# Evaluation of the effects of expected climate change on the durability of building materials with suggestions for adaptation

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**Regardless causes of climate change, changing climate parameters, such as higher temperature, amount and intensity of precipitation, different wind regime, will affect the durability of materials used in the building envelope, either individually or combined. The current paper evaluates possible trends and tendencies arising from these changing climate parameters on the durability of building materials in the Netherlands, based upon four scenario's of climate change developed by the Royal Netherlands Meteorological Institute, KNMI (2006).**

***Key words: Climate change, building envelope, durability***

## 1 Introduction

This paper focuses on effects of climate change in the Netherlands on the durability of materials in the building envelope, with emphasis on porous building materials (brick and natural stone masonry, concrete), timber and coatings. As the effects of flooding are commonly discussed, - in the Netherlands, these have, for example, been assessed on buildings exposed to sea water during the disastrous flood of 1953 (Lubelli et al. 2004)-, the current paper concentrates on other effects of climate change, such as higher temperatures, increased precipitation, (locally) increased ground water table and increased salt concentration of ground water, etc. Discussion of structural and safety aspects is given in other papers in this issue. For the Dutch situation, four scenarios of climate change have been developed by the Royal Netherlands Meteorological Institute, KNMI (Van den Hurk et al. 2006). These are denominated G – moderate (more or less unchanged), G+ – moderate, but with changing air circulation patterns, W – warm, and W+ – warm in combination with changing air circulation patterns, respectively. General tendencies in all four scenarios are:

- Temperatures will increase, resulting in a higher frequency of more temperate winters and warm summers.
- Winters will, on average, become wetter, and extreme amounts of precipitation will increase.
- Intensity of severe rain in the summer will increase, but, in contrast, the number of rain days in summers will decrease.
- Changes in wind regime will be small compared to current natural variation.
- Sea levels will continue to rise.

Details of each scenario are summarized in table 1. The current situation, i.e. effects of climate change over the past century (Van den Hurk et al. 2006) shows that average temperature in the Netherlands has risen 1.2 °C over the period 1900 – 2005. Temperatures for 2100 are expected to increase 1 to 6 °C worldwide, relative to 1990, with, probably, a slightly higher increase in Europe. For the Netherlands, scenarios vary from an increase in 2050 of 0.9 to 2.3 °C in the winter, and 0.9 tot 2.8 °C in the summer, relative to 1990 (Table 1). There is also a strong regional variation, as illustrated by the number of days with maximum temperature ≥ 25 °C (Table 1).

The amount of annual precipitation in the Netherlands has increased by + 18 % since 1906, with + 26 % in the winter, + 21 % in the spring, + 3 % in the summer and + 26 % in the fall. The amount of rain in prolonged 10 day rain periods also increased by + 29 % since 1906. KNMI scenario's depict that the expected effect on climate change on maximum wind speed in the Netherlands is rather small, within natural variation (Van den Hurk et al. 2006). The number of storms in the Netherlands has decreased by 20 – 40 % since 1962 (Van den Hurk et al. 2006); at the same time, the number of storms at Düsseldorf airport, not that far over the border in Germany, has roughly increased by 70 % from the 1960's into 1990's, accompanied by an increase in mean wind velocity (Kasperski 1998). Van den Brink (2005) also indicates a possible shift of storms with very high intensity from the Atlantic to north-western Europe.

*Table 1. Summary of effects of four possible scenarios for the Netherlands in 2050, relative to 1990 (Van den Hurk et al. 2006)*

| Scenario | | | 1990 | G | G+ | W | W+ |
|---|---|---|---|---|---|---|---|
| | | Summer | | | | | |
| Mean temperature | | °C | | + 0.9 | + 1.4 | + 1.7 | + 2.8 |
| Yearly warmest day | | °C | | + 1.0 | + 1.9 | + 2.1 | + 3.1 |
| Days ≥ 25 °C | NW Netherlands | | 8 | 11 | 14 | 16 | 22 |
| | NE Netherlands | | 20 | 27 | 30 | 34 | 41 |
| | Central Netherlands | | 24 | 30 | 34 | 39 | 47 |
| | SE Netherlands | | 28 | 36 | 41 | 44 | 53 |
| Mean precipitation | | % | | + 2.8 | - 9.5 | + 5.5 | - 19.0 |
| Wet day frequency | | % | | - 1.6 | - 9.6 | - 3.3 | - 19.3 |
| Precipitation on wet day | | % | | + 4.6 | + 0.1 | + 9.1 | + 0.3 |
| Potential evaporation | | % | | + 3.4 | + 7.6 | + 6.8 | + 15.2 |
| | | Winter | | | | | |
| Mean temperature | | °C | | + 0.9 | + 1.1 | + 1.8 | + 2.3 |
| Yearly coldest day | | °C | | + 1.0 | + 1.5 | + 2.1 | + 2.9 |
| Mean precipitation | | % | | + 3.6 | + 7.0 | + 7.3 | + 14.2 |
| Wet day frequency | | % | | + 0.1 | + 0.9 | + 0.2 | + 1.9 |
| | | Yearly | | | | | |
| Yearly maximum daily mean wind speed | | % | | 0 | + 2 | - 1 | + 4 |

