# Movement in Masonry Walls Caused by Temperature and Moisture Changes

by

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**ABSTRACT**
*Movement in masonry walls of buildings is frequently associated with changes in temperature and moisture in the constituent materials and in the surrounding elements such as reinforced concrete beams, slabs and roofs. These changes also induce stresses in the walls that may lead to considerable damage in them and consequently affect the performance and durability of the building. The purpose of this paper is to discuss the factors that influence temperature and moisture movements in walls.*

*It is well known that masonry units (concrete units and clay bricks) usually expand when wet and shrink when dry. So, experimental tests were developed to assess the dimensional and weight variations of masonry unit specimens (with or without a mortar joint) subjected to moisture and temperature changes and to evaluate the behaviour of masonry walls when exposed to weathering which results in cyclic moisture content and dimensional changes to the wall.*

*The results of these tests reveal the significant contribution of the dimensional variation of masonry constituent materials to the overall movement of the wall.*

## 1. INTRODUCTION

Changes in environment and in loading can cause significant movements in buildings. Usually the main causes of these movements are related to temperature and moisture changes, settlement of foundations, excessive deflection of supporting beams, elastic and time-dependent deformations (creep), vibration and chemical reactions within the materials [1] to [7] (see in Table 1, estimated variation of dimensional stability variables for two different types of masonry, [5]). These movements cannot be computed as a simple summation of each individual contributory effect, but are rather the result of a complex behaviour that is difficult to analyse.

With the rise or fall of temperature, the construction elements expand or contract, and due to the fact that these elements are wholly or partially restrained, stresses are consequently induced and can be considerable, even more than those from external loading. These changes of temperature may act uniformly on these elements; but under normal climatic conditions, the temperature gradient set up within the elements is usually non-linear and the induced internal stresses can be significant.

As mentioned above, another cause of movement in walls is associated with moisture change (so called "moisture movement") because masonry is a porous material. Moisture may enter in different ways such as vapour diffusion, air movement, rain penetration, and seepage. At low humidity, the migration of moisture in brickwork and block masonry is outwards, whereas at high humidity both types of masonry will absorb moisture. In practice, a wall is not totally saturated and usually stands in a relative humidity of between 50% and 80%. Besides causing movement in walls, the presence of moisture in the building envelope also affects the structural behaviour of building components through mechanical, chemical and possibly biological degradation. Damage induced by moisture is often related to efflorescence of masonry walls and corrosion of wall fixings. Excessive moisture in the envelope may also affect the health of occupants (by leading to an unhealthy indoor environment) and can reduce the effectiveness of thermal insulation and damage aesthetic appearance. Therefore, moisture control in the building envelope is important for several reasons and implies both minimizing moisture entry into the building envelope and maximizing the exit of moisture that is present inside, so that the time for which the construction elements in the building remain wet can be limited.

Frequently, movement in masonry walls of buildings is associated with changes, both in temperature and in moisture, that occur in the constituent materials and in the surrounding elements such as reinforced concrete beams, slabs and roofs. Just as masonry materials are subject to expansion due to an increase in temperature, they are also subject to shrinkage as moisture is lost.

Moisture expansion or shrinkage presents a non-linear behaviour, whereas temperature contraction or expansion is directly proportional to the change of temperature (see Table 2 for typical values of moisture and linear thermal expansion, [5]).

These combined changes induce stresses in the walls that may considerably damage them (particularly in terms of cracking), and consequently affect the performance and durability of the building. According to fracture mechanics applied to masonry [6], it is tensile stress which is associated with the formation of visible cracks, whether the load is compressive (which induces tension transverse to the axial force) or shear (which induces a diagonal tensile stress). Excessive shrinkage in masonry units and mortar when drying after initial construction can also result in cracks. If masonry constituent materials are made with Portland cement, the shrinkage is related to water loss (reversible shrinkage) and carbonation (irreversible shrinkage). Initial shrinkage is an intrinsic property of construction materials such as concrete and cement-based masonry units.

The purpose of this paper is to discuss factors that can influence temperature and moisture movement in masonry walls, particularly those related to the essential properties of the constituent materials.

## 2. EXPERIMENTAL TESTS ON MASONRY MATERIALS

### 2.1 General

Concrete and brick expand when wet and shrink when dry. When exposed to weathering, cyclic changes may occur in moisture content and consequently dimensional changes may also happen.

It has been shown by other work [6} that concrete masonry units, which had been previously dried to equilibrium with low humidity, and were subsequently sprayed on one face for two hours to simulate rain, re-expand by approximately one third of their original shrinkage from a saturated condition .

ASTM (1985) specifies for the maximum moisture content of concrete masonry units (CMU) values ranging from 25% to 45% depending on CMU shrinkage and annual relative humidity at the construction site [6]. Generally, unrestrained concrete wall shrinkage is most probably between the value of unrestrained shrinkage of the concrete masonry units and that of the mortar (usually this latter is greater than the CMU shrinkage). Total concrete masonry wall shrinkage may vary between 0.1mm/m and 10mm/m.

Experimental tests were developed at LNEC to assess the dimensional and mass variations of masonry block specimens and blockwork couplets with a mortar joint when subjected to moisture and temperature changes (temperature and moisture variation test). The main objective of these tests was to evaluate the significance of dimensional variations of masonry constituent materials for the overall movement of the wall.

All of the figures for changes in mass and dimensions that follow in this section are mean values related to the properties of the units at the start of the test period.

**2.2 Aerated autoclaved concrete blocks**

The test aimed to evaluate the behaviour in terms of mass and dimensional variation of block material of autoclaved aerated concrete when subjected to a cyclic variation of moisture and temperature (two cycles - see Table 3). Six cubic specimens (approximate dimension - 100mm) of autoclaved aerated concrete (dry density - 560kg/m$^3$) were subjected to a period of drying (3 days in a oven at a constant temperature of 70ºC and a relative humidity of about 20%) followed by a period of 3 days stored in laboratory conditions (closed ambient room - 20ºC ± 5º and relative humidity 45% ± 5%) and followed again by a period of immersion in water (7 days). The specimens were then stored in laboratory conditions for 1 day (the 14$^{th}$ day). The specimens were then subjected to a second cycle with a similar methodology to the first.

After the first three day period in the oven, there was a slight decrease in mass of the specimens (1.4%) but they almost returned to their initial mass by the end of the following period in laboratory conditions. In the same period, the specimens' dimensional change increased significantly, and on removal from the oven there was a 0.37mm/m contraction (Table 6). It then decreased significantly (i.e., it re-expanded) almost back to its original value. During the 7$^{th}$ day of the test (beginning of the immersion period), a strong increase of the mass (45%) and a dimensional deviation (0.28mm/m expansion) was detected. In the subsequent days up to the end of the 13$^{th}$ day (end of the immersion period), the mass variation showed a relatively moderate change (from a 45% to a 60% increase) and the dimensional variation almost stabilized. When there was a contraction of the specimens during their period in the oven (with peak value of 0.37mm/m after the 3$^{rd}$ day in the 1$^{st}$ cycle and 0.35mm/m after the 17$^{th}$ day in the 2$^{nd}$ cycle), the mass generally decreased (peak value of almost 1.5% after the 3$^{rd}$ day in the 1$^{st}$ cycle and a litt1e over 1.5% after the 17$^{th}$ day in the 2$^{nd}$ cycle). The expansion of the specimens during their period of immersion in water (with a peak value of 0.28mm/m after the 13$^{th}$ day in the 1$^{st}$ cycle and 0.17mm/m after the 27$^{th}$ day in the 2$^{nd}$ cycle) was accompanied by a significant increase of mass (with a peak value of 59% after the 13$^{th}$ day in the 1$^{st}$ cycle and 58% after the 27$^{th}$ day in 2$^{nd}$ cycle).

