MECHANISMS FOR PREVENTING RISING DAMP IN NEW BUILDING INFRASTRUCTURE

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Abstract

Purpose: Capillary rise of water in buildings has been an issue of concern among past and present researchers. Despite the research efforts devoted to the proper elimination of the problem in masonry construction, it still remains a challenge that needs to be addressed. This study explores treatment mechanisms that can be used to prevent rising damp in new building infrastructure.

Methodology: Fourteen test walls are constructed, conditioned, subjected to various treatments, and monitored for four years. The treatments applied to the walls include the use of polyethylene damp proof courses, damp proof coatings, and dense concrete bases. The walls are then monitored with reference to the two climate seasons in Ghana.

Findings: The results highlights that rising damp is present, as suggested by the constant increase and decrease in the height of the water levels in the walls during the rainy and dry seasons respectively. The findings further reveal that within the four-year period, the walls treated with the damp proof coatings, together with those with the dense concrete bases performed better than those treated with the polyethylene damp proof courses.

Limitations: The economic and commercial impact of these preventive mechanisms were not considered in this study. A future research can be directed at these issues.

Practical implication: The proposed treatment mechanisms highlights the effectiveness of some treatments applied to walls to prevent the capillary rise of water from the ground into the superstructure.

Social implications: Building regulations, especially in Ghana and other tropical settings should be amended to include ways to prevent rising damp phenomena by including effective methods against rising damp during the building design or construction.

Originality/Value: Series of studies worldwide have been conducted in laboratories to simulate the capillary rise of water in walls of buildings. This is among the few studies that look at how water rises from actual ground conditions into the walls of buildings.

Keywords: Building infrastructure, Rising damp, Damp Proof Courses, Damp Proof Coatings, Test Wall, dense concrete

Paper type: Research paper

1. Introduction

Building infrastructure is a bedrock for development in any country. The provision of adequate infrastructure encourages economic growth, ensures poverty reduction, and improves on the delivery of health and other services (Mitullah *et al*., 2016; World Bank, 2014; Wantchekon, 2014). For many years now, Africa has enjoyed significant social and economic progress (African Development Bank, 2018). However, the deficit in infrastructure has demoralized all the efforts towards achieving sustainable development and structural transformation. According to the African Development Bank, AfDB, (2013), though Africa still has a massive infrastructure need, it invests only 4% of its gross domestic product in infrastructure, as compared to a developed nation like China, which invests 14% of its GDP. A current survey undertaken by Afrobarometer and reported on by Mitullah *et al*. (2016) shows that infrastructure remains a major challenge in Africa. To bridge the infrastructure deficit, there is the urgency to provide buildings, roads, railways and ports, information and communication technology, energy facilities, health facilities, and the management of water (Foster, 2008).

Key to the provision of infrastructure by governments in Africa is the provision of adequate housing for its people. The rapid growth in population and urbanization, especially in Africa has resulted in sub-standard housing conditions, overcrowding of households, inadequate and unreliable infrastructure and services (Tibaijuka, 2009). Ghana, like many other developing countries, has been facing an acute shortage of housing for many years now. According to the Ghana Statistical Service, GSS, (2014), there are about 5.8 million dwelling units in Ghana. Of these units, less than half can be classified as houses (GSS, 2014). With the country’s population increasing at a rate of 2.7 per annum, the increase in housing stock is unable to keep pace and the situation is worsening (Adinkrah-Appiah *et al.*, 2015). This notwithstanding, the few houses available to the people have not been given proper maintenance attention, and are being affected by series of defects. One of the key defects associated with housing in Ghana is dampness (Agyekum *et al.*, 2013). The common type of dampness found among such buildings is rising damp (Agyekum *et al.*, 2013).

Rising damp is a widespread phenomenon and has been a major cause of decay of masonry materials for many years now (Franzoni *et al.*, 2013). It occurs ‘when groundwater flows into the base of a construction and is allowed to rise through the pore structure’ (Rirsch and Zhang, 2010, p. 1815). Rirsch *et al*. (2011) further indicated that rising damp describes the movement of moisture upwards through permeable building materials by capillary action. When serious rising damp occurs in a building, that building becomes inhospitable due to mould growth, paint blistering, plaster crumbling and wall paper separation (Rirsch *et al.*, 2011). According to Franzoni *et al*. (2014), it is one of the most significant phenomena that leads to the decay of ancient buildings, as well as modern porous building materials, probably because it speeds up all degradation processes in such buildings.

In Ghana, the problem is widespread among buildings to such an extent that more than one out of every ten residential buildings is affected by it. There have been series of studies dedicated to studying the problem and its harmful effects (Falchi et al., 2018; Franzoni, 2014; Franzoni *et al.*, 2013; Franzoni and Bandini, 2012; Franzoni and Sassoni, 2011; Rirsch and Zhang, 2010). These studies have been accompanied by several treatment methods and mechanisms. In existing buildings, techniques such as mechanical interruptions, chemical injection, Knapen Siphons, wall base ventilation, thermal methods, active electro-osmosis, passive electro-osmosis, electro-kinesis and the likes exist on the market to stop rising damp in walls (Lubelli et al., 2018; Franzoni, 2018; Vanhellemont et al., 2018; Melada et al., 2018; van Hees et al., 2018; Torres, 2018; Lubelli *et al*., 2013). Despite the huge applications of these products and techniques, scientific literature on this subject is still scarce. The few publications on the treatment of rising damp in existing buildings are limited to the study of the effectiveness of one or few products in the laboratory or on the field (Lubelli *et al*., 2013).

Lubelli *et al*. (2013) further stated that the lack of homogeneity of data, because of the different boundary conditions and test methods makes it difficult to draw general conclusions on the behavior of different classes of products. Aside these issues, there are also complications arising from the fact that producers of some so-called damp remediation chemicals are unwilling to provide clear and extensive information on their products. According to Franzoni (2014), rising damp is persistent, and its removal from both old and modern types of buildings has become very challenging. This study was conducted to explore mechanisms that can be used to prevent rising damp in new buildings. Various researchers have contributed their quota in this area. Several books regarding the description of the phenomenon in building materials like concrete, bricks, wood and the likes have been published. However, this research forms part of the few studies that looks at the on-site (actual ground) modelling of the problem of rising damp in a frequently used building material in Ghana, i.e. Sandcrete blocks.

1.1 The use of sandcrete blocks for building in Ghana

Sandcrete blocks are walling units which are made from coarse natural sand or crushed stone dust mixed with cement and water and pressed to shape (Baiden and Tuuli, 2004). The blocks on setting and hardening attain sufficient strength to be used as walling units as specified by BSI (1974, 1975).

Per the classifications of BS 2028, blocks have been classified into three types to include: Type A (Dense aggregate blocks); Type B (Lightweight aggregate blocks for load bearing walls); and Type C (Lightweight aggregate blocks for non-load bearing partitions). Baiden and Tuuli (2004) indicated that sandcrete blocks are widely used as walling units in Ghana. This fact was confirmed in the 2010 population and housing census which revealed that more than 50% of buildings in Ghana had the walling units in sandcrete blocks. As a result of its widespread use, most commercial factories have been manufactured to produce such blocks. However, the properties of the blocks, and especially, the quality, differs from one manufacturer to the other due to the different methods used in the production (Baiden and Tuuli, 2004).

