RISING DAMP EVALUATION AND TREATMENT A QUASI-EXPERIMENTAL CASE STUDY

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Leslie Sellers, May 2017.

Abbreviations

BBA	British Board of Agrément.
BCDA	British Chemical Dampcourse Association.
BRE	Building Research Establishment.
BWPDA	British Wood Preserving and Damp Proofing Association.
CITB	Construction Industry Training Board.
CMC	Capillary Moisture Content.
CSRT	Certified Surveyor in Remedial Treatment.
CSSW	Certified Surveyor in Structural Waterproofing.
EMERISDA	Effectiveness of Methods against Rising Damp in Buildings.
ERH	Equilibrium Relative humidity.
HMC	Hygroscopic Moisture Content.
M-M	Protimeter measure-mode function.
MMS	Moisture Measurement System.
PCA	Property Care Association.
RH	Relative Humidity.
RICS	Royal Institution of Chartered Surveyors.
STBA	Sustainable Traditional Buildings Alliance.
SVP	Saturated Vapour Pressure.
TMC	Total Moisture Content.
VP	Vapour Pressure.
WME	Wood Moisture Equivalent.
WPA	Wood Preserving Association.
W_0	Weight of the receptacle used to hold a sample.
W_{75}	Weight of a sample after processing at 75% relative humidity.
W_w	Weight of a sample 'as found'
W_d	Weight of a sample after oven drying.

Units of measurement

ºC	Degrees Celsius.
g	gram.
kPa	Kilopascal.
m	Metre.
µm	Micrometre.
mg	Milligram.
mg/l	Milligram per litre.
ml	Millilitre.
mm	Millimetre.
%	Percent.

Abstract

The UK has a well-established industry involved in the treatment of rising damp. Yet, critics argue that rising damp is extremely rare and remedial damp proof course treatments unnecessary and ineffective. Additionally, evaporation from rising damp affected masonry is under-researched and opinions differ with respect to the effect that this moisture may have on the local environment.

The aim of this research is to establish whether contemporary remedial damp proof course treatments are necessary and effective and if moisture affecting a damp wall is correlated with that in the environment. Due to the limitations of existing laboratory-based research in this area, a practice-based approach employing a novel methodology, blending case study and quasi-experimental methods, was chosen to assess, in a field setting, the component parts of the contemporary method of remedial damp proof course treatment, techniques of moisture measurement, evaporation, and environmental moisture.

The study found that rising damp is a real phenomenon that warrants treatment and that the contemporary method of damp proofing, installed as it would be in a real world setting, provides effective control. In addition, it determined that sample analysis is the only reliable method of diagnosing rising damp, that evaporation from a rising damp affected wall cannot be measured, and only the hygroscopic moisture component of a damp wall displays correlation with the wider environment.

A project of this type has not previously been undertaken. It makes an original contribution to existing theory, laboratory research, and practice by providing useful data with respect to common and novel techniques for the measurement of moisture and evaporation from masonry materials; valuable reassurance to property professionals, home owners, and other stakeholders regarding the phenomenon and treatment of rising damp; and through the development of its unique methodology a mechanism to facilitate future field studies in this area of practice.

Chapter 1
Introduction

1.1. Introduction

In the United Kingdom, dampness is the most common defect to affect buildings (Burkinshaw & Parrett, 2003, p. vi). In houses, the three main causes of dampness are condensation, penetrating damp, and rising damp (Oliver, Douglas, & Stirling, 1997, p. 14; Trotman, Sanders, & Harrison, 2004, p. 1).

In buildings investigated by the BRE during the period 1970-1989 where more than 50% of the defects were attributable to dampness, 25% were due to rain water penetration, 17% to condensation, 5% to construction moisture, and 5% to rising damp (Trotman, Sanders, & Harrison, 2004, p. 5).

The World Health Organization (2009a, p. 3) report that 10-50% of homes within Europe have damp environments and that either dampness or mould affects up to 50% of houses in the United States (2009b, p. 7).

