarios describe the projected climate impacts in Denmark leading up to 2100 and are shown in Tables 1 and 2.

Table 2. Extreme climate events in the present-day climate and projected changes in climate scenarios.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Scenario</th>
<th>Present</th>
<th>Projected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of days with five days/year with Tmean under (°C)</td>
<td>A2</td>
<td>44</td>
<td>33</td>
</tr>
<tr>
<td>Growth season’s length (days in a row over 5°C)</td>
<td>B2</td>
<td>39</td>
<td>22</td>
</tr>
<tr>
<td>Largest heat wave (°C)</td>
<td>EU2C</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Extreme cold snap (°C)</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Number of days with ≥10 mm rainfall/day (days/year)</td>
<td>3</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Largest volume of 5-day rainfall (mm 5 days)</td>
<td>4</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Average intensity of rainfall for days with more than 1 mm rainfall (mm/day)</td>
<td>0.3</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Extreme rainfall (mm rainfall over 25% percentile)</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Note: The mean values of the number of events measured in the period 1961-1990.

The adaptation needed in the built environment is closely related to the projected climate impacts. Available emission scenarios A2 and B2 (Nakićenović et al. 2000, DMI 2005), as well as EU2C (Danish Government 2008) were used as a basis for the Danish strategy for adapting to a changing climate (Danish Government 2008), as they are considered the most likely in Denmark. The scenarios describe the projected climate impacts in Denmark leading up to 2100 and are shown in Tables 1 and 2.

The adaptation needed in the built environment is closely related to the projected climate impacts. Available emission scenarios A2 and B2 (Nakićenović et al. 2000, DMI 2005), as well as EU2C (Danish Government 2008) were used as a basis for the Danish strategy for adapting to a changing climate (Danish Government 2008), as they are considered the most likely in Denmark. The scenarios describe the projected climate impacts in Denmark leading up to 2100 and are shown in Tables 1 and 2.

**NEEDED STRATEGIC APPROACH**

How buildings address threats or make use of opportunities presented by the projected climate impacts have enormous economic consequence. However, until the quality of input data determining reliable climate change scenarios has improved, full advantage of more advanced tools is not possible. This leaves the uncertainty of the relevant climate scenarios as being one of the key issues.

A strategy for adaptation needs to be implemented, as climate impacts will dictate future building requirements. The need for adaptation measures are closely related to the exact location of the building, building design and the local effects of climate change.

A strategic approach to climate change adaptation needs to be developed to ensure the vital economic and social role of buildings in society. The strategic approach must include the following tasks:

1. A performance model
2. An impact model
3. Vulnerability analysis
4. An adaptation strategy

The elements of a strategic approach that address the threats or make use of opportunities, presented by the projected climate impacts are given in Figure 1 and these should be included in design and continuous upgrading and maintenance of buildings. The lack of a strategic approach will result in stand-alone initiatives and ad-hoc upgrading of buildings as climate change progresses.

Figure 1. Elements in a strategic approach that include addressing effects of climate change and needs of adaptation. Absence of a strategic approach results in stand-alone initiatives and ad-hoc upgrading of buildings as climate change progresses.
The tasks 1), 2), 3) and 4) are further described in the following sections.

**A performance model**

Since buildings have a long life and since existing buildings might in future develop performance problems in meeting requirements related to climate change (Nielsen 2006, Meløysund et al. 2006), it is important to develop a performance model for the existing building stock that covers both new and old buildings. Development of a building stock typology model is necessary. The model could be developed as a basis for defining and managing risk related to the building performance.

The model could build on a typological model of the building stock based on four categories consisting of the design type (detached housing; multi-storey housing; administration, education), age and construction (external walls; roof; ground floor/foundations; internal walls/floors). Such information can be found in already published research i.e. scotch information concerning the Danish building stock is given in (Wittchen 2009). The typologies could be followed up by a set of performance criteria (Backer 2008). A criterion, e.g. structural safety could be correlated to climate parameters such as wind speed, weight of snow or soil moisture, describing necessary performance-based building requirements.

**An impact model**

There is a need to define climate impacts relevant for the building sector and based on the performance model (5.1). It will be necessary to evaluate currently known climatic parameters and define new climatic parameters such as for temperature, precipitation, wind speed, atmospheric humidity, solar radiation and soil moisture. The parameters must also include mean monthly and seasonal values as well as the frequency and extent of maximum and minimum extremes. It is important to set up a probabilistic model of the impact of climate change on the built environment.

Many of these data can be retrieved from archives containing the outputs of the regional climate model at 12-50 km resolution from the Prediction of Regional Scenarios and Uncertainties for Defining European Climate Change Risks and Effects (PRUDENCE) (DMI 2005, Christensen et al. 2007) and the Climate Change and its Impacts at Seasonal, Decadal and Centennial Timescales (ENSEMBLES) (van der Linden and Mitchell 2009) projects. The available emissions scenarios from the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES), (Nakićenović et al. 2000), as well as the EU2C scenario (Danish Government 2008) are used and described in section 2 Climate Impacts.