A sandcrete block qualifies as a walling material if it exhibits high compressive strength, low shrinkage, low moisture movement, low thermal movement and denseness and durability (Baiden and Tuuli, 2004), which can only be achieved through its adherence to BS 2028 recommendations on mix ratio, curing and quality of constituent materials. This notwithstanding, one can easily lose the quality of sandcrete blocks if proper attention is not given to the quality of constituent materials, batching of the aggregates, mixing of the constituent materials, method of production, curing, transportation and storage, mix ratio and water content (Baiden and Tuuli, 2004).

In Ghana, sandcrete blocks come in different sizes and forms, with the length, width or height greater than that specified for a brick. The blocks are produced as solid or hollow in Ghana. The blocks are used for single leaf wall construction, where the blocks are laid to overlap in one or more directions and set solidly in mortar (Baiden and Tuuli, 2004). The blocks are also laid in running or stretcher bonds in which the units of successive courses overlap half their length, and the joints in between the blocks are usually filled with cement sand mortar (Baiden and Tuuli, 2004).

Since this is the most widely used walling material in Ghana, and because previous studies had revealed that buildings constructed with sandcrete blocks were severely affected by rising damp (Agyekum et al., 2014; Agyekum et al., 2013), the current study was conducted using sandcrete blocks.

2.0 Research methodology

The study sought to explore mechanisms that can be used to prevent rising damp in new building infrastructure. This study is experimental in nature, and involved the construction of fourteen Test walls (prototype models). The first set of walls (seven in number) were constructed with Standard Manufactured Sandcrete Blocks (SB) and the second set of walls (also seven in number) were constructed with Commercially Manufactured Sandcrete Blocks (CB). The constructed test models were further conditioned, treated and monitored over a period of 4 years. In a previous paper (Agyekum *et al.*, 2016), the test walls built were monitored for 365 days, and subsequently reported on. The findings revealed that the height of rise of moisture within the walls varied with respect to the seasonal changes in Ghana. In this current paper, the walls have been monitored for an additional 3 years (making four years in total) and further findings obtained will be reported. The methodology used has been divided into four subsections to include: the materials; location of test walls and wall constructions; mechanisms applied to prevent rising damp in the test walls; and monitoring the effectiveness of the applied mechanisms.

2.1 Materials

2.1.1 Materials for manufacturing of sandcrete blocks and mortar for rendering

The standard and commercial sandcrete blocks (SBs and CBs) were manufactured with sharp sand, cement and water (Lewis, 1959). The sand used met the requirements of BS 1200 (1976). The cement used for the production of the sandcrete blocks, and rendering was Ordinary Portland cement from Ghana Cement Works Limited, and it conformed to the Ghana Standards Board Specification No. A2 (1995). Fresh, colourless, odourless and tasteless potable water free from organic matter and which conformed to the requirements as stated in BS 1200 (1976) was used in mixing the materials. Tests carried out at the West African Building Research Institute has confirmed that the strength of sandcrete blocks like other cement products increase with decreasing water cement ratio. As a result of this, the addition of the water to the mixture was based on the standard specification of 0.45 water to cement ratio. Anything beyond this could have contributed to prolonged setting time, and a reduction in the relative strength of the sandcrete block (Agyekum *et al*., 2016).

Both the standard and commercial sandcrete blocks were manufactured in an approved block-making vibrating machine which conformed to BS 2028 (1975). Both the SBs and CBs were of sizes 115 mm × 225 mm × 460 mm. The SBs were manufactured with a standard mix proportion of 1:6 (i.e. one part by volume of cement to 6 parts by volume of coarse sand) (Lewis, 1959). A mix proportion of 1:8 was used to manufacture the CBs (Agyekum *et al*., 2016). This mix proportion was based on that used on many Ghanaian construction sites. Such mixes are also used by commercial block manufacturing firms on the Ghanaian market. These two kinds of sandcrete blocks were used for the following reasons: i) to determine whether the issue of quality control contributes to the problem of moisture rise in walls constructed with such materials (Agyekum *et al*., 2016); and ii) to determine whether differences in the mix proportions of the blocks contribute to the susceptibility of the materials to damp penetration (Agyekum *et al.*, 2016). All the blocks manufactured were of the load bearing capacities, thus meeting the requirements of BS 2028 (1975). To determine the quality of the sandcrete blocks manufactured, their bulk densities, water absorption capacities and compressive strengths were determined after curing for 28 days.

2.1.2 Materials (mechanisms) for the treatment of the walls

Polyethylene damp proof courses (dpcs), damp proof coatings labelled as ‘A’ and ‘B’, and dense concrete bases were used as treatments for the walls against the capillary rise of water. The polyethylene damp proof courses used were of thicknesses 0.15 mm, 0.13 mm and 0.12 mm, and were manufactured to the requirements of BS 6515 (1984). These thicknesses were chosen based on that readily available on the Ghanaian market. Damp proof coating ‘B’ is an elastic isolation material modified with special chemicals, which provide excellent water insulation. It is liquid plastic, elastic when dry, flexible, strong, endures mechanical blows and highly impermeable to water. It is applied to all walls which require water insulation, ground, roof, terrace, etc. The damp proof coating ‘A’ is a two-pack, modified epoxy paint cured by polyamid. Pack A: BB 4301 3,2L is 8 parts in volume and Pack B: SB 5733 0.4L is one part in volume. The product is applied over carbon steel, concrete, wood, aluminium/galvanized surfaces, which are to be buried or immersed in salt or fresh water. It is also applied to damp proof walls affected by moisture and rising dampness, both internally and externally (Agyekum *et al.*, 2016). The last set of treatment used consisted of a dense concrete wall. The density of the concrete used was 2,438 kg/m^3 (1:3:6 concrete mix) after a 28-day curing state. This density fell within the range of 2,200-2,600 kg/m^3 regarded as density of normal weight concrete (Neville, 1999).

2.2 Location of test walls and wall constructions

Burkinshaw (2012) indicated that the biggest variable in a test of this kind is the ground moisture condition. The experimental test walls were constructed at Deduako, a suburb of Oforikrom Sub-Metro which falls under the Kumasi Metropolitan Assembly in the Ashanti Region of Ghana. The swampy nature of the site made it a suitable location for this study (Agyekum *et al*., 2016).

The site is generally underlain by granite which is a later intrusion into the lower birimian rocks. The soil type found in this location is mostly residual in nature with covering of weathered argellateous phyllite from the country rock (Kesse, 1985). The site is located near a river and the water table of the surrounding is high, making it suitable for a true rising damp scenario to be replicated.

Fourteen masonry test walls of dimensions 2.1 m high by 2.0 m long were constructed at the location. The walls were not erected under sheds in order to ensure their complete exposure to the inclement weather. The construction of the fourteen test walls began on 1st July 2014 and ended on 24th July 2014.