With exception of the period of immersion in the 1$^{st}$ cycle (especially between the 8$^{th}$ and 13$^{th}$ days when the dimensional variation almost stabilized), the variation of the mean value of mass was generally accompanied by a significant dimensional variation of the specimens.

**2.3 Bricks**

The same methodology of testing was used to evaluate the behaviour in terms of mass and dimensional variation of solid brick material when subjected to a cyclic variation of moisture and temperature (Table 4). Six prismatic specimens of bricks (100mm x 100mm x 65mm) were tested in same way as described previously in 2.2.

In the first period (period in an oven), there was a slight increase in the mass of the specimens (0.2%) but this almost returned to the initial value after the period in laboratory conditions. In the same period, the specimens' dimensional change (measured in one direction, $l_1$, for Z1-Z6, and in two directions, $l_1$ , $l_2$ , only for Z1-Z3) increased moderately, and after the 1$^{st}$ day was about 0.12mm/m (expansion - $l_1$), and then it decreased a little. During the 7$^{th}$ day of the test (beginning of the immersion period), an increase of the mass (12.4%) and dimensional change (0.15mm/m contraction) was detected. Up to the end of the immersion period (13$^{th}$ day), the mass variation showed a relatively small variation (13.0%) and the dimensional variation reduced a little (0.10mm/m after the 13$^{th}$ day).

**2.4 Lightweight concrete blocks with expanded clay aggregate**

The same test as described in 2.2 was carried out on six cubic specimens (approximate dimension - 100mm) aiming to assess the behaviour in terms of mass and dimensional variation of blocks made from lightweight concrete with expanded clay aggregate when there is a cyclic variation of conditions of moisture and temperature (Table 5). The blocks of lightweight concrete with expanded clay aggregate had a dry density of 1040kg/m$^3$.

All the specimens were subjected to successive periods of drying in an oven at a constant temperature (70ºC) followed by a period during which they remained in laboratory conditions and finally a period of immersion in water. After that period, the specimens were again placed in an oven and put through a second similar cycle.

During the first period (in the oven), a steady increase in the mass of the specimens (2.0% after the 1$^{st}$ day and 2.9% after the 3$^{rd}$ day) was detected. At the same time, the specimens' dimensional change increased very sharply in the first 24 hours (reaching 0.58mm/m expansion) and then decreased until end of the 6$^{th}$ day, when it reached a value of about 0.20mm/m (contraction). The mass of the specimens during the period in laboratory conditions decreased a little (2.3%) by the end of the 6º day. During the immersion period between the 6$^{th}$ and 13$^{th}$ day of the test, there was a moderate increase of mass (reaching 8.8% after the 13$^{th}$ day) and a small dimensional deviation (0.17mm/m expansion). During the immersion period, the mass variation showed a relative moderate variation after the 8$^{th}$ day (8.2% - 8.8%).

**2.5 Lightweight concrete with expanded clay aggregates blocks with mortar joints (block-block and block-concrete)**

The same characteristics were also investigated through tests using the same methodology as above on blockwork specimens. These were couplets built with a cement mortar joint (cube specimens of cement/sand mortar, 1:5, compressive strength = 5.16 N/mm$^2$). These tests aimed to investigate the behaviour of the mortar joint between blocks (Yj1-Yj2) or, to simulate joint contact between masonry and beams, floors or columns, between blocks and concrete elements (Yb1-Yb2). A total of four cubic specimens (approximate dimension of 100mm) were tested. Two of these were of lightweight concrete containing a mortar joint (Yj1, Yj2 – both halves of lightweight concrete, see Figure 5 and Table 5): the other two were composites of a normal concrete section joined to a lightweight concrete section (Yb1, Yb2 - see Figure 6 and Table 5). The deformation was measured in each specimen in two parallel directions, one in first half of the specimen, $l_1$ (in masonry block for Yj1 and Yj2, and concrete for Yb1 and Yb2), the other in the second half of the specimen, $l_2$ (masonry block).

In the first period (period in an oven), there was a slight increase in mass of specimens Yj1, Yj2, Yb1 and Yb2 similar to the increase in mass of the Y1-Y6 series. In same period, the specimens' dimensional variation increased significantly. The difference for Yb2 ($\Delta l/l_1$-$\Delta l/l_2$) was positive with the exception of the initial period (1$^{st}$ and 2$^{nd}$ days), (Figure 4) and the concrete material was contracting less than block material. The change for Yj2 was, compared with Yb1-Yb2, a little higher in absolute values (see Figure 7). Both the Yj2 and the Yb1-Yb2 changes generally a more stable evolution than the dimensional variation of the Y1-Y6 series (see Table 5 and Figure 4). Between the 6$^{th}$ and 7$^{th}$ day of the test, an increase in mass was detected. For Yj1-Yj2, this variation of mass was more pronounced than the corresponding values of the Y1-Y6 series. These latter in turn were greater than the Yb1-Yb2 values. In the subsequent days, up to the end of the 13$^{th}$ day, the mass variation showed a relatively modest variation.

It is important to stress that, compared with the unrestrained shrinkage of mortar specimens, the horizontal shrinkage of mortar in the bed joints of masonry is considerably reduced (it can be about 50% less, [6]) due the effect of restraint by shear with the masonry units. Mortar joint cracking is increased when the fineness of the mortar sand is increased. The effective free movement is likely to be greater than that of concrete units since initial moisture loss will not totally take place due to reversible movement (typical values lie between 0.3 and 0.6mm/m) after initial drying shrinkage (typical values are between 0.4 and 1.0mm/m - [6]). The shrinkage values of mortar depend upon its constituents.

## 3. MAIN CONCLUSIONS OF THE TESTS RESULTS

The results of the temperature and moisture variation test on series X1-X6 (autoclaved aerated concrete), Y1-Y6 (lightweight concrete with expanded clay aggregates) and Z1-Z3 (bricks), showed some common features between them as well as important differences in their behaviour. The same comments can be applied to specimens Yj1 and Yj2 (lightweight concrete with expanded clay aggregate block with mortar joint), and specimens Yb1 and Yb2 (lightweight concrete with expanded clay aggregate block-concrete with mortar joint).

From the results of the tests it can be concluded that the Y1-Y6 series (mean values) during “dry” periods loss their mass more than the other series (0-2$^{nd}$ days; 14$^{th}$-16$^{th}$ days). During the “immersion” periods (6-13$^{th}$ days; 20$^{th}$-27$^{th}$ days), X1-X6 series (mean values) increased their mass clearly more than the other series, especially with regard to Y series, although the Z series was very similar in this respect to the Y series.

In all these series, the difference between the two relative peaks of negative mass variation (1$^{st}$ cycle –13$^{th}$ day and 2$^{nd}$ cycle – 27$^{th}$ day) was not so significant; but a trend was detected in the specimens of each series towards the reduction of the peak in the 2$^{nd}$ cycle. Apart from that, the type of mass variation of these three series (X, Y and Z) showed a similar behaviour in the 2$^{nd}$ cycle when compared with that in the 1$^{st}$ cycle. This suggests an approximation to reversible behaviour from the point of view of mass variation during these two cycles.

