# THE INFLUENCE OF OUTDOOR CONDITIONS ON THE STRAIN IN BRICK MASONRY

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## ABSTRACT

One aspect of the investigation into the spacing of movement joints in masonry walls involved the short term and long term deformation of mortar embedded in masonry. In this research the influence of hardening conditions on the physical and mechanical properties of masonry were studied, with a focus on the influence of outdoor conditions.
Mortar made in steel moulds (according to European Standards), mortar made in brick moulds, brick-mortar couplets and wallettes have been investigated under constant (20 $^{o}$C, 60 % RH) and outdoor conditions. During the test period the deformation (for all specimens), the weight (of the small specimens) and the strength (of the mortar prisms) at the end of the period were determined.

Outdoors, the weight of the mortar prisms and couplets was always (over the whole year) higher than in the climate room. For mortar prisms shrinkage was the dominant factor, where in couplets and wallettes, due to the bond in clay brick masonry, the shrinkage was restrained and expansion was measured in summertime. The strains due to shrinkage and climate influences, in the clay brick masonry couplets and wallettes were not higher than ± 0.17 mm/m.

**KEYWORDS**: outdoor conditions, strain, movement joints, crack control

## INTRODUCTION

In the Netherlands, due to numerous regulations, many movement joints are used in masonry veneer walls. According to European standard EC 6 [1] the maximum recommended spacing of vertical movement joints is 12 m (Figure 1). Architects, owners and contractors are less enthusiastic about these movement joints, because they seldom have a positive influence on the appearance, they are expensive, they have to be maintained and they have a negative influence on the structural coherence of the veneer wall.

For this reason, Eindhoven University of Technology, began an investigation concerning façade engineering and the spacing of movement joints [2 and 3]. As part of this research project concerning crack control in veneer walls the influence of hardening conditions on the physical behaviour of masonry has been investigated. If cracks are allowed, the crack width should be limited to an acceptable value. If not, movement joints are needed. For the spacing of movement joints as well as for the determination of the crack width, design rules should be based on information about the detailing of the veneer walls (geometry, restrained deformation) and on the physical and mechanical characteristics of the masonry used (shrinkage, creep, relaxation, tensile strength). To date no such scientific based design rules have been developed.

**Figure 1: Many movement joints in a residential building**

A better understanding of the influence of hardening conditions on the behaviour of masonry was required to reach this goal. This paper will describe some time-dependent parameters influencing crack initiation and propagation such as: shrinkage (hardening and drying) and thermal deformations for fired clay brick masonry and masonry mortar. The research program in this project included experiments on mortar prisms hardened in steel moulds and brick moulds, as well as masonry couplets and wallettes.

**MORTAR PRISMS - SPECIMENS**

This section describes a year's investigation of masonry cement mortar for bricks with a high absorption rate (M5) and the influence of the type of mould and the outdoor conditions on the material properties of the mortar. It is important to note that mortar hardened in steel moulds differs from mortar hardened between bricks [4, 5 and 6].

Two types of mortar prisms were made (4 specimens per type):

1. Mortar prisms, with a nominal size of 160 x 40 x 40 mm constructed in a steel mould [1] (Figure 2 left).
2. Mortar prisms, with a size of approximately 160 x 40 x 41 mm constructed in a mould of fired clay bricks (IRA = 34 g/dm$^2$/min) and filters (Figure 2 right).