The first set of walls, which consisted of seven free standing walls were constructed of the SBs, whilst the second set of walls, also made up of seven free standing walls were constructed of the CBs. The CB construction was used to replicate to an extent the kind of blockwork construction commonly adopted during the construction of residential buildings in Ghana (Agyekum *et al*., 2016).

The first six walls for each type of sandcrete blocks (both SB and CB) had the same thicknesses, and consisted of several courses laid in stretching bonds to heights of 2.1 m and lengths of 2.0 m in a single width. The various courses were bonded with cement and sand mortar mix proportion of 1:4 as specified by the National Building Regulation of Ghana (Section 32(2) (1989) (Lewis, 1959). All the block walls were finished with 13 mm thick sand and cement render (1:5), applied in several layers (Agyekum *et al*., 2016).

The seventh test walls for the SB and CB comprised of mass concrete bases of heights 900 mm above ground, and each with a mix ratio of 1:3:6. The top levels above the 900 mm concrete bases were completed with sandcrete blocks up to the heights of 2.1 m each (Agyekum *et al*., 2016).

Fig 1 Photograph of test walls (extreme left are those constructed with SBs and extreme right are those constructed with CBs) (Source: Agyekum *et al.*, 2016)

2.3 Mechanisms applied to prevent rising damp in the test walls

Several mechanisms were identified in literature and through personal interactions with construction professionals. The various mechanisms applied to prevent rising damp in the walls are presented in Table 1.

Figure 2 shows how the polyethylene dpcs for the test walls 1, 2 and 3 (for both SBs and CBs) were laid. Figure 3 also shows the complete set of walls with the different polyethylene dpcs in place as described in Table 1.

Table 1. Summary of mechanisms applied to prevent rising damp in the walls

CODE	EXPLANATION	TYPE OF MECHANISM
SB1 & CB1	Standard and commercially manufactured sandcrete block walls with 0.15 mm thick damp proof course (dpc).	Polyethylene dpc with a thickness of 0.15 mm.
SB2 &CB2	Standard and commercially manufactured sandcrete block walls with 0.13 mm thick dpc.	Polyethylene dpc with a thickness of 0.13 mm.
SB3 & CB3	Standard and commercially manufactured sandcrete block walls with 0.12 mm thick dpc.	Polyethylene dpc with a thickness of 0.12 mm.
SB4 & CB4	Standard and commercially manufactured sandcrete block walls with damp proof coating ‘A’	Damp proof coating ‘A’ applied to walls.
SB5 & CB5	Standard and commercially manufactured sandcrete block walls with damp proof coating ‘B’.	Damp-proof coating ‘B’ applied to walls.
SB6 & CB6	Standard and commercially manufactured sandcrete block walls with no treatment (control test walls).	Control test walls (No treatment applied).
SB7 & CB7	Standard and commercially manufactured sandcrete block walls with concrete bases.	150 mm thick concrete bases to heights of 900 mm each.

(Source: Agyekum *et al.*, 2016)

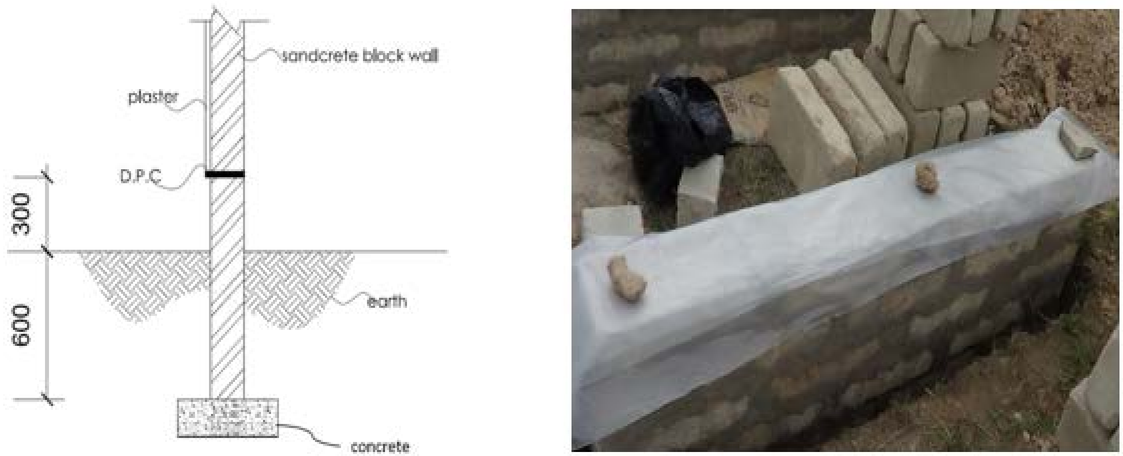


Fig 2 (a) Schematic diagram of the position of the dpc (b) Photograph showing how the dpc was laid (Source: Agyekum et al., 2016)

Fig 3 Photograph of test walls after the dpcs were laid

The damp proof coatings were also applied to the fourth sets of test walls. During the application of damp proof coating ‘A’, the wall surfaces were thoroughly cleaned and dried (Figure 4). The soil of the adjoining walls was excavated about 3 feet (900 mm) deep. A catalyzer was mixed with the epoxy paint, stirred and left to stand for 30 minutes. The catalyzer was part of the product as specified by the manufacturer. The damp proof coating 'A' was then applied on the perimeters of the walls, 3 feet from the soil and allowed to dry (Agyekum *et al.*, 2016).

Similar preparations as done for the application of damp proof coating 'A' was done for the damp proof coating 'B'. Before its application the product was thinned with water in the rate of 40% and applied to the walls. After drying first coat, the second and third coats were applied without dilution and allowed to stand for 48 hours after which the walls became completely dried (Agyekum *et al.*, 2016). Figures 5 and 6 show the test walls after the applications of the damp proof coatings.

Fig 4 Photograph showing the preparation of the wall surfaces

Fig 5 Photographs of the walls after the damp proof coatings 'A' (left) and 'B' (right) were applied

Fig 6 Photograph of test walls after they were treated with the damp proof coatings

Test walls 6 for each of the different wall constructions (SBs and CBs) were left untreated to serve as controls. These walls were untreated to have reference walls against which to evaluate the effectiveness of the treatments applied to the other walls. Figure 7 shows the schematic diagrams of the test walls 6. For Test walls 7 of the two different constructions, concrete bases were erected to heights of 900 mm above ground levels. Figure 8 is a schematic diagram of how the test walls 7 were constructed (Agyekum *et al.*, 2016).