The results showed that, generally, Y series (mean values) shrink during “dry” periods (0-2$^{rd}$ days and 14$^{th}$-16$^{th}$ days) while the X and Z series expand during the same periods, even though in the second cycle the Z series did not reach positive values as the X series did. In the first immersion period (6$^{th}$-13$^{th}$ days), the dimensional variation of the Z series exhibited a similar pattern to that of the X series; but a different type of progression was detected in the second dry period (20$^{th}$-27$^{th}$ days) with a trend to a strong contraction of the specimens. From the type of dimensional variation shown by these three series, a slight tendency to a similar behaviour of X and Y series in the 2$^{nd}$ cycle when compared with those obtained in the 1$^{st}$ cycle can be found. However, for the Z series, a different type of trend during the two cycles was evident.

The difference of dimensional variation ($\Delta l/l_1$-$\Delta l/l_2$) of Yj2 (with mortar joint- block-block) was a bit larger in absolute values than that of Yb1-Yb2 (with mortar joint - block-concrete), and both generally followed the trend of variation of Y1-Y6, although with higher absolute values (see Figure 7).

The results of these tests revealed the differences of dimensional variations, and the associated mass variations, of each type of masonry block material. That fact indicates a potential influence of the dimensional variations of masonry constituent materials in the overall movement of the different types of wall.

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**Table 1**
**Estimated variation of dimensional stability variables [5]**

| | Brick Masonry | | | | | | Hollow concrete masonry | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Modulus of elasticity (MPa x $10^3$)** | **Elastic strain (mm/m)** | **Creep (mm/m)** | **Moisture expansion (mm/m)** | **Temperature change (ºC)** | **Thermal dimensional change (mm/m)** | **Modulus of elasticity (MPa x $10^3$)** | **Elastic strain (mm/m)** | **Creep (mm/m)** | **Moisture expansion (mm/m)** | **Temperature change (ºC)** | **Thermal dimensional change (mm/m)** |
| Minimum | 2.57 | 0 | 0 | 0 | 0 | 0 | 2.07 | 0 | 0 | 0 | 0 | 0 |
| Maximum | 29.67 | -0.472 | -0.471 | +0.486 | 62.2º | 0.773 | 8.28 | -0.80 | -2.40 | 0 | 42.7º | +0.578 |
| Mean | 11.73 | -0.176 | -0.088 | +0.186 | 37.2º | 0.228 | 17.25 | -0.25 | -0.438 | 0 | 17.8º | +0.138 |

**Table 2**
**Typical values of moisture and linear thermal expansion [5]**

| **Materials** | | | | |
|---|---|---|---|---|
| Dense concrete (gravel aggregate) | **Moisture expansion- dry to saturated (mm/m)** | | **Linear thermal expansion** | |
| | **minimum reference value** | **maximum reference value** | **Coefficient of expansion per ºC x $10^{-6}$** | **Expansion mm/m (T=100ºC)** |
| Light aggregate concrete | 0.2 | 0.6 | 11.7 | 1.17 |
| Ultra-Light aggregate concrete | 0.3 | 0.6 | 8.3 | 0.83 |
| Limestone (average) | 1 | 2 | - | - |
| Sandstone | 0.1 | 0.1 | 2.5-9.0 | 0.25-0.90 |
| Brick (clay) | 0.5 | 0.8 | 7.0-16.0 | 0.70-1.60 |
| Brick (sand-lime) | 0.03 | 0.2 | 5.0 | 0.5 |
| Mortar | 0.1 | 0.5 | - | - |
| Glass reinforced cement | | | 3-11 | |
| Timber (perp. to the grain) | 1.5 | 2.5 | 7.0-12.0 | 0.70-1.20 |
| Timber (along the grain) | 20 | 80 | 50-60 | 5.0-6.0 |
| Aluminium | 0.5 | 1 | 3.8-6.5 | 0.38-0.65 |
| Stainless steel | - | - | 23.5 | 2.35 |
| Structural steel | - | - | 18.0 | 1.80 |
| Granite | - | - | 12.1 | 1.21 |
| Marble | - | - | 8.5-11.0 | 0.85-1.10 |
| Glass | - | - | 13.2 | 1.32 |
| | | | | |

**Table 3**
**Temperature and moisture variation test (specimens of autoclaved aerated concrete - X1 a X6)**

| **Temp. (ºC)** | **Mass value and mass and dimensional variation (relative to the initial value)** | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Period in oven** | | | **Lab. cond.** | **Immersion in water** | | | **Lab. cond.** | **Period in oven** | | | **Lab. Cond.** | **Immersion in water** | | | **Lab. conditions /end of test** |
| Time Days | 0ºD | 1ºD | 2º D | 3ºD | 6ºD | 7ºD | 8ºD | 13ºD | 14º D | 15ºD | 16ºD | 17ºD | 20ºD | 21º D | 22ºD | 27ºD | 28ºD |
| **X1**-m | 587 | 579 | 579 | 579 | 587 | 872 | 903 | 962 | 937 | 639 | 594 | 578 | 586 | 876 | 904 | 947 | 919 |
| Δm/m | 0 | 0.0136 | 0.0136 | 0.0136 | 0 | -0.4855 | -0.5383 | -0.6388 | 0.5963 | -0.08859 | -0.01193 | 0.01533 | 0.00170 | -0.49233 | -0.54003 | 0.61329 | -0.56559 |
| Δl/l | 0 | -0.2 | -0.3 | -0.35 | 0 | 0.2 | 0.2 | 0.2 | 0.15 | -0.2 | -0.2 | -0.6 | -0.55 | -0.3 | -0.35 | 0 | 0.15 |
| **X2**-m | 618 | 609 | 609 | 609 | 617 | 900 | 928 | 979 | 957 | 676 | 628 | 609 | 616 | 908 | 931 | 966 | 943 |
| Δm/m | 0 | 0.0146 | 0.0146 | 0.0146 | 0.0016 | -04563 | -0.5016 | -0.5841 | 0.5485 | -0.09385 | -0.01618 | 0.01456 | 0.00324 | -0.46926 | -0.50647 | 0.56311 | -0.52589 |
| Δl/l | 0 | -0.3 | -0.4 | -0.45 | -0.05 | 0.2 | 0.2 | 0.25 | 0.2 | -0.1 | -0.1 | -0.35 | -0.4 | -0.2 | -0.25 | 0.1 | 0.2 |
| **X3**-m | 619 | 610 | 610 | 610 | 618 | 894 | 924 | 967 | 938 | 669 | 625 | 609 | 617 | 902 | 933 | 959 | 933 |
| Δm/m | 0 | 0.01454 | 0.01454 | 0.01454 | 0.0016 | -0.4443 | -0.4927 | -0.5622 | 0.5153 | -0.08078 | -0.00969 | 0.01616 | 0.00323 | -0.45719 | -0.50727 | 0.54927 | -0.50727 |
| Δl/l | 0 | -0,.5 | -0.25 | -0.3 | 0.05 | 0.25 | 0.25 | 0.25 | 0.2 | 0.05 | 0.15 | -0.15 | -0.2 | 0.05 | 0 | 0.3 | 0.2 |
| **X4**-m | 592 | 583 | 583 | 583 | 591 | 865 | 895 | 947 | 923 | 649 | 601 | 583 | 590 | 882 | 911 | 944 | 916 |
| Δm/m | 0 | 0.01520 | 0.01520 | 0.01520 | 0.0017 | -0.4611 | -0.5118 | -0.5997 | 0.5591 | -0.09628 | -0.01520 | 0.01520 | 0.00338 | -0.48987 | -0.53885 | 0.59460 | -0.547297 |
| Δl/l | 0 | -0.3 | -0.3 | -0.35 | 0.1 | 0.35 | 0.35 | 0.35 | 0.3 | -0.05 | -0.05 | -0.4 | -0.35 | -0.1 | -0.15 | 0.2 | 0.3 |
| **X5** | 612 | 603 | 603 | 603 | 610 | 872 | 909 | 957 | 936 | 669 | 621 | 603 | 609 | 888 | 919 | 948 | 928 |
| Δm/m | 0 | 0.01471 | 0.01471 | 0.01471 | 0.0033 | -0.4248 | -0.4853 | -0.5637 | 0.5294 | -0.09314 | -0.01471 | 0.01471 | 0.00490 | -0.45098 | -0.50163 | 0.54902 | -0.51634 |
| Δl/l | 0 | -0.3 | -0.35 | -0.4 | 0.1 | 0.35 | 0.35 | 0.35 | 0.3 | 0 | 0 | -0.3 | -0.25 | -0.1 | -0.15 | 0.2 | 0.3 |
| **X6** | 598 | 590 | 589 | 589 | 597 | 870 | 913 | 978 | 950 | 652 | 604 | 588 | 596 | 893 | 919 | 957 | 933 |
| Δm/m | 0 | 0.01338 | 0.01505 | 0.01505 | 0.0017 | -0.4548 | -0.5268 | -0.6355 | 0.5887 | -0.09030 | -0.01003 | 0.01672 | 0.00335 | -0.49331 | -0.53679 | 0.60033 | -0.56020 |
| Δl/l | 0 | -0.25 | -0.3 | -0.35 | 0.05 | 0.3 | 0.3 | 0.3 | 0.2 | 0.05 | 0.1 | -0.3 | -0.2 | 0 | -005 | 0.2 | 0.2 |