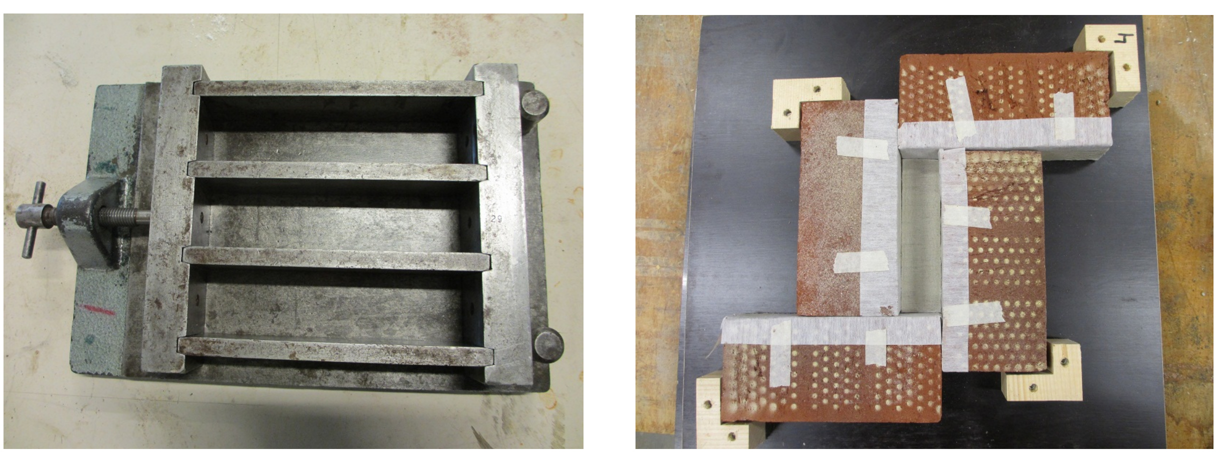


**Figure 2: Steel and brick mould**

The prisms were stored for the first 7 days in a humid condition (20 $^oC$ / 90-95 % RH) and afterwards in a climate controlled room (20 $^oC$ / 60 % RH) on wooden strips (Figure 3) or outdoors on wooden strips (2 per type per climate condition). The time dependant properties of the prisms (weight and deformations) were monitored at specified times.

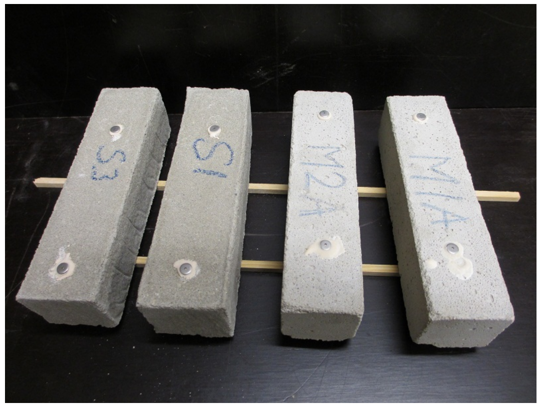



**Figure 3: Masonry mortar prisms on wooden strips**

**MORTAR PRISMS - RESULTS**

Figure 4 shows the average test results for the change of weight (Figure 4 left) and the change of length or strain (Figure 4 right) at specified times for the different prism types.

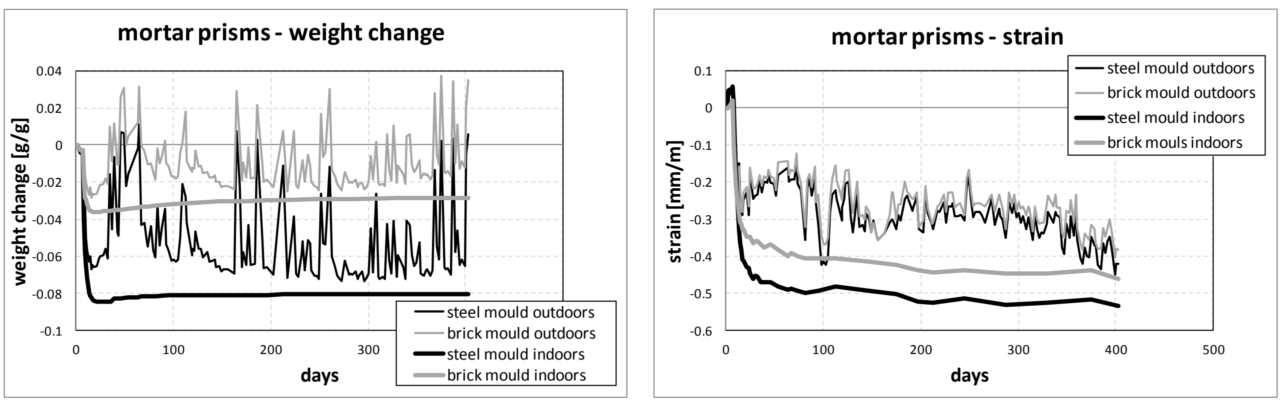



**Figure 4: Results mortar prisms, change of weight and strain**

From the results it was concluded that:

- The weight loss that occurred in the first days after 7 days exposure to a humid environment is less for mortar prisms made in brick moulds (3%), than for mortar prisms made in steel moulds (8%) (factor 2.5). The brick mould prisms already lost water to the bricks in the mould;
- The total shrinkage for brick mould prisms is less (0,46 mm/m at 400 days indoors) than for steel moulds prisms (0,53 mm/m at 400 days indoors);
- The outdoor prisms for steel and brick moulds show the same trend, also the strain is almost the Same, but the weight loss is lower for brick mould prisms than for steel mould prisms;
- The weight loss and shrinkage is always smaller in outdoor prisms, than in indoor prisms.

Table 1 gives the test results for the mechanical properties: density, flexural strength and compressive strength at 403 days for the different prism types (1 specimen per type).

**Table 1: Mechanical properties at 403 days**

| Results / Hardening condition | Density | Flexural strength | Compressive strength |
|---|---|---|---|
| | [kg/m$^3$] | [N/mm$^2$] | [N/mm$^2$] |
| | 403 days | 403 days | 403 days |
| indoor steel mould | 1660 | 1.6 | 3.8 |
| indoor brick mould | 1585 | 5.1 | 7.1 |
| outdoor steel mould | 1720 | 1.9 | 5.9 |
| outdoor brick mould | 1785 | 4.6 | 9.3 |

From the results it was concluded that:
- The flexural and compressive strengths are higher for brick mould prisms (factor 2) than for steel mould prisms;
- The flexural and compressive strengths are slightly higher for outdoor prisms than for indoor prisms;
- As a result, for calculating the spacing of movement joints in clay brick masonry, the values of the strength of mortar hardened in steel moulds and hardened indoors gives incorrect results.

In previous research the same trends for the behaviour of indoor masonry mortar prisms were observed [7]: brick mould prisms showed less weight loss and shrinkage and the end strength was higher (Figure 5 and Table 2).

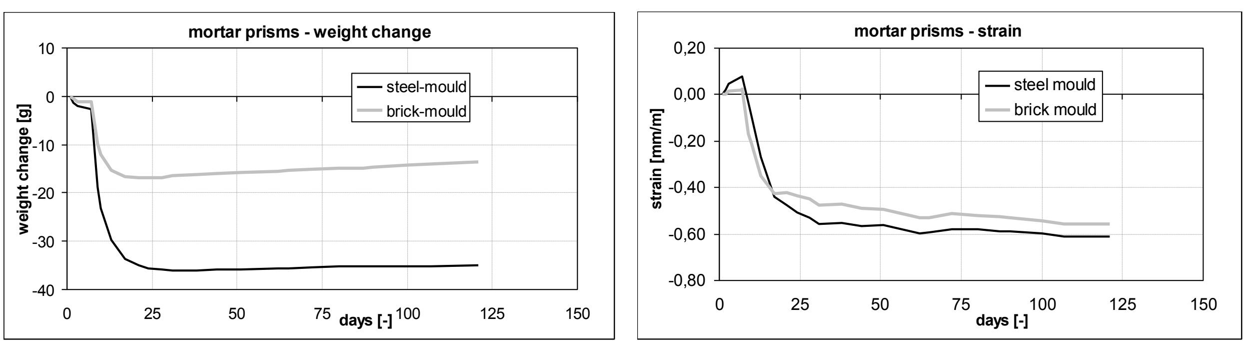



**Figure 5: results brick masonry mortar interaction (weight change and strain)**

**Table 2: Mechanical properties brick masonry mortar interaction**

| Results / Type mould | Flexural strength | | | Compressive strength | | |
|---|---|---|---|---|---|---|
| | [N/mm$^2$] | | | [N/mm$^2$] | | |
| | 28d | 90d | 240d | 28d | 90d | 240d |
| steel mould | 2.5 | 2.3 | 2.3 | 6.1 | 5.6 | 5.6 |
| CS-mould | 3.7 | 4.1 | 5.1 | 4.2 | 5.7 | 7.4 |

## COUPLETS AND WALLETTES - SPECIMENS

In this section the investigation into the influence of the outdoor conditions on the material properties of the fired clay brick masonry is presented.