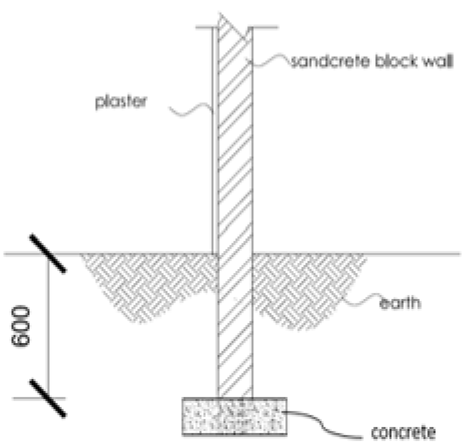


Fig 7. A schematic diagram of control test walls constructed without any treatment

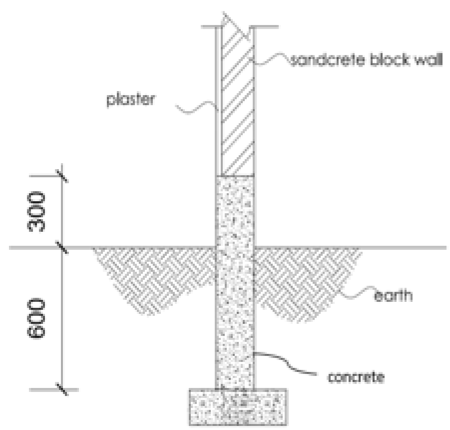


Fig 8. A schematic diagram of test walls 7 with dense concrete base

2.4 Monitoring the effectiveness of the applied mechanisms

The constructed test walls were left for five months after which the effectiveness of the applied mechanisms were monitored. In a similar study conducted by Rirsch and Zhang (2010), the erected walls were allowed to reach a steady level of saturation a little over five months before the first measurement was taken. As part of the monitoring, the level achieved by the damp front was of great importance. This was necessary to tell whether water had risen in the bases of the walls, and also to determine whether the mechanisms were performing very well. Moisture contents were measured on the walls using the PCE MMK1 moisture meter with deep probes, and the heights achieved by the damp front was visually measured with a steel tape.

Prior to the measurement of the height achieved by the damp front, it was very necessary to determine whether the bases of the walls had been soaked with water, and that the water seen was not just at the surfaces of the walls. The PCE MMK1 moisture meter assisted in carrying out this task. Data on the level achieved by the damp front was recorded in two seasons, (i.e. the rainy and the dry seasons) for four years. This was very important to be able to monitor the effect of the seasonal changes on the capillary rise of water in the walls. The primary use of the moisture meter in this study was not to measure the moisture contents of the individual walls. It was used to determine whether the bases of the walls were actually wet and that the heights achieved by the damp front was not only a matter of surface water.

For the PCE-MMK1 universal moisture meter, maximum moisture content for masonry materials like cement mortar are recorded at 3.0%. Moisture content readings were interpreted as follows (Agyekum et al., 2014): The wall is considered a very wet zone where the moisture contents recorded are greater than 2.8%; A moist condition is recorded where the moisture content ranges between 1.5% and 2.8%; and a dry condition or level of dampness is recorded where the moisture content is less than 1.5%.

The distribution of the moisture contents (recorded using the moisture meter) along the lengths of the walls at the damp front are shown in Figure 9. Test walls SB 6 and CB 6 were used as the test cases. For the purposes of this study, the researchers were only interested in the level achieved by the damp front, and so only the results on the height of reach of the water in the walls have been presented.

Figure 9 shows the moisture meter readings on the surfaces of the walls. The percentage moisture contents circled showed the problematic areas. Mortar samples were obtained from these areas to determine the level of wetness at the various depths.

As already described, the walls were constructed with sandcrete blocks, and the joints between the blocks were filled with 150 mm thick mortar. Mortar samples were selected because it is the dominant path through which damp rises in walls of buildings (Burkinshaw and Parrett, 2004). The equipment used to obtain the mortar samples were cordless drill bits, sharp tungsten carbide drill bits, 35 mm camera film cases for holding the samples, plastic resealable sample bags, sharp 65 mm bolster and small piece of card for collecting dust. The mortar samples were obtained at depths of 0-25 mm, 25-50 mm and 50-75 mm to determine whether the internal parts of the test walls were wet.

Samples of mortar collected from the walls were sent to the Geotechnical Laboratory at the Building and Road Research Institute (BRRI) of the Council for Scientific and Industrial Research

(CSIR) in Kumasi, Ghana, where the moisture contents were determined in accordance with BS 1377 (1990).

The moisture content (MC) was determined by the oven-dry method at 105° to constant weight. The amount of moisture in the samples was determined and expressed as a percentage of its dry mass. Fifty (50) grams each of the mortar (in the SB 6 and CB 6) were put into moisture cans and the masses were measured (M_1). The samples were then oven dried and measured again (M_2). The moisture content was determined using the formular below:

$$MC = \frac{M1-M2}{M2} \times 100\%$$

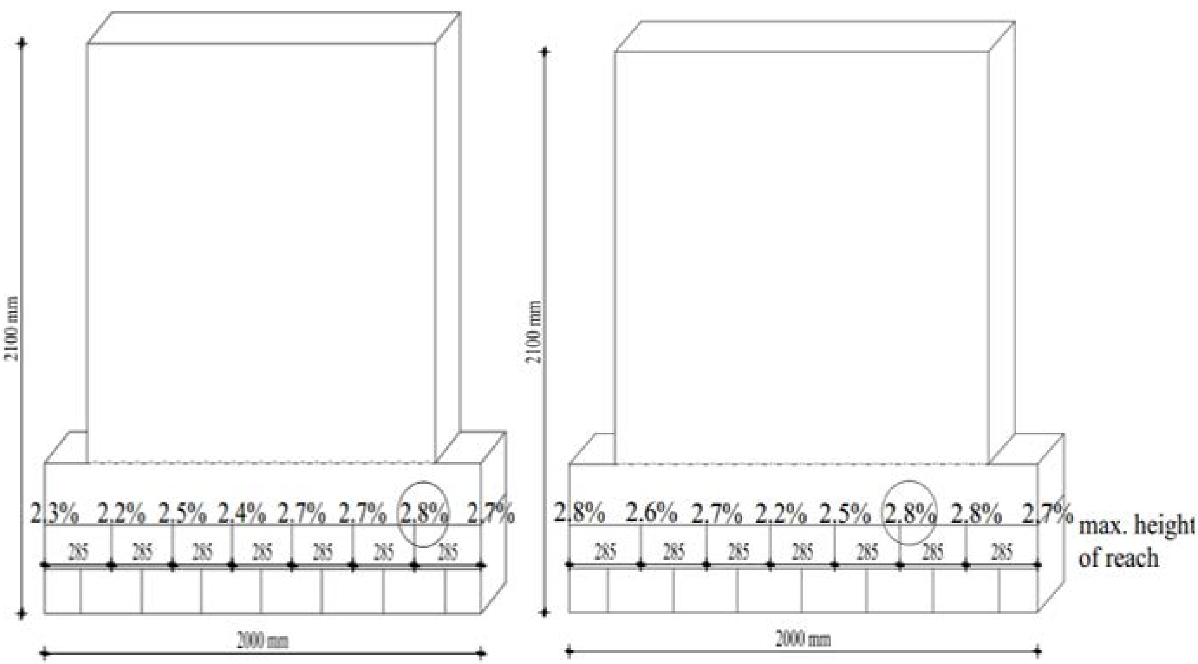


Fig 9 Schematic diagrams of the two walls with the various moisture contents as recorded by the moisture meter. (left-SB6 and right-CB6)

3.0 Results and discussion

The results obtained from monitoring the effectiveness of the mechanisms are presented to include the following:

3.1 Visual observation

One month after erecting the walls, a slowly progressing rising water front was visually observed. By the fifth month, the front had reached close to a third of the first course from ground level for the walls constructed with SB, and more than two thirds for that constructed with the CB. These initial observations were closely associated with the quality of the sandcrete blocks manufactured in the two cases. For instance, preliminary sorptivity test conducted on the two sets of sandcrete block samples (SB and CB) indicated that the those manufactured with the CB were more susceptible to water rise as compared to those made from SB. This indicate that the issue of quality control should really be taken into consideration during the manufacture of sandcrete blocks to be used in construction in Ghana.