The KNMI scenarios only assess the direct climate characteristics. Several other effects relevant to the durability of building materials that have not been assessed by the KNMI, include (e.g. Sanders & Phillipson 2003):

- Specific and relative humidities; the first is likely to increase, but relative humidity may decrease, especially in the summer.
- Amount of solar radiation, which is likely to increase.
- Soil moisture content; in the UK, these are expected to fall by 20 to 40 %.

## 2 Possible effects of climate change on building materials

Below, general trends or tendencies of individual climate parameters affecting building materials are concisely discussed. The paper identifies the major trends in risks for building materials, due to climate changes. A quantitative estimate of the potential effects- if possible- cannot be given as major data relating impact, specific materials and effects are lacking.

### *2.1 Higher temperatures*

- Less frost and near zero days in the winter, lowering the necessity of use of deicing salts; this lowers the chloride load on concrete infrastructure, decreasing risks of chloride-induced rebar corrosion, with a positive infrastructure service life. It may also affect the amount of water soluble salts in rising damp, lowering the risk of salt damp due to the later in relevant situations.
- Faster biocolonization, involving other species than currently encountered in the Netherlands, and increased biodegradation, as more periods with optimum temperature will occur (Grosser 1985). A salient example is the recent shift of the habitat of wood-eating termites towards more northern directions, from southern Spain to the middle of France. Other genera will develop that are typical for the Mediterranean area in the West-European maritime climate, causing accelerated biodeterioration; a typical example is the (booming) occurrence of *Trentepohlia odorata* on (calcium silicate) masonry.

### *2.2 Higher precipitation*

- Higher precipitation (especially in the winter), more extreme precipitation and wind driven rain may result in deeper penetration of moisture in a façade, affecting (combined thermal-) hygric expansion with accompanying stresses (e.g. Sabbioni et al. 2006). Deeper penetration may, especially by small dimensions, result in water seepage through walls. The effect of a higher potential run-off is difficult to assess.

### *2.3 Combination of higher temperature and higher precipitation*

- Higher mean winter temperatures will result in less freeze-thaw cycles in the winter; in practice, this effect might be limited, as the decrease in the number of freeze – thaw cycles in north-western Europe by the end of the 21$^{st}$ century (2079

- 2099) is less than one cycle compared to the period 1961 - 1990 (Grossi et al. 2007). However, at the same time, porous building materials may be more wet due to higher precipitation in the winter, possibly resulting in more intense damage upon frost.

- Higher temperatures and higher precipitation will influence atmospheric and relative humidities, with direct effects on salt damage to porous building materials, those in built cultural heritage in particular. Whereas the average RH may decrease, the effect of the number of RH cycles is less clear. Such cycles, causing salts to go in solution, be transported and reprecipitate (e.g. Lubelli 2006), may strongly increase the risk of damage (e.g. Koster et al. 2008).
- Biocolonization patterns will change, with manifest effects on biodeterioration and biodegradation. Higher temperature and precipitation will cause faster development of micro-organisms (e.g. higher germination power rates), and affect the species of micro-organisms occurring. Likely, a shift will occur from algae to cyanobacteria and fungi (moulds) as in the Latin American situation (cf. Gaylarde & Gaylarde 2002, 2005). The latter may result in development of more pronounced aesthetical damage on stony, cement-based and polymeric building materials.

Especially the availability of moisture is, together with the availability of organic nutrients, a controlling factor in biocolonization. Analysis of the microclimate of the city of Rome over the period 1850 – 1980 has shown that a decrease in precipitation, -i.e. the opposite of what is expected in climate change scenarios for the Netherlands-, and 10 % decrease in relative humidity, accompanied by an increase in temperature of 0.5 to 1.5 °C as well as increasing air pollution, resulted in a decrease of micro flora diversity (especially affecting lichens), but did not significantly reduce the total biomass on stony biomaterials (Caneva et al. 1995).