The English Housing Survey of 2014 (2016, p. 33) found dampness to affect 13.6% of homes (2.6 million) in 1996 and although this figure had fallen to 4% of the total housing stock (one million homes) by 2014, damp prevailed in 5% of social rented and 9% of private rented housing (Department for Communities and Local Government, 2016, p. 33). Despite this falling trend, which is illustrated in Figure 1 below, dampness is significant and is found in all types of buildings where it causes material degradation and unhealthy living conditions (Burkinshaw & Parrett, 2003, p. vi).
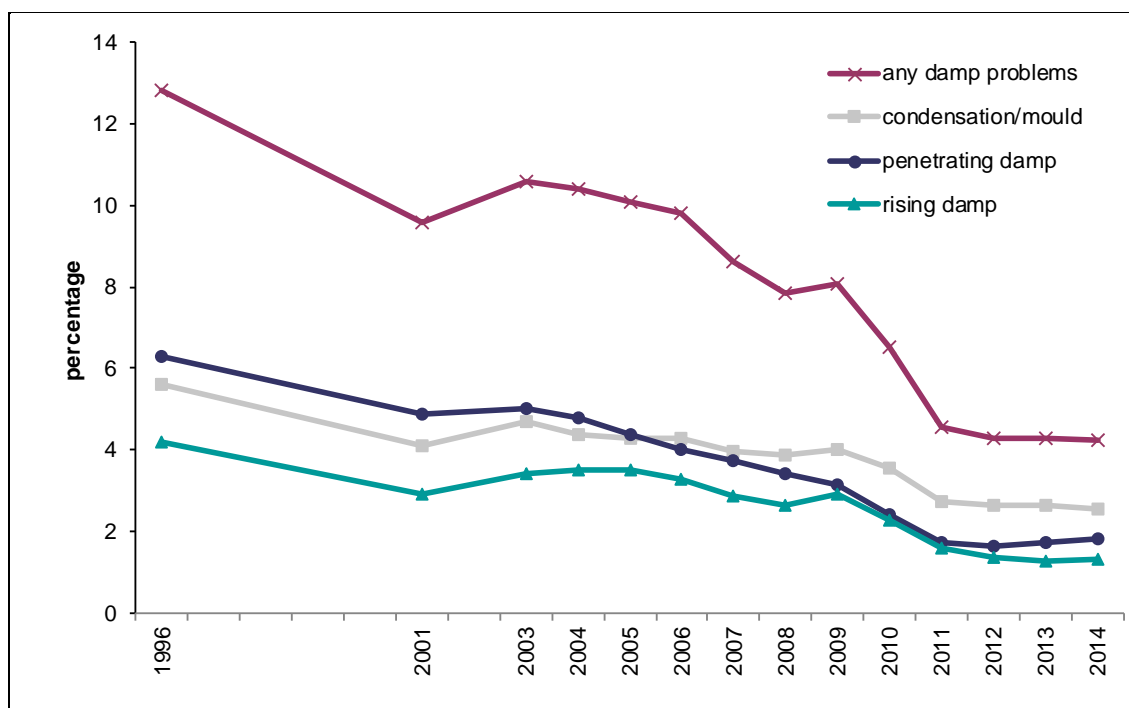
Figure 1: English Housing Survey houses with damp problems 1996 to 2014 (Adapted from Department for Communities and Local Government, 2016, p. 33).

This research project is not concerned with all forms of dampness; instead, for reasons that will be explained later in this chapter, it is interested in the phenomenon and treatment of rising damp.

Given the information provided by the BRE (Trotman, Sanders, & Harrison, 2004, p. 5) and the English Housing Survey (2016, p. 33), summarised in Figure 1 above, it is clear that the percentage of properties affected by rising damp has fallen over the past twenty-five years or so from around 5% to 1%, in line with the trend of other forms of dampness. That rising damp is present in fewer houses than condensation or penetrating damp, or indeed that it has shown a reduction overtime, is unsurprising. Rising damp is a problem essentially confined to older buildings without an effective damp proof course and, therefore, is restricted to a particular type of structure rather than to the wider housing stock (Department for Communities and Local Government, 2016, p. 34; Trotman, Sanders, & Harrison, 2004, p. 6). Furthermore, logic suggests that successful treatment of rising damp would lead to a systematic reduction in the number of properties in which it persists; nevertheless, rising damp was reported to affect

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311,000 houses in 2014 (Department for Communities and Local Government, 2016, p. 33).