Fig 10a Photograph showing the damp front achieved by moisture in the walls constructed

3.2 Height of rise of moisture in the walls

The walls were further allowed to reach steady levels of saturation a little over five months after which the height of rise of the moisture levels were visually recorded. In this study much emphasis was placed on the ability of the water to rise and fall within the test walls constructed. This was very important because in addition to the aim the study was also conducted to replicate the scenario of rising damp in a normal ground condition, as opposed to that simulated in laboratories as has been conducted in several studies (Franzoni and Bandini, 2012; Rirsch and Zhang, 2010; Torres *et al*., 2010). The readings taken for the various measurements are presented in Tables 2a to 2c (indicated in the appendix). From the trend in Table 2, it can clearly be seen that during the rainy seasons, there was a general increase in the level of capillary rise of moisture. However, in the dry seasons, the capillary rise decreased. This clearly shows the movement of water to and fro within the walls. This scenario can well be explained based on the explanation given by Riley and Cotgrave (2005).

According to Riley and Cotgrave (2005), majority of construction materials are porous, and because they are always embedded in or in contact with the ground such materials encourage the migration of water from the ground through capillary action. If the water table of the ground surrounding the wall is very high, then such a condition can be achieved, clearly explaining why within the rainy season, the moisture rose higher in the current walls under investigation.

Riley and Cotgrave (2005) further stated that if the ground is not saturated, the soil exerts a suction that opposes the upward pull of the water in the wall. As a result, when the water table falls, the height of the moisture in the walls will drop to a new level provided there is sufficient time for equilibrium to be achieved. This further shows why in the dry season, the water levels recorded in the walls were lower (Figure 10b). Each period of heavy rain on the ground at the base of the wall produces a temporary condition of saturation following which the water level in the wall rises again.

Fig 10b Photographs showing the conditions of the walls in the dry season

Tables 2a to 2c further shows that though water rose in the walls constructed with the SBs, the heights of rise was lower than that constructed with the CBs. The extent to which any wall will be affected by rising damp depends on the level of moisture in the ground, the features of the wall enabling or restricting evaporation from its surface, the porosity of the materials used to construct the walls, and the chemical composition of the migrating water (Riley and Cotgrave, 2005).

Figures 11a, 11b and 11c show the capillary rise of water recorded at various heights at the bases of the different walls. Only the values measured at the peak seasons (i.e. November for the rainy seasons and May for the dry seasons) have been presented in the figures. The peak seasons were chosen because it was found that during the peak of the rainy season, the water table rose, thereby increasing the amount of water in the ground and subsequently the increase in water in the walls (Figures 11a, 11b and 11c). During the peak of the dry seasons however the opposite happened (Figures 11a, 11b and 11c). All the other readings taken for the individual months are shown in Tables 2a, 2b and 2c attached as an Appendix.

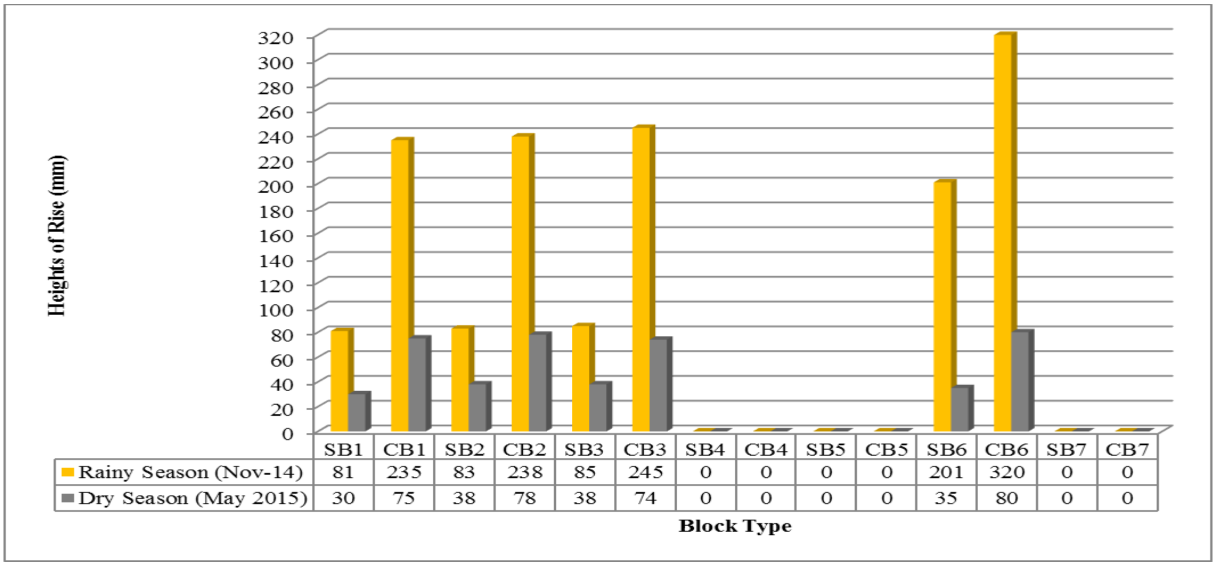


Fig 11a Capillary rise of water visually recorded at the peak of the seasons for 2014-2015

