

# Hygro thermal simulation of frost damage in masonry : effects of climate change

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# hygro thermal simulation of frost damage in masonry

## effects of climate change

marcel van aarle

The European project “Climate for culture” (Cfc) investigates the impact of the threat of climate change on cultural heritage (Climate for culture, 2009). Climate change will result in an increase of air temperature and rainfall intensities for the Netherlands in winter (Klein Tank and Lenderink, 2009; Sluijter, 2011). Climate change also threatens cultural heritage (Sabbioni et al. 2009), which was investigated in the European project: Noah’s Ark: “Global Climate Change Impact on Built Heritage and Cultural Landscapes”. Not only the interior and the collection are important to preserve for future generations, but also monumental buildings themselves. Frost damage may disintegrate masonry.

The risk of frost damage to an external building envelope will become less due to the increase in air temperature (Grossi et al. 2007). However, the risk of frost damage rises as a construction will be wet for a longer time due to the increase in rainfall intensities (Nijland et al. 2010). In this study, a statement will be made about these conflicting frost damage effects. Research will be done on the following topics: the type of material that is sensitive to frost, the conditions under which the material damage occurs, the outside climate conditions in future (frost damage winters) and the possibility to predicted frost damage with a multi-physical model. The methodology was:

1. literature review on frost damage
2. verification of a coupled heat–moisture model
3. simulation of case studies to predict frost damage
4. analysis of the external climate
5. drawing of conclusions from literature and case studies

### literature

Frost damage can be caused by several mechanisms to porous mechanisms including the increase in volume as a result of the phase change of water into ice (Scherer and Valenza, 2005). Three conditions must occur simultaneously (Hayen, 2008):

1. The temperature should be lower than the freezing point of water. The temperature doesn’t have to be exactly 0° C.
2. The material should be wet.
3. The material should be sensitive to frost.

Freezing in calcium silicate brick can happen when the

moisture content is close to, or higher than capillary saturation (Sedlbauer and Künzel, 2000). The capillary saturation level in masonry can be reached after a long-term spell of rain. Frost damage occurs when the long-term rainfall is immediately followed by severe frost (Klugt, 1999), as excessive internal stresses arise (Scherer, 2006). Winters with these climatic circumstances are indicated as so-called “typical frost damage winters”. Examples of typical frost damage winters in the Netherlands are 1962/1963, 1978/1979 and 1981/1982 (Klugt, 1999).

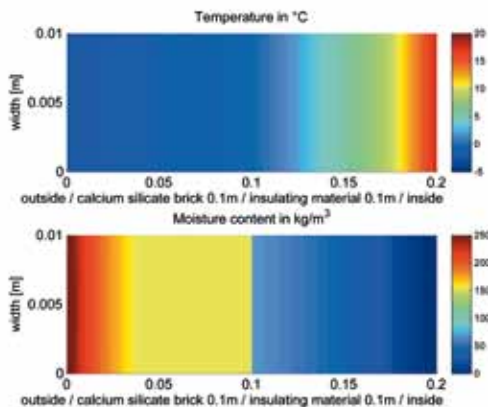
In the Netherlands a method of testing for the bearing of frost damage exists under different air temperatures and moisture loads, which is described in NEN 2872 (1989) and the national assessment guideline, BRL 1007 (IKOB-BKB B.V., 2010). The aim of the freeze-thaw test is to examine if bricks are suitable for practical applications with appearance of high moisture loads (bricks for outdoor applications) or even extremely high moisture loads (bricks which are continuously in water).