Lacking data required by the building sector need to be assumed as well. For assumed and found data, it is seen that there can be considerable uncertainty regarding the accuracy of the predictions. It will therefore be necessary to take account of these elements of risk by developing a model for climate impacts that span the predicted ranges of error.

**Vulnerability analysis**

On the basis of the performance model (section 5.1) and the impact model (section 5.2), it is possible to develop a method to analyse where future climate impacts causes weaknesses in building performance. For each performance requirement and design criteria defined in the performance model (section 5.1), it is necessary to define relevant calculation methods that can be used in relation to the climate scenario data sets developed in the impact model (section 5.2). This analysis will then be able to be carried out for each of the building types and ages defined in the performance model (section 5.1). Design criteria could i.e. cover structural safety, indoor comfort and energy consumption with climatic parameters such as wind speed/weight of snow/soil moisture, outdoor temperature/absolute humidity and outdoor temperature evaluated in...
relation to calculation methods outlined in ISO

The models should be tested on representa-
tive buildings that should be followed up by on-site
investigations related to the design criteria.

An adaptation strategy
The results of the vulnerability analysis (section 5.3)
are expected to show, where performance vulnera-
bility exists in relation to selected climate scenarios.
On this basis, a risk-based strategic framework for
climate adaptation for the building stock can be
developed. This cross-disciplinary framework can
include assessment models, monitoring technolo-
gies, and specific design solutions. This will lead to
a method to describe the risks associated with
adaptation to climate change based on climate
impacts in relation to building performance vulner-
ability.

From these analyses, concrete adaptation
solutions can be described according to the typo-
logical model of the building stock suggested to be
the most suitable for each specific case.
Suggestions can even be levelled according to the
need of a low-, medium- or high-risk adaptation
strategy ranging from the need of changes in build-
ing regulations and design approach to monitor
changes of the certainty of climate change impacts.

DISCUSSION
Buildings play a vital economic and social role in
most industrialised countries. In Danish society, it is
estimated that buildings have a replacement value
of €1,600 to €1,850 billion. The consequences
that climate impacts may have on the existing built
environment are not known, as climate impacts and
hence the vulnerability of the existing building stock
has yet to be investigated. This leaves society with
major challenges that, if not addressed and taken
into account, will grow far more serious as climate
change progresses. The need for a strategic
approach becomes even more urgent. Until a
strategic approach has been launched, initiatives to
challenge the climate impacts will be ad-hoc and
stand-alone initiatives.

Many resources have been spent on defining
data relevant for the building sector regarding
the impact of climate change, and ever more data
are needed as assumptions change over time.
Assumptions are closely related to the successful
mitigation of climate impacts. The impact of climate
change on the built environment is unknown and
there are inevitably degrees of uncertainty associat-
ed with individual parameters such as temperature,
precipitation, wind speed, relative humidity, solar
radiation or soil moisture. In addition to the sce-
arios describing projected climate impacts; most
countries in the world, including Denmark, have
already witnessed extreme single events. Single
events have been more intense than predicted and
include extreme rainfall, heavier cloudburst, more
frequent and longer periods of drought as well as
increased winter rainfall. In Denmark data clearly
show a rise in precipitation in the period from 1874
to 2010 (Drews et al. 2011).

Observations, from the last 100 years, show
changes in the geographic pattern of precipitation
globally. The connection between a warmer climate
and heavier rainfall is confirmed by several studies.
Some studies even estimate that the change in the
total amount, seasonal variations and the intensity
of rainfall estimated by the Intergovernmental Panel
on Climate Change (Solomon et al. 2007) is
underestimated both for the tropics and for Europe
(Allan and Soden 2008, Lenderink and van
Meijgaard 2008).

Without a strategic approach, building own-
ers are presently uncertain which climate impacts
are necessary to address and which scenarios have
the most credibility. Existing buildings and buildings
constructed today should be able to withstand cli-
mate impacts until 2100, as the main structures of
buildings are expected to last for at least 100 years.
The challenge of contemporary building require-
ments is that they should take account climate
impacts for a period corresponding to the service
life of individual building components. Climate
impacts therefore pose a serious problem in rela-
tion to the design and upgrading of buildings.
Besides threats from extreme rainfall and heavier
cloudburst, which in most countries are considered
the most urgent threats the threat of increased wind
loads is also an extremely important threat which
should be included in building design.

Scenario A2 in table 1 foresees an increased
maximum wind load at sea of about 20% in year
2100, as the wind load depends on the square of
the wind speed. Wind load is critical for most build-
ings and a threat that must be dealt with. A heavier
wind load calls for stronger constructions.
Compared with the safety margin of load-bearing
structures in buildings, a 20% increase in the wind
load is not critical. However, in 1999 a heavy storm
in Denmark reached today’s design wind standard
and cost insurance companies sums that equalled
about 10% of the yearly investment in buildings in Denmark (Nielsen 2006). In addition, it was found that the damaged buildings had strengths of about half of what is required according to the building requirements (Munch-Andersen and Buhelt 2000).