Values of m (mass) in grams; Δm/m (mass relative variation) in % ; Δl/l (dimensional variation) in mm/m

**Table 4**
**Temperature and moisture variation test (specimens of bricks - Z1 to Z6)**

| **Temp. (ºC)** | **Mass value and mass and dimensional variation (relative to the initial value)** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Period in oven** | | | **Lab. cond.** | **Immersion in water** | | | **Lab. Cond.** | **Period in oven** | | | **Lab. cond.** | **Immersion in water** | | | **Lab. conditions /end of test** | |
| Time Days | 0ºD | 1ºD | 2º D | 3ºD | 6ºD | 7ºD | 8ºD | 13ºD | 14º D | 15ºD | 16ºD | 17ºD | 20ºD | 21º D | 22ºD | 27ºD | 28ºD |
| **Z1**-m | 1435 | 1432 | 1432 | 1432 | 1434 | 1607 | 1609 | 1616 | 1577 | 1436 | 1432 | 1432 | 1434 | 1601 | 1610 | 1614 | 1553 |
| Δm/m | 0 | 0.0021 | 0.0021 | 0.0021 | 0.0007 | -0.1199 | -0.1213 | -0.1261 | -0.0990 | -0.0007 | 0.0021 | 0.0021 | 0.0007 | -0.1157 | -0.1220 | -0.1247 | -0.0822 |
| $\Delta l/l_1$ | 0 | 0 | 0 | -0.1 | -0.4 | -0.3 | -0.2 | -0.2 | -0.4 | -0.1 | -0.3 | -0.4 | -0.7 | -0.8 | -0.9 | -0.6 | -0.6 |
| $\Delta l/l_2$ | 0 | 0 | 0 | 0 | -0.3 | -0.1 | 0 | 0 | -0.3 | -0.3 | -0.1 | -0.2 | -0.5 | -0.7 | -0.7 | -0.5 | 0 |
| **Z2**-m | 1211 | 1209 | 1209 | 1209 | 1211 | 1363 | 1365 | 1370 | 1344 | 1214 | 1209 | 1209 | 1211 | 1364 | 1366 | 1368 | 1325 |
| Δm/m | 0 | 0.0017 | 0.0017 | 0.0017 | 0 | -0.1255 | -0.1272 | -0.1313 | -0.1098 | -0.0025 | 0.0017 | 0.0017 | 0 | -0.1263 | -0.1280 | -0.1296 | -0.0942 |
| $\Delta l/l_1$ | 0 | 0.1 | 0.1 | 0.1 | -0.2 | * | - | - | - | - | - | - | - | - | - | - | - |
| $\Delta l/l_2$ | 0 | 0.2 | 0.1 | 0.1 | -0.3 | -0.1 | -0.1 | -0.1 | -0.3 | 0.2 | 0.2 | 0 | -0.3 | -0.4 | -0.4 | -0.2 | 0 |
| **Z3**-m | 1421 | 1418 | 1418 | 1418 | 1421 | 1602 | 1603 | 1609 | 1578 | 1427 | 1419 | 1419 | 1421 | 1602 | 1604 | 1609 | 1559 |
| Δm/m | 0 | 0.0021 | 0.0021 | 0.0021 | 0 | -0.1274 | -0.1281 | -0.1323 | -0.1105 | -0.0042 | 0.0014 | 0.0014 | 0 | -0.1274 | -0.1288 | -0.1323 | -0.0971 |
| $\Delta l/l_1$ | 0 | 0.1 | 0 | 0 | * | - | - | - | - | - | - | - | - | - | - | - | - |
| $\Delta l/l_2$ | 0 | 0.2 | 0.2 | 0.2 | -0.2 | 0 | 0 | 0.1 | -0.2 | * | - | - | - | - | - | - | - |
| **Z4**-m | 1407 | 1404 | 1404 | 1404 | 1406 | 1578 | 1580 | 1585 | 1555 | 1407 | 1404 | 1404 | 1399 | 1579 | 1580 | 1586 | 1541 |
| Δm/m | 0 | 0.0021 | 0.0021 | 0.0021 | 0.0007 | -0.1215 | -0.1230 | -0.1265 | -0.1052 | 0 | 0.0021 | 0.0021 | 0.0057 | -0.1222 | -0.1230 | -0.1272 | -0.0953 |
| $\Delta l/l_1$ | 0 | 0.1 | 0.1 | 0.1 | -0.2 | * | - | - | - | - | - | - | - | - | - | - | - |
| **Z5** | 1370 | 1367 | 1367 | 1367 | 1370 | 1547 | 1548 | 1553 | 1520 | 1376 | 1367 | 1367 | 1369 | 1547 | 1551 | 1553 | 1509 |
| Δm/m | 0 | 0.0022 | 0.0022 | 0.0022 | 0 | -0.1292 | -0.1299 | -0.1336 | -0.1095 | -0.0044 | 0.0022 | 0.0022 | 0.0007 | -0.1292 | -0.1321 | -0.1336 | -0.1015 |
| $\Delta l/l_1$ | 0 | 0.2 | 0.2 | 0.2 | -0.2 | 0 | 0 | 0 | -0.3 | 0 | -0.1 | -0.2 | -0.5 | -0.5 | -0.5 | -0.5 | -0.4 |
| **Z6** | 1402 | 1398 | 1398 | 1398 | 1401 | 1582 | 1584 | 1588 | 1556 | 1407 | 1399 | 1399 | 1394 | 1583 | 1584 | 1588 | 1534 |
| Δm/m | 0 | 0.0029 | 0.0028 | 0.0029 | 0.0007 | -0.1234 | -0.1299 | -0.1327 | -0.1098 | -0,0036 | 0.0022 | 0.0022 | 0.0057 | -0.1291 | -0.1298 | -0.1327 | -0.0942 |
| $\Delta l/l_1$ | 0 | 0.2 | 0.2 | 0.2 | * | - | - | - | - | - | - | - | - | - | - | - | - |