Two types of masonry specimens were constructed (Figure 6 and 7 right, 2 specimens per type), with masonry cement mortar for bricks with a high absorption rate (M5) and fired clay bricks (IRA = 33 $g/dm^2/min$):

1. Couplets (Figure 6).
2. Wallettes, 2½ bricks wide and 9 bricks high (Figure 7).

The bricks had a nominal size of 196 x 96 x 50 mm and the layer of mortar was approximately 12 mm thick. The couplets and wallettes were stored for the first 7 days in a humid condition (20 $^oC$ / 90-95 % RH) and afterwards in a climate room (20 $^oC$ / 60 % RH) or outdoors.

The time dependant properties of the couplets (weight and deformations) and wallettes (deformations) were monitored at specified times (Figure 6 and 7 left).

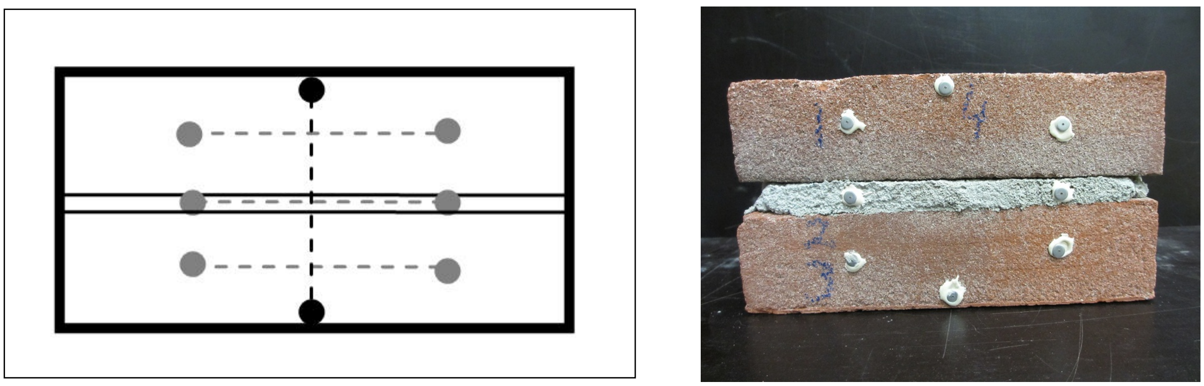


**Figure 6: Masonry couplet**

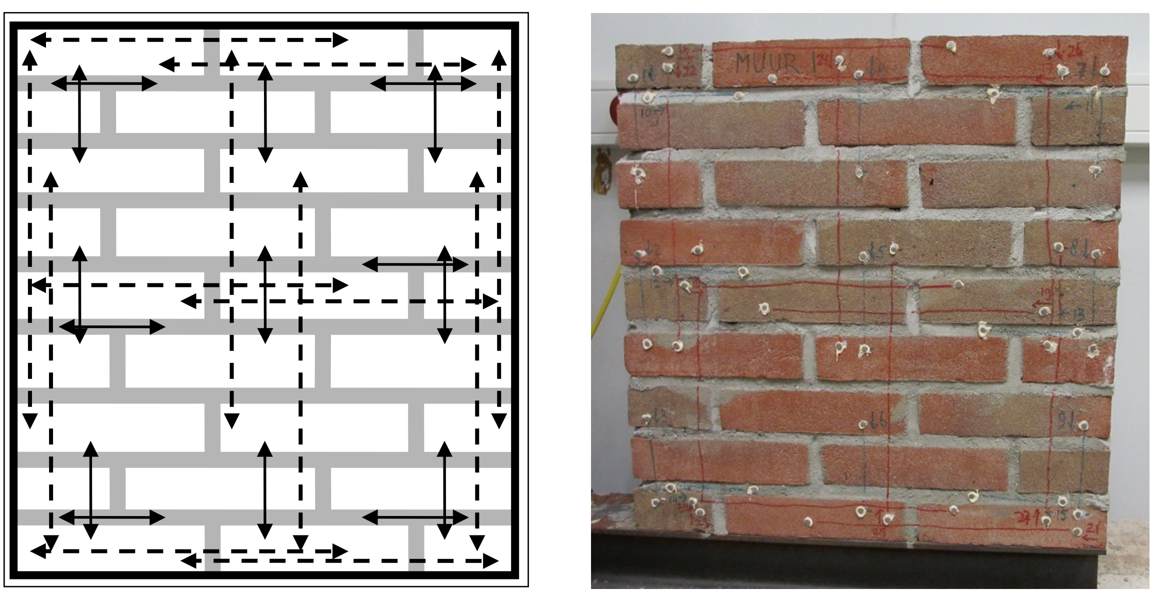
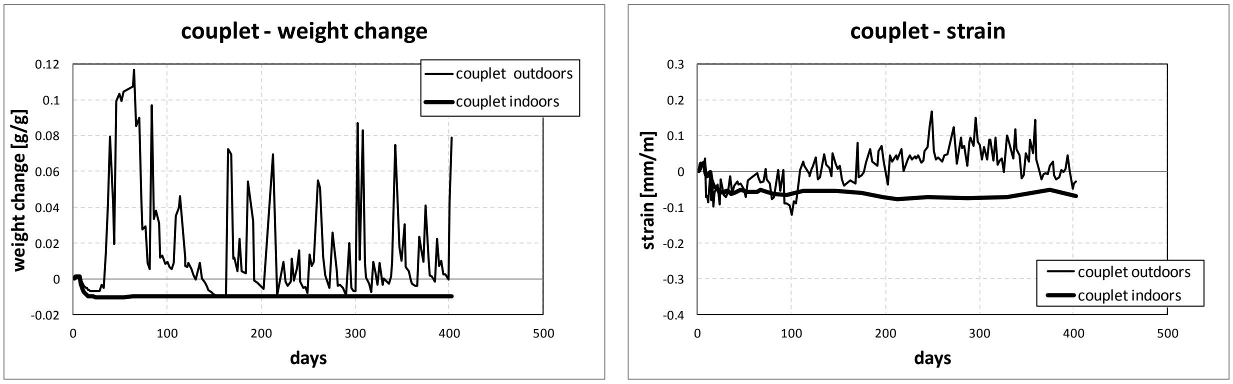



**Figure 7: Masonry wallette**

## COUPLETS AND WALLETTES - RESULTS

Figure 8 shows the average test results for the change of weight (Figure 8 left) and the change of length or strain (Figure 8 right) at specified times for the different couplets and wallettes (Figure 8 right bottom).