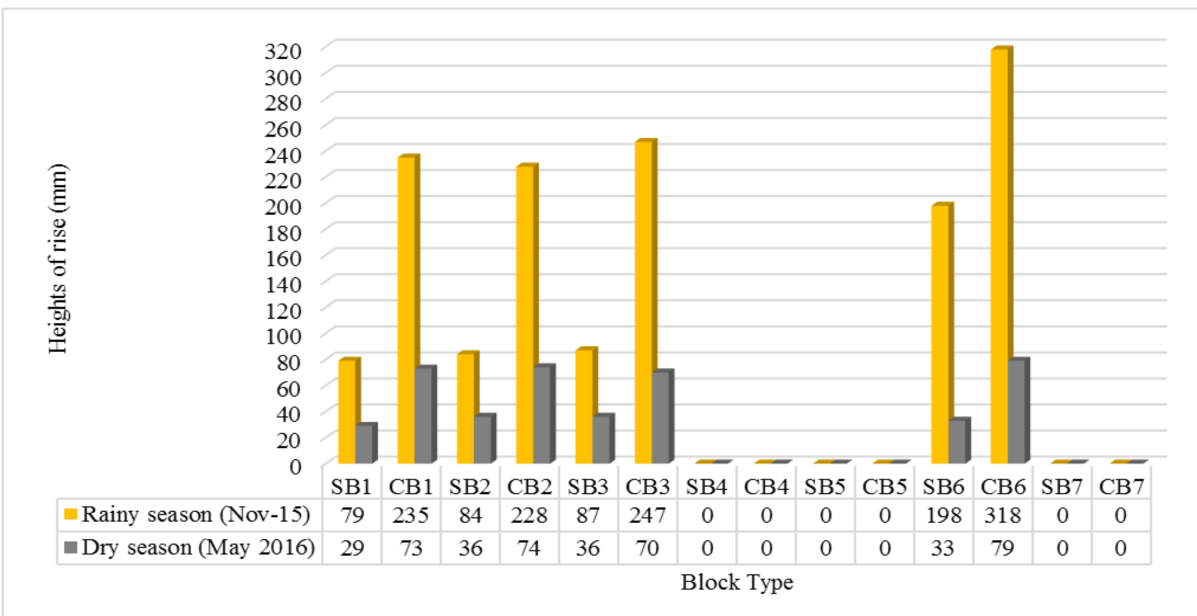
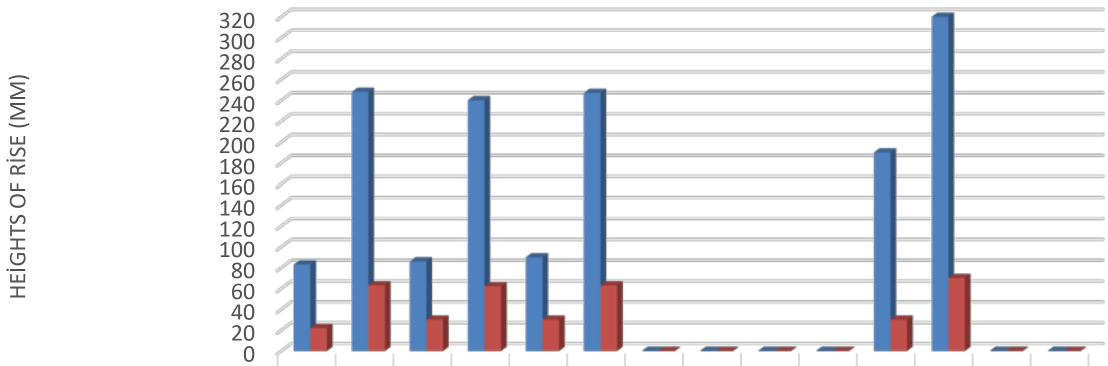


Fig 11b Capillary rise of water visually recorded at the peak of the seasons for 2015-2016



	SB1	CB1	SB2	CB2	SB3	CB3	SB4	CB4	SB5	CB5	SB6	CB6	SB7	CB7
Rainy Season (Nov-16)	83	248	86	240	90	247	0	0	0	0	190	320	0	0
Dry Season (May 2017)	22	63	30	62	30	63	0	0	0	0	30	70	0	0

Fig 11c Capillary rise of water visually recorded at the peak of the seasons for 2016-2017

3.3 Effectiveness of the mechanisms to prevent the capillary rise of water in the walls

The effectiveness of the various treatment methods determined based on measurement of the capillary rise of water in the walls are discussed under the following sub-headings to include:

3.3.1 Test walls (SB1and CB1; SB2 and CB2; SB3 and CB3) with polyethylene dpcs

Though at the peak of the rainy seasons (Figure 12) the water levels rose higher, especially in the block walls manufactured with the CBs, the water could not go beyond the dpcs.

Fig 12 Water rise at the bases of the walls treated with three different DPCs - 0.15 mm thick (A), 0.12 mm thick (B) and 0.13 mm thick (C)

This indicates that the dpcs acted as barriers that prevented the water from rising higher. Comparing this scenario to that in SB 6 and CB 6 (Figure 14), there is the likelihood that water would have risen higher in the walls had the dpcs not been in place. From Figure 12 it is clearly evident that the bases that had not been treated had been soaked with water. The ability of the water to rise in the walls depended on factors such as ground and soil conditions, environmental factors, climatic factors, etc of the area.

3.3.2 Test walls with the damp proof coatings

Figures 13a and 13b show the conditions of the two sets of walls (SB 4, CB 4; SB 5, CB 5) treated with the damp proof coatings during the rainy and dry seasons. The monitoring revealed that 4 years into the treatment of the walls, the damp proof coatings ‘A’ and ‘B’ are working perfectively. Moisture content measurements with the PCE MMK1 moisture meter with deep probes showed no traces of water at the bases of the walls, and the inner parts were considerably dry. This is because the entire perimeters of the wall bases were completely covered with the coatings, which filled the pore spaces within the sandcrete blocks, making it difficult for water to rise and penetrate.

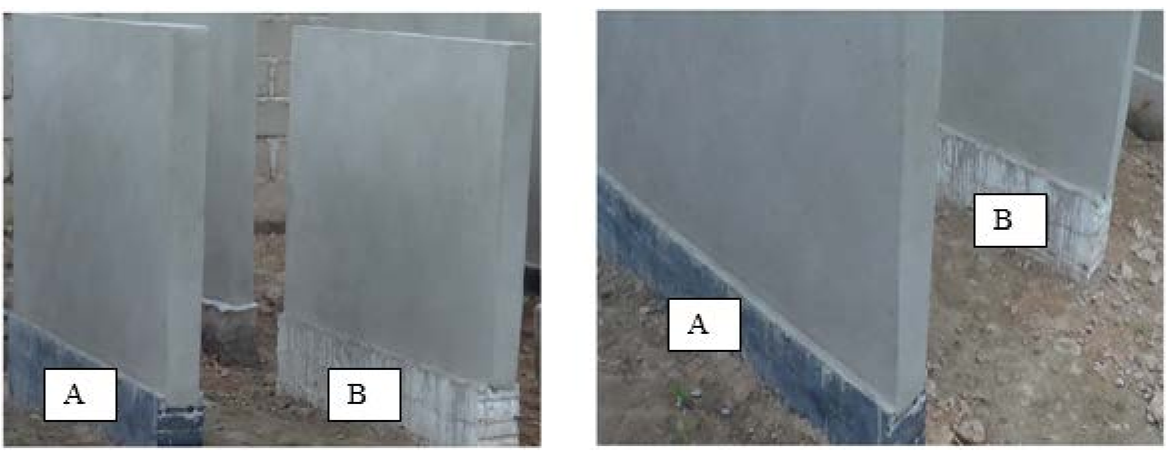


Fig 13a Photographs showing the conditions of the treated walls in the rainy season

Fig 13b Photographs showing the conditions of the treated walls in the dry season

3.3.3 Results from test walls with concrete bases

Test wall 7 for the two sets of sandcrete blocks were constructed with dense concrete bases. After four years of monitoring the walls against the capillary rise of moisture, the findings revealed that the bases of the walls showed no traces of moisture rise or penetration. The concrete bases were very dense and did not permit the ingress of water by capillary action. Figure 14 is a photograph that shows the conditions of the walls for the two different constructions.