In case of timber, the decay of wood due to fungal attack directly relates to the climate:

$$\text{Climate Index} = \frac{\sum\limits_{\text{dec-jan}} (T_{\text{mean}} - 2)(D - 3)}{n}$$

in which $T_{mean}$ is the mean monthly temperature in °C, $D$ is the mean number of days in the month with 0.254 mm or more precipitation, and $n$ is a scale factor to scale the index to a range of 0 to 100, $n$ being 16.7 for the US and 10 for Norway, for example (Scheffer 1971, Setliff 1986, Lisø et al. 2006). The relationship is valid for temperatures below 30 °C. Climate index < 35 indicates a low risk, 35 ≤ CI ≤ 65 a moderate risk and CI > 65 a high risk (Scheffer 1971). The relationship clearly illustrates that increasing rainfall and mean temperature will result in increasing risk of deterioration of timber structures and building parts due to wood-deteriorating fungi, which will also reflect variations in local microclimates. Besides fungi, timber will also suffer from faster growth of more devastating insects.

### *2.4 **Higher precipitation in combination with wind load***

- At high levels, wind driven rain generally results in more weathering. Combined with a higher amount and intensity of precipitation, increased wind load may cause increased weathering of high-rise buildings (cf. Tang et al. 2004).

### *2.5 **Increased solar radiation***

- Possible lower durability of bituminous roofings, plastics, paintings and coatings as well as specific hydrofobic or antigraffiti coatings.
- Increased short-wave UV radiation will negatively affect the preservation of historic wall coverings and polychromy.
- Increased degradation of (painted) timber construction element used on the exterior façades, such as cladding, window-frames, fences, etc.; untreated timber and wood products will be more prone to colour changes.

Next to the increase of solar ultraviolet radiation itself, the degradation potential of any UV-B environment is enhanced by higher temperatures and, possibly higher relative humidities.

### *2.6 **Soil moisture contents***

It is unclear whether and how higher precipitation will affect soil moisture contents. Given that ground and surface water in the Netherlands are controlled in most areas, any effect will strongly depend on measures taken with this respect. For example, in built environments such as cities, there is no regulation of the water level, and building owners are responsible for degradation on their wooden pile foundations.

- Lower soil moisture contents:
  - May result in drying accompanied in shrinkage and resulting subsidence, which may result in cracking of foundations and walls.
  - May expose wooden pile foundations, especially common in the historic city centres of most towns in the western provinces of the Netherlands like Amsterdam, to oxygen, due to lower ground water levels, resulting in degradation by fungi and final failure, leading to uneven settlement.
  - Lower the risk of damage due to rising damp.
- Higher soil moisture contents:
  - Higher the risk of damage due to rising damp, by higher moisture contents of porous building materials at onset of freeze – thaw cycles, or increased transfer of water soluble salts from soil (and de-icing) into the building shell.

### *2.7 **Increased salinity of ground water***

The Veerman report describes several expected effects as a result of climate change, as well as proposals to accommodate these. Combined, these will affect ground water table and salinity (Deltacommissie 2008):

- Sea level rise and decreasing river transport towards sea during summer.
- Longer dry periods and penetration of salt water via rivers and groundwater
  - Both increasing and decreasing ground water tables.
  - Increasing salt concentration in ground water.
- The level of IJsselmeer will be increased by max. 1.5 m as proposed by the Deltacommissie (2008).

Result will be higher salt loads on building materials, for example due to capillary rising damp from the soil. The higher salt load may lead to faster decay of building materials. Adequate measures, treatments and interventions will be necessary to prevent this fast decay and to protect valuable cultural heritage objects in particular.

### *2.8 Higher wind speed*

- An increase in wind load would have implications for the anchoring of cladding materials, as discussed by Steenbergen et al. (this issue). Otherwise, the effects on building materials in the Netherlands are expected to be minor.

## 3 Impact of climate change on durability of building materials in the Netherlands and adaptation possibilities

Above, the KNMI climate change scenarios for the Netherlands have been discussed in relation to relevant physical-chemical processes affecting the durability of building materials. Various lines of approach might be distinguished to adapt to the effects of climate change on building materials in the Netherlands, but any approach is complicated by the fact that climate change may affect degradation and durability of different building materials involved in opposite directions.