| | date | day no. |
|---|---|---|
| Start | October 31th, 2011 | 0 |
| Winter | December 21th, 2011 | 51 |
| Spring | March 21th, 2012 | 142 |
| Summer | June 21th, 2012 | 234 |
| Autumn | September 21th, 2012 | 326 |

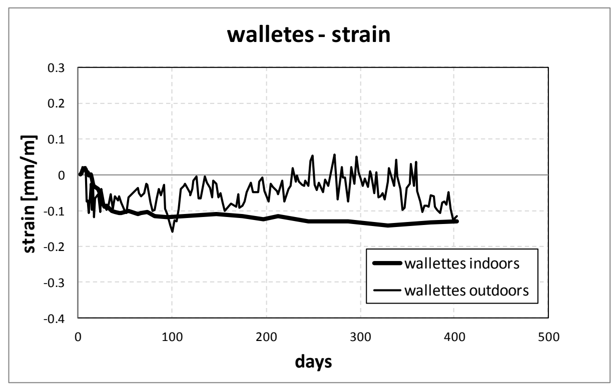



**Figure 8: Results couplets and wallettes**

From the results it was concluded that:

- The weight for the couplets outdoors is always higher (between -1% and + 12 %) than in the climate room (-1%);
- The deformations were not as strongly influenced by the climate conditions in the autumn and winter seasons: The shrinkage for the wallettes in the climate room remained restricted to 0.12 mm/m and for the couplets to 0.08 mm/m. The strain for the wallettes outdoors was between 0 and -0.16 mm/m and for couplets between +0.05 and -0.12 mm/m;
- The outdoor specimens exhibited less shrinkage than indoor specimens, and even a slight swelling was observed (couplets: -0.05 to +0.17 mm/m and wallettes: -0.07 to +0.06 mm/m);
- It is clear that the bond in the clay bricks masonry prevented the shrinkage of the mortar in the horizontal and vertical directions.