*The measurment of dimensional variation of Z specimens was troubled by the fact that during the test some of the metal settings became unglued from the surface of the specimen; at that point, the measurement of the variable was discontinued

**Table 5**

**Temperature and moisture variation test - Y1-Y6 series (lightweight concrete blocks with expanded clay aggregate) and Yj1,Yj2 ( with mortar joint- block/block), Yb1,Yb2 (with mortar joint - block/concrete) specimens**

| **Temp. (ºC)** | **Mass value and mass and dimensional variation (relative to the initial value)** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Period in oven** | | | **Lab. cond.** | **Immersion in water** | | | **Lab. cond.** | **Period in oven** | | | **Lab. Cond.** | **Immersion in water** | | | **Lab.condition. /end of test** | |
| Time Days | 0ºD | 1ºD | 2º D | 3ºD | 6ºD | 7ºD | 8ºD | 13ºD | 14º D | 15ºD | 16ºD | 17ºD | 20ºD | 21º D | 22ºD | 27ºD | 28ºD |
| **Y1**-m | 1178 | 1153 | 1145 | 1141 | 1148 | 1272 | 1280 | 1286 | 1244 | 1178 | 1158 | 1150 | 1155 | 1271 | 1273 | 1280 | 1226 |
| Δm/m | 0 | 0.02122 | 0.02801 | 0.03140 | 0.02547 | -0.07980 | -0.08659 | -0.091681 | -0.05603 | 0 | 0.0170 | 0.0238 | 0.01953 | -0.0790 | -0.0807 | -0.0866 | -0.0408 |
| Δl/l | 0 | 0.3 | 0.3 | 0.3 | -0.2 | 0 | -0.2 | 0 | 0.15 | 0.5 | 0.6 | 0.3 | -0.2 | 0 | 0 | 0.15 | 0.15 |
| **Y2**-m | 1128 | 1106 | 1100 | 1098 | 1105 | 1238 | 1240 | 1253 | 1193 | 1125 | 1108 | 1102 | 1108 | 1238 | 1239 | 1245 | 1183 |
| Δm/m | 0 | 0.01950 | 0.02482 | 0.02659 | 0.02039 | -0.09751 | -0.09929 | -0.11082 | -0.05762 | 0.0027 | 0.0177 | 0.0230 | 0.0177 | -0.0975 | -0.0984 | -0.1037 | -0.0488 |
| Δl/l | 0 | 0.5 | 0.4 | 0.4 | -0.3 | 0.2 | -0.3 | 0.1 | 0.2 | 0.6 | 0.6 | 0.4 | -0.3 | 0.2 | 0.1 | 0.3 | 0.3 |
| **Y3**-m | 1186 | 1162 | 1154 | 1150 | 1157 | 1277 | 1288 | 1291 | 1248 | 1188 | 1168 | 1159 | 1164 | 1277 | 1281 | 1290 | 1239 |
| Δm/m | 0 | 0.02023 | 0.02698 | 0.03035 | 0.02445 | -0.07672 | -0.08600 | -0.08853 | -0.05227 | -0.0017 | 0.0152 | 0.0228 | 0.0186 | -0.0767 | -0.0801 | -0.0877 | -0.0447 |
| Δl/l | 0 | 0.5 | 0.4 | 0.4 | -0.1 | 0.1 | -0.1 | 0.3 | 0.2 | 0.5 | 0.5 | 0.4 | -0.1 | 0.1 | 0 | 0.1 | 0.1 |
| **Y4**-m | 1236 | 1214 | 1206 | 1201 | 1208 | 1308 | 1323 | 1330 | 1298 | 1243 | 1223 | 1214 | 1218 | 1311 | 1316 | 1329 | 1290 |
| Δm/m | 0 | 0.01779 | 0.02427 | 0.02831 | 0.02265 | -0.05825 | -0.07038 | -0.07605 | -0.05016 | -0.0057 | 0.0105 | 0.0178 | 0.0146 | -0,0607 | -0.0647 | -0.0752 | -0.0437 |
| Δl/l | 0 | 0.8 | 0.7 | 0.6 | -0.2 | 0.2 | -0,2 | 0.2 | 0.3 | 0.8 | 0.8 | 0.6 | -0.2 | 0.2 | 0.2 | 0.3 | 0.3 |
| **Y5** | 1281 | 1257 | material | 1246 | 1252 | 1345 | 1359 | 1365 | 1338 | 1284 | 1266 | 1258 | 1262 | 1349 | 1356 | 1366 | 1335 |
| Δm/m | 0 | 0.01873 | 0.02341 | 0.02732 | 0.02263 | -0.04996 | -0.06089 | -0.06557 | -0.04449 | -0.0023 | 0.0117 | 0.0180 | 0.0148 | -0.0531 | -0.0586 | -0.0664 | -0.0422 |
| Δl/l | 0 | 0,6 | 0,4 | 0,4 | -0,3 | 0 | -0,3 | 0,2 | 0,2 | 0,8 | 0,9 | 0,6 | -0,1 | 0,2 | 0,2 | 0,3 | 0,3 |
| **Y6** | 1172 | 1149 | 1141 | 1137 | 1145 | 1266 | 1273 | 1280 | 1243 | 1175 | 1155 | 1147 | 1152 | 1264 | 1269 | 1278 | 1228 |
| Δm/m | 0 | 0.01962 | 0.02645 | 0.02986 | 0.02303 | -0.08020 | -0.08617 | -0.09215 | -0.06058 | -0.0026 | 0.0145 | 0.0213 | 0.0171 | -0.0785 | -0.0828 | -0.0904 | -0.0478 |
| Δl/l | 0 | -0.25 | -0.3 | -0.35 | 0.05 | 0.3 | 0.3 | 0.3 | 0.2 | 0.6 | 0.6 | 0.4 | -0.3 | 0 | 0.1 | 0.1 | 0.1 |
| **yj1**-m | 1316 | 1306 | 1305 | 1304 | 1310 | 1431 | 1435 | 1453 | 1402 | 1315 | 1305 | 1304 | 1309 | 1429 | 1433 | 1447 | 1374 |
| Δm/m | 0 | 0.00799 | 0.00835 | 0.00911 | 0.00455 | -0.08738 | -0.09042 | -0.10410 | -0.06535 | 0.00076 | 0.0084 | 0.0091 | 0.0053 | -0.0859 | -0.0889 | -0.0995 | -0.0441 |
| $\Delta l/l_1$ | *0 | 0.4 | -0.2 | -0.2 | -0.5 | -0,5 | -0.4 | -0.5 | -0.5 | -0.2 | -0.4 | -0.6 | -0.9 | -0.8 | -0.7 | -0.7 | 0 |
| $\Delta l/l_2$ | 0 | 0 | -0.1 | -0.1 | -0.6 | -0.4 | -0.3 | -0.4 | -0.5 | -0.2 | -0.4 | -0.6 | -0.9 | -0.9 | -0.8 | -0.8 | -0.8 |
| $\Delta l/l_1$- | 0 | 0 | -0.1 | -0.1 | 0.1 | -0.1 | -0.1 | -0.1 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0 | 0.1 | 0.1 |
| **yj2**-m | 1302 | 1292 | 1291 | 1291 | 1297 | 1427 | 1427 | 1450 | 1395 | 1298 | 1291 | 1290 | 1295 | 1425 | 1430 | 1442 | 1358 |
| Δm/m | 0 | 0.00845 | 0.00844 | 0.00844 | 0.00384 | -0.0960 | -0.09600 | -0.11367 | -0.07142 | 0.00307 | 0.0085 | 0.0092 | 0.0054 | -0.0945 | -0.0983 | -0.1075 | -0.0430 |
| $\Delta l/l_1$ | 0 | 0.2 | -0.5 | -0.3 | -1.0 | -0.8 | -0.7 | -0.7 | -0.8 | -0.5 | -0.6 | -0.8 | -1.2 | -1.1 | -1.1 | -1.1 | 0 |
| $\Delta l/l_2$ | 0 | 0.6 | 0.4 | 0.4 | 1.0 | 0.1 | 0.2 | 0.2 | 0.1 | 0.4 | 0.2 | 0 | -0.3 | -0.3 | -0.3 | -0.2 | -0.2 |
| $\Delta l/l_1$- | 0 | -0.4 | -0.9 | -0.7 | -1.0 | -0.9 | -0.9 | -0.9 | -1.0 | -0.9 | -0.8 | -0.8 | -0.9 | -0.8 | -0.8 | -0.9 | -0.9 |
| **yb1**-m | 1871 | 1861 | 1858 | 1856 | 1861 | 1978 | 1977 | 1989 | 1943 | 1879 | 1866 | 1862 | 1865 | 1977 | 1978 | 1986 | 1925 |
| Δm/m | 0 | 0.00692 | 0.00694 | 0.00801 | 0.00534 | -0.05718 | -0.05665 | -0.06306 | -0.03848 | -0.00427 | 0.0027 | 0.0048 | 0.0032 | -0.0567 | -0.0572 | -0.0615 | -0.0289 |
| $\Delta l/l_1$ | 0 | 0 | 0 | -0.3 | -0.7 | -0.5 | -0.4 | -0.3 | -0.5 | -0.2 | -0.2 | -0.4 | -0.9 | -0.8 | -0.7 | -0.8 | 0 |
| $\Delta l/l_2$ | 0 | 0,2 | -0.5 | -1.0 | -1.0 | -0.9 | -1.2 | -1.2 | -1.2 | -0.9 | -0.9 | -1.2 | -1.6 | -1.6 | -1.6 | -1.5 | -1.5 |
| $\Delta l/l_1$- | 0 | -0.2 | 0.5 | 0.7 | 0.3 | 0.4 | 0.8 | 0.9 | 0.7 | 0.7 | 0.7 | 0.8 | 0.7 | 0.8 | 0.8 | 0.8 | 0.7 |
| **yb2**-m | 1858 | 1847 | 1844 | 1842 | 1847 | 1955 | 1959 | 1968 | 1918 | 1866 | 1853 | 1849 | 1852 | 1955 | 1959 | 1966 | 1905 |
| Δm/m | 0 | 0.00754 | 0.00753 | 0.00861 | 0.00592 | -0.05220 | -0.05436 | -0.05920 | -0.03229 | -0.00430 | 0.0027 | 0.0048 | 0.0032 | -0.0522 | -0.0544 | -0.0582 | -0.0253 |
| $\Delta l/l_1$ | 0 | 0 | 0.2 | 0 | -0.5 | -0.3 | -0.3 | -0.4 | -0.4 | -0.1 | -0.1 | -0.3 | -0.8 | -0.7 | -0.6 | -0.6 | 0 |
| $\Delta l/l_2$ | 0 | 0.1 | 0.2 | -0.3 | -0.9 | -0.4 | -0.5 | -0.7 | -0.7 | -0.4 | -0.4 | -0.7 | -1.2 | -1.2 | -1.1 | -1.0 | -1.0 |
| $\Delta l/l_1$- | 0 | -0.1 | 0 | 0.3 | 0.4 | 0.1 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.5 | 0.5 | 0.4 | 0.4 |