### coupled heat and moisture transport

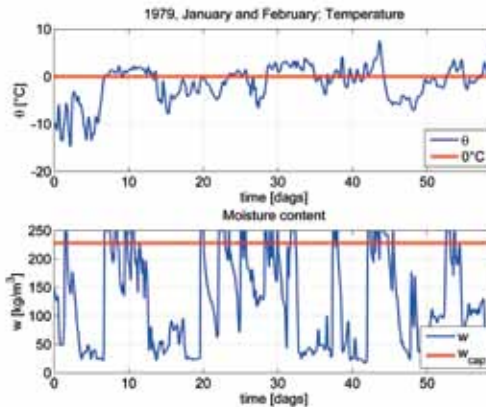
This study shows that modeling of coupled heat, vapor and water transport is a method to predict the risk of frost damage. The heat and moisture transport is coupled because the transport is interdependent (Wit, 2009). The validity of the heat and moisture model has been proven by Benchmarks, verified with similar studies (Schijndel, 2008). Heat and moisture flow rates should be calculated for porous bricks to determine temperatures and moisture contents in the material. For this purpose boundary conditions are necessary at the inside and outside boundary of the construction. Internal boundary conditions are assumed to be constant. The external boundary conditions are:

1. climate data of the KNMI for years 1971 to 2011. From these data typical frost damage winters could be determined.
2. climate data determined with REMO for climate scenario A1B for the years 1971 to 2011. REMO means REgional atmospheric Model. The weather data are compiled by Max Planck Institute.
3. future climate data from 2059 to 2099, also determined by REMO. The future outdoor climate scenario has been described by Huijbregts (2012).

From 2 and 3 should follow whether the risk for frost damage will increase or decrease.



1. calculated temperatures ( $\theta$ ) and moisture contents ( $w$ ) over the



2. calculated temperatures ( $\theta$ ) and moisture contents ( $w$ ) that occur 1 mm below the outer surface for the months January and February

### simulation of case studies

The occurrence of frost damage has been tested with the heat and moisture model using four case studies. The following variants were examined: the composition of the construction, the orientation and the heat and moisture model.

In figure 1 calculated temperatures ( $\theta$ ) and moisture contents ( $w$ ) over the cross section of the construction are presented for a time on January 22, 1979.

Close to the outer surface of the construction a temperature ( $\theta$ ) occurs which is lower than  $0^\circ\text{C}$  and simultaneously the moisture content ( $w$ ) is higher than capillary saturation ( $w_{\text{cap}}$ ). Under these conditions there is a probability of frost damage in brick. Frost damage arises mainly at the exterior surface of the construction. Temperatures ( $\theta$ ) and moisture contents ( $w$ ) that occur 1 mm below the outer surface of the construction for the months of January and February of 1979 are presented in figure 2.

Eleven times the conditions are as such that there is a chance for frost damage. The depth of the risk of frost damage seen from the external surface into the construction as a function of time is illustrated in figure 3.

Simulated are four case studies with climate data from the past to the present (KNMI and REMO) and with future climate data (REMO).

### conclusions

The following conclusions can be drawn. Based on the results from simulations of the case studies with a heat and moisture model and climate data determined by REMO, it is expected that the risk of frost damage decreases by an order of magnitude of 70 %. It follows from

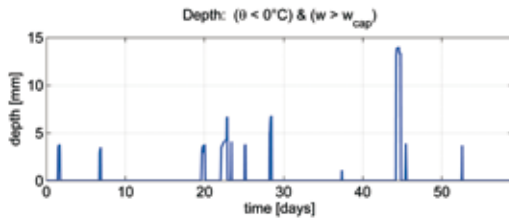
literature that a calcium silicate material is sensitive to frost. For the occurrence of frost, the temperature should be lower than the freezing point of water, while simultaneously the moisture content should be close to or higher than the capillary saturation. Frost damage occurs during an outdoor exposure where a prolonged rainy period is immediately followed by severe frost. Results of simulations of the case studies with KNMI climate data indicate the most risk for frost damage to occur during the winters 1978/1979 and 1981/1982. It follows from literature that these winters in reality, indeed have been observed as typical frost damage winters.

### recommendations

Try to make a correlation between the depth where possible risk of frost damage can occur in brick and the outside air temperature and rain intensity just before the occurrence of frost damage.

The developed heat and moisture model can be used to investigate possible frost damage in other areas in Europe, so by applying other climate data research.

The complete research is written in the master thesis of Aarle (2013).



3. depth of the risk of frost damage seen from the outer surface into the construction for the months January and February of 1979

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