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Publication date:
2006

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

ON THE DESIGN OF BUILDINGS IN RELATION TO CLIMATE CHANGE

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Abstract

Climate change and its impact on the design of buildings are currently subject to concern. Large resources have been put into development of models for predicting future climate changes. However, considering the huge investment in buildings combined with their expected long service life, only few resources have been put into adaptation strategies for buildings.

In line with other countries, Denmark is at the beginning of developing a strategy to address the effect of climate change on a broad scale. The present paper is based on one of the pre-studies for this work and focuses only on the impact on the design of buildings.

It is shown how performance requirements for buildings may be taken as a starting point for a systematic evaluation of which climate related data are needed as a background for the design of buildings.

Among the conclusions are that the lack of knowledge about the uncertainty of the relevant climate parameters is in itself a problem, and that the building sector should be more active in presenting its need for knowledge about specific climate related parameters.

Introduction

A great part of the value of our infrastructure is bound in buildings. Satisfactory performance of those buildings can only be achieved by proper considerations to climate effects. The load-bearing structures of buildings are usually expected to last for at least 100 years. Climate change is therefore a serious problem in relation to design and renewal of buildings.

Many studies on climate change aim at developing models by which climate change scenarios are developed. Part of that is to establish a relation between climate key parameters, such as global warming, and the driving forces, i.e. greenhouse gases. This paper does not challenge these studies but take the results (Intergovernmental Panel on Climate Change, 2001) as the starting point for considerations related to decision making in the design of buildings.

The idea in this contribution is to start with the performance requirements for buildings and then evaluate which climate parameters that do influence the design of buildings. Next step is to look for changes in the relevant climate parameters as presented in climate scenarios, and finally to evaluate the impact (threats and opportunities) and potential adaptation strategies to be used in the design of buildings, including changes in buildings codes and regulations.

This approach differs from the approach in previous studies (Sanders and Phillipson, 2003) in which impact from flooding, wind, rain and overheating are considered as a background for strategies for adaptation to climate change and (Camilleri et al., 2001) in which Australian buildings are considered in a similar way. Both studies are substantial and take the change in climate parameters as the starting point for evaluations of the impact on buildings. Although the most important parameters, which have been identified, are equivalent to those identified in this study, it is found that the performance requirements approach offers a more systematic way to identify climate related parameters of importance to the design of buildings.

The work presented here is based on two initiatives. The Danish Environmental Agency is heading a programme which addresses the effect of climate change on different sectors (buildings, farming, traffic, etc). The present paper is based on one of the pre-studies for this work and focuses only on the impact on the design of buildings. Part of the work has also been done in relation to a screening of the effect of climate change, organised by the Danish Academy of Technical Science (ATV, 2003).

Performance related climate parameters

Building performance in relation to climate parameters may be characterised as indicated in Table 1.

The table illustrates that buildings should offer a safe place to stay, with no danger of collapse, even during extreme storms or snowfalls. They should be comfortable to live in, i.e. provide us with thermal comfort, whether the weather is warm or cold, have a good indoor air quality, and facilitate the use of the surroundings when the weather is for that. They should also be durable with moderate maintenance costs.

It should be noted that lack of thermal comfort and bad air quality may be life threatening for vulnerable people. In such cases, these criteria shall be characterised as safety criteria.

It should also be noted that the design of a building aims at achieving a building which satisfies all the demands of the client. The climate-related performance requirements are only part of these demands, which also consist of requirements to the use of the building, to architecture, etc.