*The measuring of dimensional variation $l_1$ of Yj1 specimen on the 1st day was troubled by the fact that during the test some of the metal settings became unglued from the surface of the specimen (generally, measuring the dimensional variation $l_1$ , $l_2$ of Yj1, Yj2 Yb1, Yb2, specimens was a difficult task and the corresponding precision was lower than that obtained in the other series); at that time the metal settings were glued on again and the test was restarted (the initial value relative to the end of the 1st day)

**Table 6**

**Summary of test results: mean values for X1-X6 (autoclaved aerated concrete), Y1-Y6 (lightweight concrete with expanded clay aggregate), Z1-Z3 (bricks) series and Yj1-Yj2 (lightweight concrete block with expanded clay aggregate with mortar joint), Yb1-Yb2 (lightweight concrete block with expanded clay aggregate-concrete with mortar joint)**

| Temp. (ºC) | Mass and dimensional variation (relative to the initial value) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Period in oven | | | Lab. condit. | Immersion in water | | | Lab. condit. | Period in oven | | | Lab. condit. | Immersion in water | | | Lab. condit. /end of test | |
| Time Days | 0ºD | 1ºD | 2º D | 3ºD | 6ºD | 7ºD | 8ºD | 13ºD | 14º D | 15ºD | 16ºD | 17ºD | 20ºD | 21º D | 22ºD | 27ºD | 28ºD |
| **X1-X6** | | | | | | | | | | | | | | | | | |
| Δm/m | 0 | 0.01434 | 0.01462 | 0.01462 | 0.00164 | -0.45449 | -0.50943 | -0.59734 | -0.5562 | -0.0905 | 0.0130 | 0.0154 | 0.0033 | -0.4735 | -0.5218 | -0.5783 | -0.5371 |
| Δl/l | 0 | -0.27 | -0.32 | -0.37 | 0.04 | 0.28 | 0.28 | 0.28 | 0.23 | -0.04 | -0.02 | -0.35 | -0.33 | -0.11 | -0.16 | 0.17 | 0.23 |
| **Y1-Y6** | | | | | | | | | | | | | | | | | |
| Δm/m | 0 | 0.0195 | 0.0257 | 0.0290 | 0.0230 | -0.0737 | -0.0816 | -0.0875 | -0.0535 | -0.0016 | 0.01444 | 0.02111 | 0.01704 | -0.07443 | -0.0775 | -0.0850 | -0.0446 |
| Δl/l | 0 | 0.58 | 0.48 | 0.45 | -0.2 | 0.12 | -0.2 | 0.17 | 0.23 | 0.63 | 0.67 | 0.45 | -0.2 | 0.12 | 0.1 | 0.21 | 0.21 |
| **Z1-Z6** | | | | | | | | | | | | | | | | | |
| Δm/m | 0 | 0.0022 | 0.0022 | 0.0022 | 0.0004 | -0.1245 | -0.1265 | -0.1304 | -0.1073 | -0.0026 | 0.0019 | 0.0019 | 0.0021 | -0.1250 | -0.1273 | -0.1300 | -0.0941 |
| $\Delta l_1/l$ | 0 | 0.12 | 0.1 | 0.08 | -0.24 | -0.15 | -0.1 | -0.1 | -0.35 | -0.05 | -0.2 | -0.3 | -0.6 | -0.65 | -0.7 | -0.55 | -0.5 |
| $\Delta l_2/l$ | 0 | 0.13 | 0.1 | 0.1 | -0.27 | -0.07 | -0.03 | 0 | -0.27 | -0.05 | 0.05 | -0.1 | -0.4 | -0.55 | -0.55 | -0.35 | 0 |
| **Yj1-2** | | | | | | | | | | | | | | | | | |
| Δm/m | 0 | 0.00807 | 0.00840 | 0.00878 | 0.00420 | -0.09170 | -0.09322 | -0.10889 | -0.0683 | -0.0011 | 0.00554 | 0.00700 | 0.00428 | -0.07230 | -0.07469 | -0.08167 | -0.0353 |
| $\Delta l/l_1$- | 0* | -0.4 | -0.9 | -0.7 | -1.0 | -0.9 | -0.9 | -0.9 | -1.0 | -0.9 | -0.8 | -0.8 | -0.9 | -0.8 | -0.8 | -0.9 | -0.9 |
| **Yb1-2** | | | | | | | | | | | | | | | | | |
| Δm/m | 0 | 0.00724 | 0.00724 | 0.00831 | 0.00563 | -0.05470 | -0.05551 | -0.06114 | -0.0354 | -0.0043 | 0.00268 | 0.00483 | 0.00322 | -0.05443 | -0.05577 | -0.05980 | -0.0270 |
| $\Delta l/l_1$- | 0 | -0.15 | 0.25 | 0.5 | 0.35 | 0.25 | 0.5 | 0.6 | 0.5 | 0.5 | 0.5 | 0.6 | 0.55 | 0.65 | 0.65 | 0.6 | 0.55 |