Fig 14 Photographs showing the conditions of the test walls with concrete bases

3.4 Conditions of the control test walls (SB 6 and CB 6) without treatment mechanisms

For the test walls that were untreated and used as controls, considerable amount of water could be observed in the walls during the rainy season. However, in the dry seasons the water levels decreased drastically because of a drop in the water table within the vicinity. It is worthy to note that as compared to the other walls with the control mechanisms, the water levels always rose past the dpc level. This is what makes these walls the controls because the effectiveness of the other mechanisms can easily be compared against them. For the four-year period of monitoring these control walls, this scenario has been occurring.

To further demonstrate that the moisture was not only present on the surfaces of the walls but internally as well, mortar samples were obtained from the control test walls for laboratory testing during the rainy season in November 2016. The moisture contents were determined for the mortar samples obtained from Test walls 6 for both the SB and the CB. The results are shown in Tables 3a and 3b respectively.

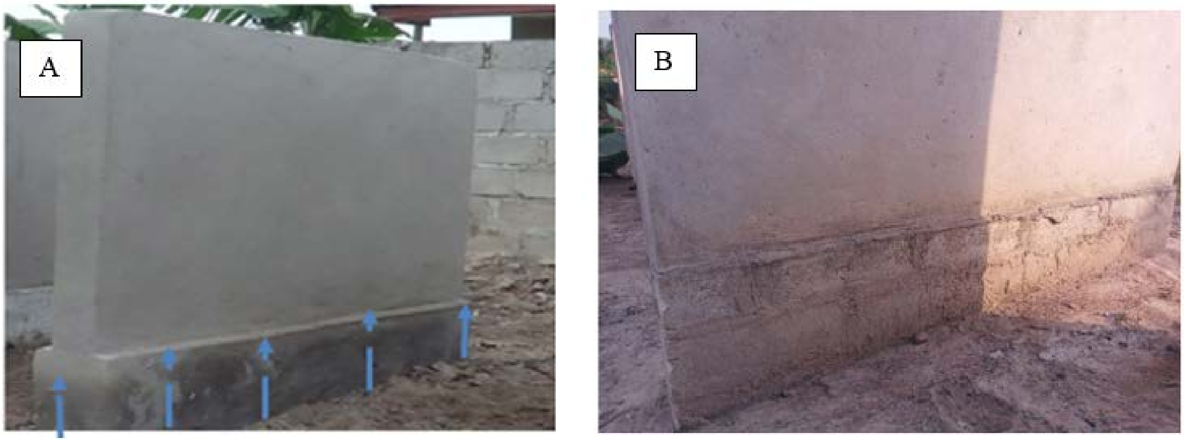


Fig 15 Photographs showing the presence (left) and absence (right) of water at the bases of the walls

Table 3a Moisture content of mortar samples collected at different depths in Test wall 6 (SB)

DEPTH	**% MOISTURE CONTENT**
Maximum height reached (201 mm for Test wall 6 manufactured with SB)	
0-25 mm	3.284
25-50 mm	3.404
50-75 mm	3.450

Table 3b Moisture content of mortar samples collected at different depths in Test wall 6 (CB)

DEPTH	**% MOISTURE CONTENT**
Maximum height reached (320 mm for Test wall 6 manufactured with CB)	
0-25 mm	3.193
25-50 mm	3.609
50-75 mm	3.772

The results show that the moisture contents varied with depths, that is, the deeper the mortar sample, the higher the moisture content and vice versa. This is a clear indication that the walls were sufficiently soaked with water. Hence, the moisture was not only present on the surfaces, but internally as well.

3.5 Parallel comparison of results with previously published laboratory results

As stated earlier on in the introduction, the study of rising damp has received numerous attention worldwide. This sub-section compares the findings from the current study with some of the previously published findings from laboratory experiments.

In 1991 Aghamo et al. conducted a laboratory experimental study on how rising damp occurs in masonry. Twenty masonry walls (12 of which were made of Tufa blocks and 8 clay filled bricks) were constructed in tanks that were filled with water. To replicate a true rising damp scenario, the researchers kept the water level in the tank at constant rate using an overflow pipe. The researchers closely monitored the wall specimens, and after every two weeks, they poured water into the tank until it leaked out of the copper pipe (overflow). The water used to fill the tank was sourced from a water tank that was periodically supplied by a well that collects ground water. The researchers used this source of water to replicate water with salt characteristics like those in actual ground soil. After a year, the researchers visually observed water traces in some of the walls that resulted from the capillary rise of water from the tank. Between June 1992 and September 1993, the researchers subjected 10 out of the 20 walls to chemical dpcs, four untreated (to act as reference walls), and the others to mechanical dpcs. The findings from their study revealed the ability of water to rise up in the walls erected in the tanks, and further confirmed the validity of the proposed laboratory method to check the effectiveness of the proposed treatments.

This current study was a replication of the study of Aghamo et al. (1991), but with different material (i.e. sandcrete block wall) and with walls erected in actual ground conditions, not in the laboratory. Despite using a different material and actual ground setting, the findings also confirmed the ability of water to rise in masonry materials (in this case sandcrete blocks) when subjected to ground water. Similar to the effectiveness of the chemical dpcs presented in Aghamo et al. (1991) work, the damp proof coatings used in the current study also exhibited similar effectiveness as had been reported. This finding confirms the fact that water truly rise in buildings when they are subjected to the ground without any proper preventive measures in place. Similar laboratory studies that confirm this fact have also been reported by: Burkinshaw (2012) in the Lambeth Pier Test Walls; Torres and de Freitas (2007), who simulated rising damp in the laboratory and applied the wall base ventilation system to treat it; Hola et al. (2008) who also demonstrated the ability of water to rise by capillarity in brick walls through impedance tomography; Rirsch and Zhang (2010) who erected different walls on trays in a laboratory to simulate rising damp in masonry walls, and to show the importance of the properties of mortar in the capillary rise of water; among others.

The uniqueness of the current study lies in two things: the demonstration of the ability of water rise in a material (sandcrete block) different from other materials reported in the numerous literature reviewed; and the ability to demonstrate that rising damp truly exist through the construction of the walls in actual ground conditions.

4.0 Conclusion and recommendations

The use of modern technology in building infrastructure has increased in recent years. Despite this revolution, the industry is still battling one major issue, i.e. defects associated with building infrastructure. Defective building construction may not only affect the final cost of the product, but also the cost of maintenance of the product. It is therefore very important to ensure that as much as possible, all or most of the defects in buildings are eliminated right from the onset of construction. As a common building defect, rising damp has become a torn in the flesh of most construction professionals, as well as building occupants. This study was conducted to explore mechanisms that can be used to prevent rising damp in new buildings. Fourteen prototype test walls were constructed and different treatment mechanisms were applied. The test walls were constructed with sandcrete blocks manufactured to standard and commercial specifications. The test walls were monitored for four years against rising damp, followed by the close monitoring of the effectiveness of the treatment mechanisms. The monitoring of the walls was done based on the two climatic seasons in Ghana (rainy and dry seasons). From the findings it was evident that rising damp truly exists. This was confirmed by the constant increase and decrease in the height of the water levels in the walls during the rainy and dry seasons. The findings further revealed that although all the treatment mechanisms performed well within the four-year period, the walls treated with the damp proof coatings, together with those with the dense concrete bases performed better than those treated with the polyethylene dpcs. Despite this encouraging results, it should be noted that the application of epoxy coatings to materials may completely seal off all the pores within such materials, and this may intend lead to blistering, causing such coatings to fail. It is recommended that the walls to which the epoxy coatings have been applied be monitored for longer periods against such blistering, and effective measures put in place to prevent such. The study further recommends a future study to look at the economic and commercial impacts of the proposed preventive mechanisms. The safety of the mechanical interruptions (polyethylene dpc) in seismic conditions is also an issue worth noting and studying. Finally, it is recommended that simulation tests be performed to understand what is expected to occur in the long term. The results obtained from the simulation could assist in validating the conclusion. This will assist surveyors in advising clients on how they would achieve better value for their money, whilst they attain quality in the methods they use to prevent the problem.