In previous research, the same trends for small wallettes (Figure 9) in indoor and outdoor conditions were observed [7]. (The start date for this research was November 3th 2009.): the weight was outdoors always higher, the deformations in autumn and winter time were in the same range as indoors and the shrinkage in summer and spring time was always lower for outdoor wallettes than for climate room wallettes (Figure 10).

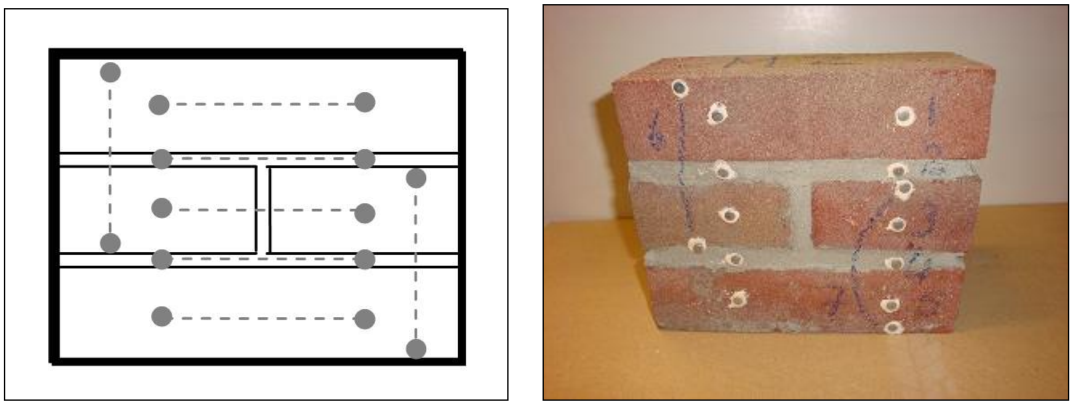


**Figure 9: Small wallettes** [7]

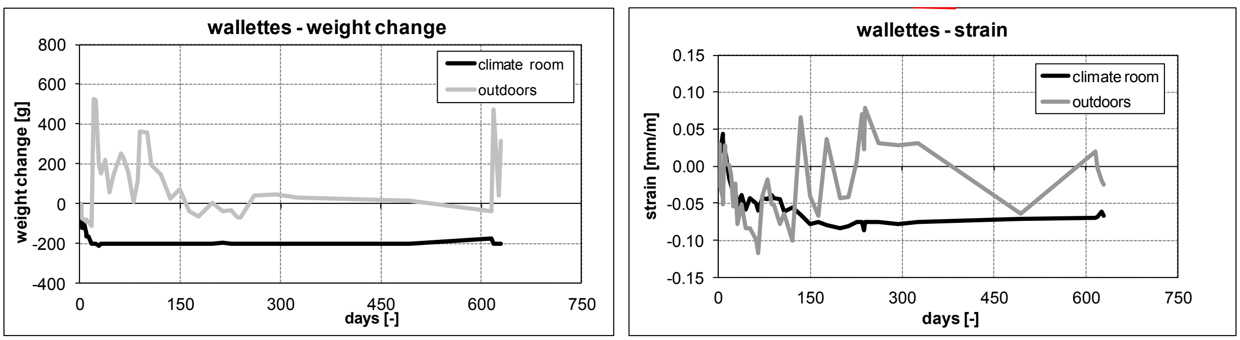



**Figure: weight change and strain results for small wallettes [7]**

## DISCUSSION

A comparison was made between the results of this research and the theoretical behaviour of clay brick masonry in winter and summer times, the acceptable shrinkage values from EC 6 [9], and the numerical results of van Zijl [10].