* results relative to Yj2 only

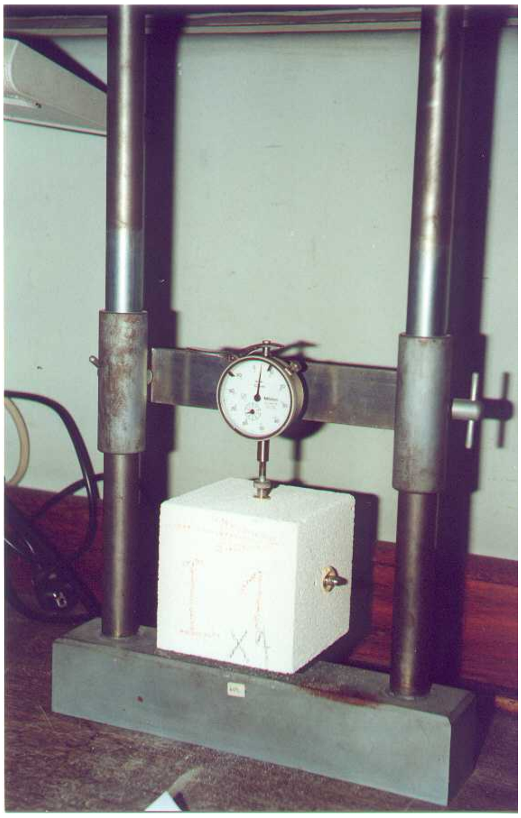

Figure 1-Measuring dimensional variation of X series specimen (autoclaved aerated concrete)

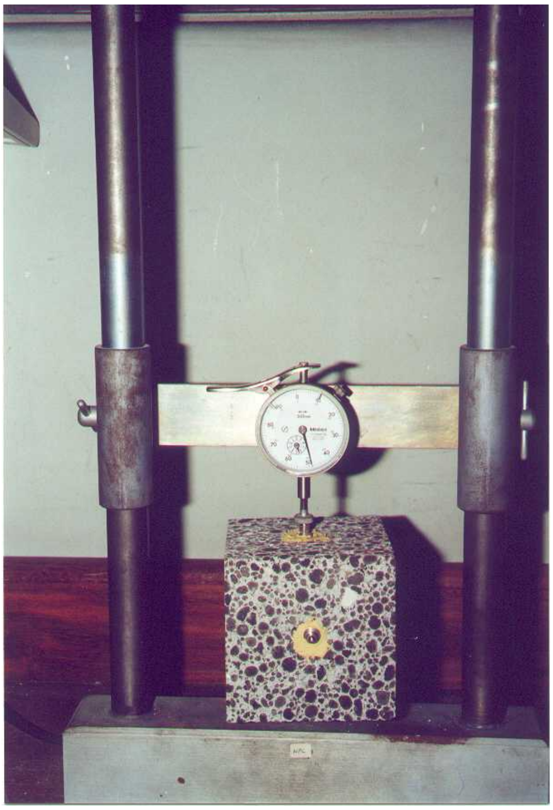

Figure 2-Measuring dimensional variation of Y series specimen (lightweight concrete with expanded clay aggregates)

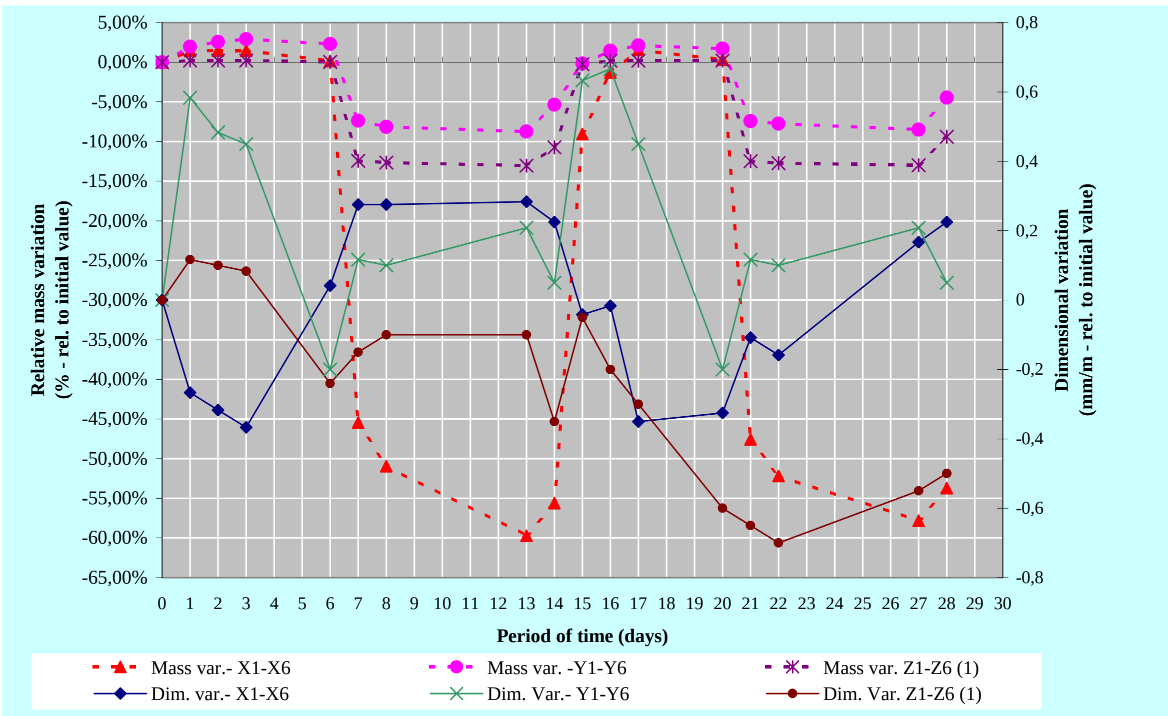


Figure 3-Mass and dimensional variation of X1-X6 (autoclaved aerated concrete), Y1-Y6 (lightweight concrete with expanded clay aggregate) and Z1-Z6 (bricks) - Temperature and moisture variation test