Table 1. Climate parameters in relation to performance of buildings

Performance requirements	Building subject	Climate related parameters to be considered
o Safety (life)	o Load-bearing structure, including foundation (strength)	o Maximum wind speed o Maximum weight of snow o Ground water level (maximum and minimum)
o Comfort	o Building envelope (rainproof, temperature insulated) o Indoor environment (temperature, air quality) o Surroundings (building integration with the surroundings)	o Maximal rainfall o Outdoor temperatures (maximum - heat waves, minimum, average winter temperatures) o Relative humidity o Toxic releases as from biological activity, such as mould or house-dust mites
o Durability	o The whole building	o Relative humidity o Air temperature o Ultra-violet radiation o Frost-thaw cycles o Attacks from insects such as termites or House Longhorn (hylotrupes bajulus) o Dry rot

The design situation

Part of the design process is to distinguish between different classes of consequences such as loss of life or health, lack of comfort, economic loss or opportunities for better comfort or economic savings.

These consequences call for a differentiation of the safety levels, where loss of life or health, being the most serious, must be prevented at a high level, while some (temporary) loss in comfort or some increase in maintenance costs may be accepted if the climate change should develop more seriously than expected.

Climate change, with its changing conditions for satisfying a specific performance requirement, means that a certain standard of a building may not in the future satisfy the performance requirements which were satisfied in the original design.

Part of the background knowledge is also that in some cases it may be much more expensive to upgrade a building after having finished the construction than it would have been if that standard had been part of the original design. A typical example of that is when a load-bearing structure must be strengthened. In other cases upgrading can be done at almost no costs, as when a window, which cannot last any longer, is substituted with at better insulated window.

Even if one aims at adapting to climate change, the outcome of the design decision process may not prove to be adequate. The chosen standard may have been too high which means that part of the investment is wasted. It may also be chosen so that an upgrading turns out to become necessary, so that one ends out with an initial investment as well as costs for an upgrading. In this case it might be so that it had been better to save the initial investment and wait for more reliable information on the relevant climate parameter and then upgrade. The decisions are of course most difficult for the load bearing structures with their long expected life time, and easier for parts of the building envelope which regularly are renewed.

These considerations should only be taken as illustrations of how uncertainty associated to climate change parameters makes decisions on initial investments in higher standards more complicated. The key question is: When shall we act, and how far should we go in meeting the threats or make use of the opportunities?

A systematic treatment of risk assessment and decision making may be found in (Willows and Connell (Eds), 2003) and (Lisø, 2006). However, it looks as if the more advanced tools cannot be to much help until the quality of input data is better. This means that the lack of knowledge about the uncertainty of the relevant climate parameters is in itself a problem.

Whether an initial investment is a good idea basically depends on the uncertainty concerning relevant parameters in the climate data and how large the investment is in relation to the potential benefit. This decision situation is illustrated in Table 2.

Table 2. Decision situations

	Small uncertainty on climate data	**Large uncertainty on climate data**
Small investment in relation to the potential benefit	Go for it	Maybe
Large investment in relation to the potential benefit	Maybe	Wait

In waiting for more reliable climate data, the task for the building sector therefore is to look at the costs for different adaptation solutions, i.e. develop more economic solutions, as done in (Hacker et al., 2005) and (Graves and Phillipson, 2000)

Climate data for Denmark

One of the climate scenarios which have been considered is based on IPCC scenario A2 (medium-high emissions). Danish Meteorological Institute and Danish Environmental Agency have down-scaled the IPCC scenario and obtained specific data for Denmark, see Table 3 (Danish Meteorological

Institute and Danish Environmental Agency, 2005). The following discussion on climate change adaptation is based on these data.

Table 3. Climate data for Denmark (2071-2100), based on IPCC scenario A2 (Danish Meteorological Institute and Danish Environmental Agency, 2005)

Average temperature	+ 3,1°C
Yearly rainfall	+ 9%
Summer rainfall	-15%
Maximum 24 hour rainfall	+ 21%
Average wind speed	+ 4%
Maximum wind speed (storms)	+ 10%
Maximum see level at the west coast	+ 0,45m – 1,05m

By comparing the information in Table 3 with the information in Table 1 it can be seen that the provided data only contain data for some of the parameters needed in the design of buildings. One also misses the statistical information on these parameters, but that is the nature of scenarios, since they prescribe a point perspective rather than an interval at a certain level of confidence. As indicated above this means that the more sophisticated tools for risk analysis (Willows and Connell, 2003) cannot be applied.