First the results from this research were compared with the theoretical thermal behaviour of clay brick masonry walls. The thermal expansion coefficient ($\alpha$) for clay brick masonry is $6x10^{-6}$ $K^{-1}$. The theoretical deformation ($\Delta L$) per m of clay brick masonry, with a minimum temperature ($T_{winter}$) of -10 $^{o}C$, a maximum temperature ($T_{summer}$) of 70 $^{o}C$ and a building temperature ($T_{build}$) of 20 $^{o}C$ (in the climate room) is (see equation 1 and 2):

$$\Delta L_{winter} / m = \alpha * (\Delta T) = \alpha * (T_{build} - T_{winter}) = 6x10^{-6} *1000 * (20 - -10) = 0.18\ mm/m \quad (1)$$

$$\Delta L_{summer} / m = \alpha * (\Delta T) = \alpha * (T_{summer} - T_{build}) = 6x10^{-6} *1000 * (70 - 20) = 0.30\ mm/m \quad (2)$$

In this research the highest shrinkage observed was 0.16 mm/m in the outdoor wallette in winter time and the largest swelling observed was +0.17 mm/m in the outdoor couplet in summer time (+0.05 for the wallette).

The measured deformation in summer time was lower than the theoretical expected deformation. Therefore, on a sunny day on August 24th 2012 the surface temperature of the outdoor couplet and wallette was measured at 40 $^{o}C$ (air temperature 24 $^{o}C$). The highest surface temperature on a small house measured on-site [3 and 8] was 49.2 $^{o}$C over a measuring period of two years, for a similar colour fired clay brick masonry.

According to European standard EC 6 [9] the long term hygrical deformations should be between -0.2 and +1.0 mm/m. This corresponded with the measurements in this research, where the deformations observed were between -0.16 (in winter) and +0.17 mm/m (in summer).

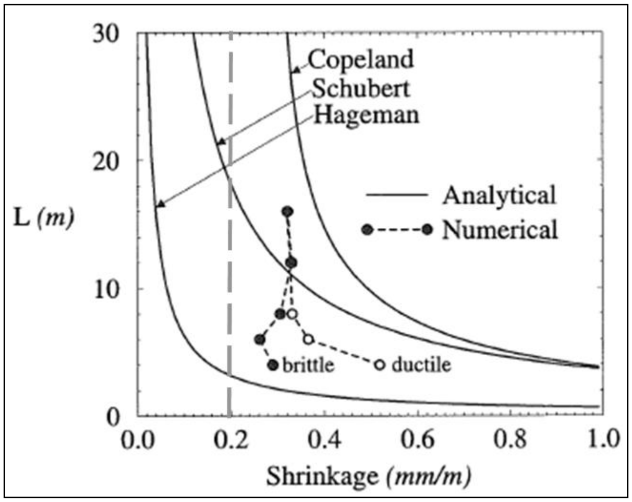



**Figure 11: Comparison of numerically and analytically determined "uncracked" brick wall length under base-restrained shrinkage [10]**

Van Zijl [10] made a comparison between his numerical calculations and analytical rules developed by Copeland, Hageman and Schubert (Figure 11). All values of wall lengths can be considered as crack free or ensure that cracks wider than 0.5 mm will not occur, when the shrinkage is lower than the numerical modelled values (< 0.2 mm/m).

In this research, in the couplets and wallettes, measured deformations smaller than 0.17 mm/m were found, for hardening, drying, winter and summer conditions. So the measured deformations are smaller than the numerical modelled values for crack free masonry. This suggests that it is not necessary to place movement joints in this type of clay brick masonry, because of shrinkage by hardening and drying and thermal deformations.

## CONCLUSION

Brick mould prisms showed less total weight loss and shrinkage and the end strength was higher than in steel mould prisms.
The values of the strength of mortar hardened in steel moulds and mortar hardened indoors gave incorrect results for calculating the spacing of movement joints.

The weight of the outdoor specimens was always higher than of the indoor specimens. The deformations in autumn and winter time were in the same range as indoors and the shrinkage in summer and spring time was always lower for outdoor wallettes than for climate room wallettes.

The results confirm the shrinkage values from theoretical thermal behaviour, EC 6 and numerical values in the thesis of van Zijl [10].

The strains measured in the clay brick masonry couplets and wallettes were not higher than 0,17 mm/m. Therefore placing movement joints in this type of masonry is not necessary because of shrinkage by hardening and drying and thermal deformations.

This research will continued with experiments on veneer walls in a building façade and other material combinations of masonry mortars or thin bed layer mortars, bricks, blocks and other (larger) elements.

In the future all the collected information will be implemented in numerical and analytical modelling of crack control of (veneer) masonry walls culminating in practical design rules.

**ACKNOWLEDGEMENT**
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