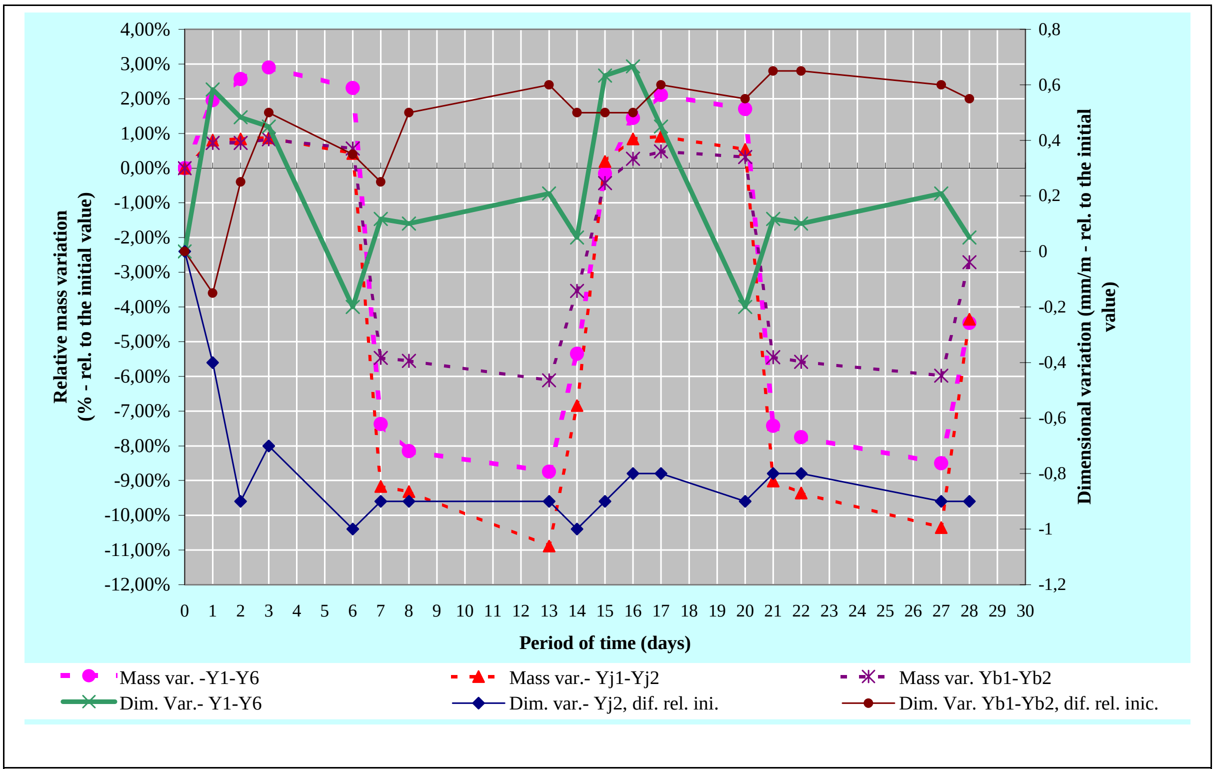


**Figure 4-Mass and dimensional variation of Y1-Y6 series (lightweight concrete blocks with expanded clay aggregate) and Yj1,Yj2 (with mortar joint - block/block), Yb1,Yb2 (with mortar joint - block/concrete) - Temperature and moisture variation test (dif. rel. ini. - means difference of dimensional variation ($\Delta l/l_1$-$\Delta l/l_2$) relative to the initial value)**


**Figure 5-Measuring mass variation of Yj1 specimen (with mortar joint - block/block)**


**Figure 6-Measuring mass variation of Yb1 specimen (with mortar joint - block/concrete)**

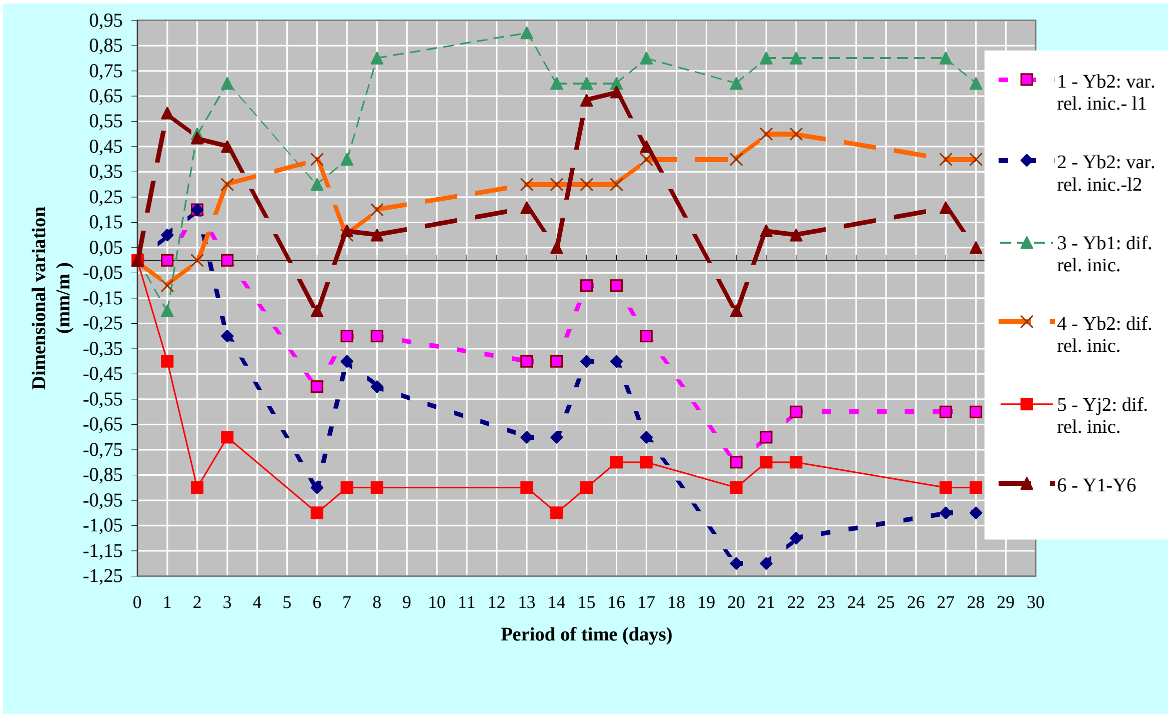


**Figure 7-Dimensional variation of Y1-Y6 series (lightweight concrete blocks with expanded clay aggregate) and Yb1,Yb2 (with mortar joint – block/concrete),Yj2 (with mortar joint- block/block) - Temperature and moisture variation test (dif. rel. ini. - means difference of dimensional variation ($\Delta l/l_1$-$\Delta l/l_2$) relative to the initial value)**