The missing data are not simple to derive. Concerning snow loads one might expect a decrease, since the average temperature increases, but this is not sure, because more rain/snow will fall during the winter. Concerning the level of ground water, it might be so that the minimum level becomes smaller due to less rainfall during the summer, and the maximum level will increase because the winter rainfall increases. But again, it may not be the case. Only more sophisticated models can give us the necessary information. Also design data for heat waves are missing in Table 3, and when it comes to comfort in general and to durability one again misses more detailed information about minimum winter temperatures, relative humidity, ultra-violet radiation and frost-thaw cycles. Table 1 also shows the need of data on changed biological activity dependent on changed climate. It is clear that the building sector is interested in other species than the farming or the forestry sectors. This information can only be provided in a co-operation between meteorologists, biologists and building experts.

It becomes obvious that standard metrological parameters as they are presented in table 3 are not sufficient input for building design. The building sector should be more active in presenting its need for specific parameters.

Climate change adaptation in Denmark

In comparing Table 1 and Table 3 it can be seen that climate change will give rise to threats as well as opportunities in the design of buildings. Those which are considered the more important are discussed below. Flooding is not included because the risk of flooding is normally not treated by the designer of individual buildings, but part of national or regional planning.

Wind loads
The above mentioned scenario indicated increased wind loads of about 20 % (load depends on the square of the wind speed). Wind load is a critical

loading case for most buildings, so higher wind load calls for stronger structures. Compared to the safety margin of load bearing structures in buildings, a 20 % increase in the wind load ought not be critical. However, a heavy storm in 1999, which just reached the design wind of today, gave the insurance companies expenses which reached about 10 % of the yearly investment in buildings in Denmark. It was also found that the damaged buildings had strengths at about half of what is required according to the standards (Munch-Andersen and Buhelt, 2000). A 20% increase in wind loads (10 % in extreme wind speed) is therefore supposed to result in a situation for which adaptation actions must be developed.

There are several possibilities for such actions. One is that the client demands a better quality control in new building projects to be sure that the strength will be as prescribed. Another possibility is that the insurance companies will demand the strength documented as a condition for keeping the premium at the present level. A third possibility is to increase the loads prescribed in standards. This will, as also pointed out by (Sanders and Plillipson, 2003) lead to a conflict with the tradition to base the magnitude of wind loads (and snow loads) on historical data using an advance statistical approach to reach a specified level of formal safety.

For existing buildings the challenge is to identify types of weak buildings and strengthen them before they are damaged. This is an expensive process, but probably far less expensive than rebuilding damaged buildings after a storm worse than the 1999-storm.

The indirect damages on buildings from fallen trees have been considerable. It is not likely that trees will become more resistant simultaneously with the increase in wind loads. The means that we should be better to evaluate when a tree may represent a threat to a building and to chop it down before it damages the building.

Ground water level

A changed ground water level may have an implication on the design of the foundation as well as floors and walls of the basement. If the drainage is insufficient a higher level of ground water (also a false ground water level after a heavy rainfall) may undermine the structural safety, and a lower groundwater level may lead to increased settlements and cracks in the walls of the building dependent on the type of soil below the foundation.

Heat waves

Already today many people find warm summer days hard to overcome. With more severe heat waves, higher income and cheaper technology an uncontrolled spontaneous investment in inefficient, electricity driven cooling equipment might be the result.

Cooling could also lead to uncontrolled condensation which may give rise to mould and house-dust-mites.

A substantial discussion on adaptation strategies aiming at improved indoor climate performance in different types of buildings may be found in (Hacker et al., 2005).

Extreme rainfalls
More extreme rainfalls may threat with overrun of gutters and water running into the basement from the surroundings. Water penetrating the building envelope is a main cause for deterioration of building materials.