5.0 Implications

Rising damp has been on the known among researchers worldwide for years now. However, there have been series of myths disapproving its existence in buildings in Ghana. This study has therefore proven to critics that rising damp is evident in walls and therefore closed that knowledge gap. This study bridges that gap as the constructed test walls offer insights into the potential for moisture to rise up in solid block walls from the ground. The proposed treatments mechanisms have also shed light on the effectiveness of some treatments applied to walls to prevent the capillary rise of water from the ground into the superstructure. The findings from this study provides knowledge on how basic construction principles could be used to prevent the problem of rising damp, especially, in the construction of new buildings. With the annual growth of housing stock increasing yearly in Ghana, the proposed treatment mechanisms if properly implemented, should devoid new trends of buildings of the problem of rising damp. This will provide adequate time for existing buildings with the problem to be studied and remedied. Rising damp may have taken its roots and position in existing buildings. However, if proper measures are put in place during the construction of new buildings, the problem could be prevented right at its source, with little work to be done in tackling it in existing buildings.

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Table 2a Heights of rise of moisture in the walls from August 2014 to May 2015

	BLOCK TYPE	RAINY SEASON				DRY SEASON					
		August 2014	**September 2014**	**October 2014**	**November 2014**	**December 2014**	**January 2015**	**February 2015**	**March 2015**	**April 2015**	**May 2015**
HEIGHTS OF RISE	SB1	70 mm	75 mm	79 mm	81 mm	55 mm	40 mm	40 mm	40mm	38mm	30mm
	CB1	215 mm	228 mm	230 mm	235 mm	150 mm	95 mm	82 mm	80mm	80mm	75mm
	SB2	73 mm	78 mm	80 mm	83 mm	64 mm	43 mm	43 mm	41mm	40mm	38mm
	CB2	220 mm	230 mm	235 mm	238 mm	162 mm	100 mm	85 mm	83mm	80mm	78mm
	SB3	75 mm	80 mm	82 mm	85 mm	64 mm	45 mm	45 mm	43mm	40mm	38mm
	CB3	235 mm	240 mm	243 mm	245 mm	164 mm	98 mm	85 mm	80mm	78mm	74mm
	SB4	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	CB4	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	SB 5	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	CB 5	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	SB 6	72 mm	75 mm	78 mm	201 mm	78 mm	65 mm	50 mm	45mm	42mm	35mm
	CB 6	215 mm	250 mm	265 mm	320 mm	195 mm	150 mm	95 mm	90mm	86mm	80mm
	SB7	100 mm	80 mm	50 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	CB7	112 mm	85 mm	55 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	Moisture content increased with month in the rainy season				**PEAK VALUES Moisture content recorded is maximum**	Moisture content decreased with month in the dry season					**Moisture content recorded is minimum**

Table 2b Heights of rise of moisture in the walls from August 2015 to May 2016

	BLOCK TYPE	RAINY SEASON				DRY SEASON					
		August 2015	**September 2015**	**October 2015**	**November 2015**	**December 2015**	**January 2016**	**February 2016**	**March 2016**	**April 2016**	**May 2016**
HEIGHTS OF RISE	SB1	68 mm	73 mm	75 mm	79 mm	53 mm	38 mm	38 mm	40mm	37mm	29mm
	CB1	209 mm	218 mm	230 mm	235 mm	146 mm	92 mm	78 mm	80mm	78mm	73mm
	SB2	75 mm	77 mm	81 mm	84 mm	62 mm	41 mm	39 mm	41mm	38mm	36mm
	CB2	222 mm	232 mm	234 mm	228 mm	160 mm	98 mm	83 mm	81mm	80mm	74mm
	SB3	73 mm	82 mm	85 mm	87 mm	61 mm	40 mm	42 mm	44mm	39mm	36mm
	CB3	230 mm	242 mm	245 mm	247 mm	163 mm	95 mm	81 mm	78mm	75mm	70mm
	SB4	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	CB4	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	SB 5	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	CB 5	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	SB 6	74 mm	76 mm	80 mm	198 mm	76 mm	63 mm	49 mm	41mm	39mm	33mm
	CB 6	213 mm	248 mm	263 mm	318 mm	190 mm	148 mm	90 mm	87mm	82mm	79mm
	SB7	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	CB7	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	Moisture content increased with month in the rainy season →				**PEAK VALUES Moisture content recorded is maximum**	Moisture content decreased with month in the dry season →					**Moisture content recorded is minimum**

Table 2c Heights of rise of moisture in the walls from August 2016 to May 2017

	BLOCK TYPE	RAINY SEASON				DRY SEASON					
		August 2016	**September 2016**	**October 2016**	**November 2016**	**December 2016**	**January 2017**	**February 2017**	**March 2017**	**April 2017**	**May 2017**
HEIGHTS OF RISE	SB1	72 mm	74 mm	75 mm	83 mm	48 mm	35 mm	32 mm	37 mm	35mm	22 mm
	CB1	220 mm	238 mm	240 mm	248 mm	140 mm	90 mm	73 mm	74 mm	71mm	63 mm
	SB2	78 mm	82 mm	84 mm	86 mm	60 mm	38 mm	35 mm	40mm	34mm	30 mm
	CB2	231 mm	234 mm	236 mm	240 mm	156 mm	97 mm	80 mm	73mm	75mm	62 mm
	SB3	75 mm	81 mm	87 mm	90 mm	63 mm	42 mm	38 mm	40mm	33mm	30 mm
	CB3	232 mm	242 mm	245 mm	247 mm	160 mm	93 mm	79 mm	74mm	70mm	63 mm
	SB4	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	CB4	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	SB 5	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	CB 5	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	SB 6	72 mm	74 mm	82 mm	190 mm	73 mm	60 mm	45 mm	39mm	36mm	30mm
	CB 6	225 mm	233 mm	245 mm	320mm	192 mm	137 mm	85 mm	82mm	78mm	70mm
	SB7	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	CB7	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0 mm	0mm	0mm	0mm
	Moisture content increased with month in the rainy season →				**PEAK VALUES Moisture content recorded is maximum**	Moisture content decreased with month in the dry season →					**Moisture content recorded is minimum**