Therefore, a 20% increase of the wind load as a result of a 10% increase of extreme wind speed is supposed to result in a situation for which adaptation measures must be developed, both for existing buildings and for buildings that are to be designed for climate impacts. Such adaptation measures are expensive, but far less expensive than rebuilding damaged buildings after a storm worse than the Danish storm in 1999.

Another important climate impact is the possible threat posed by a more humid and warmer climate. This would challenge the building design that provides humans with thermal comfort, good indoor air quality, and durable constructions. Such challenges are unlikely to be met at moderate maintenance costs.

Data describing climate impacts for the different scenarios also contain data for some of the parameters needed for the design of buildings. Unfortunately, the data for the various scenarios omit statistical information about the different effects. However, that is the nature of scenarios, since they prescribe a point perspective rather than an interval at a specified level of certainty. This means that more sophisticated tools for risk analysis cannot be applied (Willows and Connell 2003). Circumstances demand a continued need for a strategic approach to climate impacts and adaptation for existing buildings and building requirements.

CONCLUSION

Lack of international agreements on the reduction of the emissions of greenhouse gases makes it difficult to expect anything but an economically regulated use of available fossil fuels such as oil, coal and gas globally. Due to the shortage of available fossil fuels together with an increasing demand and higher production costs, the same economic conditions will drive policy for energy use and the development of new and other energy-supply sources. However, the economically regulated use of fossil fuels and hence the emissions of greenhouse gases will lead to climate impacts that are very difficult to forecast and leave threats as well as opportunities for the design of buildings unknown. Therefore, it is unknown whether or not buildings constructed today will be able to withstand the effects of climate change in 2100, as the main structures of buildings are expected to last for at least 100 years.

As climate change progresses, the effects of climate change will change the building requirements. However, as the impact of climate change is unknown, it is very difficult to forecast the necessary building requirements. This will leave investments that are necessary for the preservation of the value of the building stock as ad-hoc and stand-alone investments, as future climate impacts emerge. Losing the opportunity to upgrade a building to meet key climate impacts as part of the maintenance which increases the costs of necessary measures. Therefore, the uncertainty of the scenarios leaves major challenges that, if not addressed and taken into account in building design, will grow far more serious as climate change progresses.

A continuous strategic approach to climate change and adaptation needed to ensure the vital economic and social role of buildings in society grows ever more urgent. Until such a strategic approach is launched, initiatives to challenge climate impacts will be ad-hoc and stand-alone initiatives that leave building owners at a crossroads, uncertain of which climate impacts that are necessary to address and which scenarios have the most credibility.

Circumstances related to national and international policy, economics, energy use, emissions of greenhouse gases and the development of new energy-supply sources, demand a continued strategic approach to climate impacts and adaptation for existing buildings as well as building requirements.
REFERENCES


CEU 2009, Presidency conclusions, 15265/1/09 REV1 CONCL 3, Council of the European Union (CEU), Brussels, Belgium.


DANISH GOVERNMENT 2008, Danish Strategy for adaptation to a changing climate, Danish Energy Agency (Energiestyrelsen), Copenhagen, Denmark.

DANISH METEOROLOGISKE INSTITUT 2010, IPCC’s udsilppsscenarier, Danish Meteorological Institute, Copenhagen, Denmark.


LENDERINK, G. and VAN MEUGAARD, E. 2008, Increase in hourly precipitation extremes beyond expectations from temperature changes, Nature Geoscience, 1, 511–514.


MINISTRY OF TRANSPORT AND ENERGY. 2005, Handlingsplan for en fornyet energispareindsats - Energibesparelser og marked, Ministry of Transport (Transportministeriet), Copenhagen, Denmark.

MUNCH-ANDERSEN, J. and BUHELT, M. 2000. Stormskader på bygninger, By og Byg Resultater 001, Danish Building and Urban Research, (Statens Byggeforskningsinstitut), Dr. Neergaards Vej 15, Hørsholm, Denmark.


STATISTICS DENMARK 2010, Statistikbank, Danmarks Statistik (Statistics Denmark), Copenhagen, Denmark.


VAN DER LINDEN, P. and MITCHELL, J.FB, (Eds.) 2009, ENSEMBLES: Climate change and its impacts at seasonal.
decadal and centennial timescales, final report of the ENSEMBLES project, Met Office, Exeter, UK.


WITTCHEN, K. B. 2009, Potential energy savings in the existing building stock, Danish Building Research Institute (Statens Byggeforskningsinstitut), Hørsholm, Denmark.

Author(s):

T. Valdbjørn Rasmussen
Danish Building Research Institute,
Department of Construction and Health,
Aalborg University
Dr. Neergaards Vej 15, 2970 Hørsholm, Denmark
Email: tvr@sbi.aau.dk
Web: http://www.sbi.dk