Better water protection, larger gutters, adequate drainage and surface regulation near the buildings are some of the measures to take into account.

Milder climate
In Denmark the traditional view is that buildings protect us from an unpleasant outdoor climate, and a few days a year we may enjoy the surrounding gardens and parks.

The future climate may offer quite different opportunities for an integration of buildings with the surroundings, which may add considerably to the comfort from spring to autumn.

One might also look forward to a smaller bill for heating during the winter, but it is not clear when we may prescribe cheaper heating systems with lower capacity.

Deterioration of building materials
Table 1 shows the relevant parameters. The challenge is that the effect on different building materials is different for each parameter, and the magnitude of the effect is even not know sufficiently well in many cases. A discussion on the behaviour of different building materials can be found in (Graves and Phillipson, 2000).

Research needs

The study has revealed a number of building research items to be considered with the view to strengthen the decision making for a future with a warmer climate. They are:

- On which basis may the prescription of performance criteria, regulated by building codes, change its basis from historical climate data to future data?
- How is the distribution of strength of structures in existing buildings and how may weak buildings be identified and strengthened in an economical way?
- How will the future climate influence the durability of the different building materials?
- Architecture for a warmer climate (natural ventilation, integration with the surroundings)

Conclusions

- Performance criteria for buildings seem to be an adequate starting point for evaluation of climate change impacts on buildings
- The lack of knowledge about the uncertainty of the relevant climate parameters is in itself a problem

- The building sector should be more active in presenting its needs for specific climate related parameters
- The most important threats on buildings are storm damages, warm and toxic indoor climate and short durability of some building materials
- The use of data from climate scenarios as basis for prescribed loads on buildings is in conflict with the existing tradition of using historical data and a sophisticated statistical approach
- The present knowledge is not sufficient to allow for advanced cost-benefit analysis as a basis for investments in climate adaptation measures

Acknowledgements

The work on which this paper is based has been carried out in co-operation with the National Agency for Enterprise and construction (www.naec.dk), who also contributed financially, and the Danish Environmental Agency (www.mst.dk), who control and co-ordinate a wider programme on Danish adaptation to climate change.

References

1. ATV. "Effects of climate change – adaptations in Denmark." (In Danish) *Danish Academy of Technical Science*. Lyngby, 2003
2. Camilleri, M., Jaques, R., Isaacs, N. "Impacts of climate change on building performance in New Zealand". *Building Research & Information*, volume 29, number 6, pp 440-450. 2001
3. Danish Meteorological Institute and Danish Environmental Agency. "Climate scenarios as a basis for a Danish strategy for climate adaptation." 2005. (In Danish). Not published.
4. Graves, H.M., Phillipson, M.C. "Potential implications of climate change in the built environment." *FBE Report 2*. 2000.
5. Hacker, J.N., Belcher, S.E., Connell, R.K. "Beating the heat: Keeping UK buildings cool in a warmer climate." *UKCIP Briefing Report*. UKCIP, Oxford, 2005.
6. Intergovernmental Panel on Climate Change. "IPCC Third Assessment Report – Climate Change 2001." 2001. Available at www.ipcc.ch. Accessed July 2006.
7. Lisø, K.R. "Integrated approach to risk management of future climate change impacts." *Building Research & Information*, volume 34, number 1, pp 1-10. 2006
8. Munch-Andersen, J. and Buhelt, M. "Storm damaged buildings." (In Danish). *By og Byg Resultater 001*, Danish Building Research Institute. 2000
9. Sanders, c.h., Phillipson, M.C. "UK adaptation strategy and technical measures: the impacts of climate change on buildings." *Building Research & Information*, volume 31, number 3-4, pp 210-221. 2003
10. Willows, R. I. and Connell, R. K. (Eds). "Climate adaptation: Risk, uncertainty and decision-making." *UKCIP Technical Report*, UKCIP, Oxford. 2003.