### *3.1 Biocolonization and biodegradation*

The combined effect of higher temperature and higher precipitation is likely to speed up biocolonization and increase effects of biodeterioration and biodegradation, for stony materials, (organic) coatings and timber. Possible adaptation measures may range from the development and use of new, innovative materials with slow controlled release of biocides to selection of currently available and more sustainable materials. In the current case, materials with a low water retention will be less prone to biocolonization than those with a high water retention, which is favoured by a large amount of pores with diameters below 0.1 µm. Hence, apparently the use of more coarsely porous building materials may serve as an adaptation measure. The use of water repellent treatments may also be considered (Adan 2003). The latter would, however, not be an option, given the risk of future damage by other processes, in case of the presence of salts or rising damp, which may be affected by climate change itself, whilst at the same time increased solar radiation is likely to speed up degradation of water repellent agents themselves.

### *3.2 Salt damage*

Salt damage on fired clay brick and natural stone masonry in general, and in built cultural heritage in particular, may possibly increase. Besides higher temperatures may result in faster evaporation, water penetration into façades will be deeper, potentially dissolving more salts that may be transported and accumulated, giving rise to damage. This may happen, for example, in case of masonry made with an outer shell of higher firing temperature, harder bricks, and inner core of low firing temperature, sulfate-rich bricks. To what extent higher temperatures and higher precipitation will result in more relative humidity cycles in which the equilibrium relative humidity of water soluble salts is crossed, is yet unclear. Only a limited increase of such cycles, however, may have rather severe effects on salt damage to porous building materials (Lubelli 2006, Koster et al. 2008). Measures at the design level, affecting indoor climate, might help to adapt. In case of smaller objects, such as sculptures, desalination may be an approach of adaptation. However, for larger salt-loaded objects, such as entire façade walls, this is, with current techniques, not practical. Desalination systems like electro-osmosis (e.g. Ottosen & Rörig-Dalgaard 2008) and poultices (e.g. Vergès-Belmin & Siedel 2005) deserve further research.

In case of materials applied during renovation, restoration or new construction, adaptation measures might be found in use of more salt-resistant materials, such as salt transporting or salt accumulating restoration plasters or bricks with a pore structure favouring salt crystallization at the surface (efflorescence) rather than behind that (crypto-efflorescence). A promising field might be the use of (restoration) mortars with mixed-in crystallization inhibitors (e.g. Lubelli & Van Hees 2007, 2008, Van Hees & Lubelli 2008). As far as crystallization inhibitors are concerned also possible effects on health and environment may need attention, apart from their performance.

### *3.3 **Freeze – thaw damage***

Contrary to what might be expected, freeze – thaw damage, -not of major concern to concrete in the Netherlands, but rather to brick and natural stone masonry-, may not decrease. The expected decrease in the number of freeze-thaw cycles is small, whereas materials may be wetter at onset of frost, due to higher precipitation, with a possible increase in freeze - thaw damage. Enhancing frost resistance of masonry and, in particular, pointing mortars by use of air entraining agents or gap-graded sand (Van Hees et al. 2001) may be an adaptation approach.

In case of concrete in civil infrastructure, the slightly lower amount of freeze – thaw cycles due to higher temperatures may have a possible minor beneficial effect, not on freeze – thaw damage itself, but on rebar corrosion, as a more restricted use of de-icing salts will reduce chloride loads.

### *3.4 Increased solar radiation*

The effect of increased solar radiation is likely to be compensated by the development of advanced light-stabilizer technologies, based on both conventional and improved photostabilizer systems (Andrady et al. 2003).

## 4 Conclusion

Evaluation of the climate scenario's developed by the KNMI for the Netherlands (Van den Hurk et al. 2006) shows that the combined effect of different climate parameters is rather complex. Action of individual climate parameters may strengthen each other, such as higher temperature combined with higher precipitation, or may result in effects contrary to what might be expected, such as the combination of higher precipitation combined with only a slight decrease in the number of frost-thaw cycles.

Well known damage processes affecting building materials, such as salt damage, rising damp and biodeterioration, will intensify. Adaptation at a materials level may, depending on the material involved, consist of a different choice of already available materials or techniques, or new materials or methods currently being developed. However, also at a higher level of design (detailing, ventilation), measures should be considered to enhance durability of building materials in the future situation.

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