Is rising damp as prevalent as these figures suggest? Is the fall in the occurrence of rising damp a direct result of successful treatment or simply because it was misdiagnosed in the first place? These questions are posed because they are common criticisms of rising damp, the damp proofing industry, and the treatments that this industry undertakes.

1.2. Rising damp and its treatment

Rising damp is the upward movement of moisture from the ground by capillary action: a natural phenomenon that allows water to rise up a tube through the forces created by the surface tension of the liquid (Oliver, Douglas, & Stirling, 1997, p. 186; Oxley & Gobert, 1983, p. 47). In the context of buildings, rising damp can affect any porous construction material that is in direct contact with the ground, but it is generally used as a description for such dampness that affects the lower parts of ground floor walls (Hall & Hoff, 2007, p. 1871).

Technically, rising damp describes a mechanism that can conceivably result from faults to below ground drainage, rainwater goods, or mains pipework that enabled water to seep into the ground and thus could be addressed by rectifying these primary defects. Furthermore, not all moisture that affects the bases of ground floor walls will be attributable to rising damp: condensation, penetrating damp, and plumbing leaks are all tangible sources of moisture that can produce similar symptoms (Trotman, 2007, p. 2). However, this study is concerned with 'true' rising damp, that is, in the absence of sources other than naturally occurring ground water, the rise of moisture from the ground by capillary action into the bases of ground floor walls.

The installation of damp proof courses to prevent rising damp is said to have become mandatory following the introduction of the Public Health Act 1875 and they are generally found in houses built after this date (Burkinshaw & Parrett, 2003, p. 31;

Douglas & Noy, 2011, p. 120; Marshall, Worthing, & Heath, 2003, p. 274; Trotman, 2007, p. 2). Thus houses constructed before 1875 (i.e. built without a damp proof course) or where an existing damp proof course has failed will be susceptible to rising damp.

Early damp proof courses were formed from tar, lead, slate, and dense bricks (Marshall, Worthing, & Heath, 2003, p. 334). For new construction, damp proof courses can be fashioned from flexible, semi-rigid or rigid materials, but they commonly comprise a black polythene membrane inserted into a horizontal mortar bed joint (BSI, 1984; 1991, p. 1; Visqueen Building Products, 2017, pp. 1-2). This study is not concerned with new build damp proof courses but, instead, is interested in chemical injection, retrofit damp proof courses that are used for the remedial treatment of rising damp.[1]

Chemical injection damp proof courses were introduced into the UK in the 1950s. Initially, they involved high or low-pressure pressure injection of water-repellent silicones or aluminium stearate into holes drilled into the brick or stone units at the base of a wall (Oliver, 1984, pp. 34-37; Oliver, Douglas, & Stirling, 1997, pp. 196, 199). But since the beginning of the twenty-first century, the use of pressure injection methods has declined and water or organic solvent based damp proofing chemicals have largely been replaced with silane/siloxane creams such as 'Dryzone' (Safeguard Europe Ltd., 2015), 'Tri-Gel' (Triton Chemical Manufacturing Co. Ltd., 2011), 'Ultracure' (Wykamol Group, 2009), and other similar products.

Using a caulking gun or proprietary applicator, damp proofing creams are inserted into holes drilled in the horizontal mortar bed joint rather than the masonry units (Safeguard Europe Ltd., 2015, pp. 2-3). These hydrophobic chemicals form a non-wetting surface within the capillaries, which, by altering the contact angle between the water and the capillary (i.e. pore) sides, create a convex meniscus that exerts a downward pressure, thereby supressing rising damp, as illustrated in Figure 2 below (Safeguard Europe Ltd., 2007, p. 9).

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[1] There are other remedial damp proof course methods but they are beyond the remit of this study.
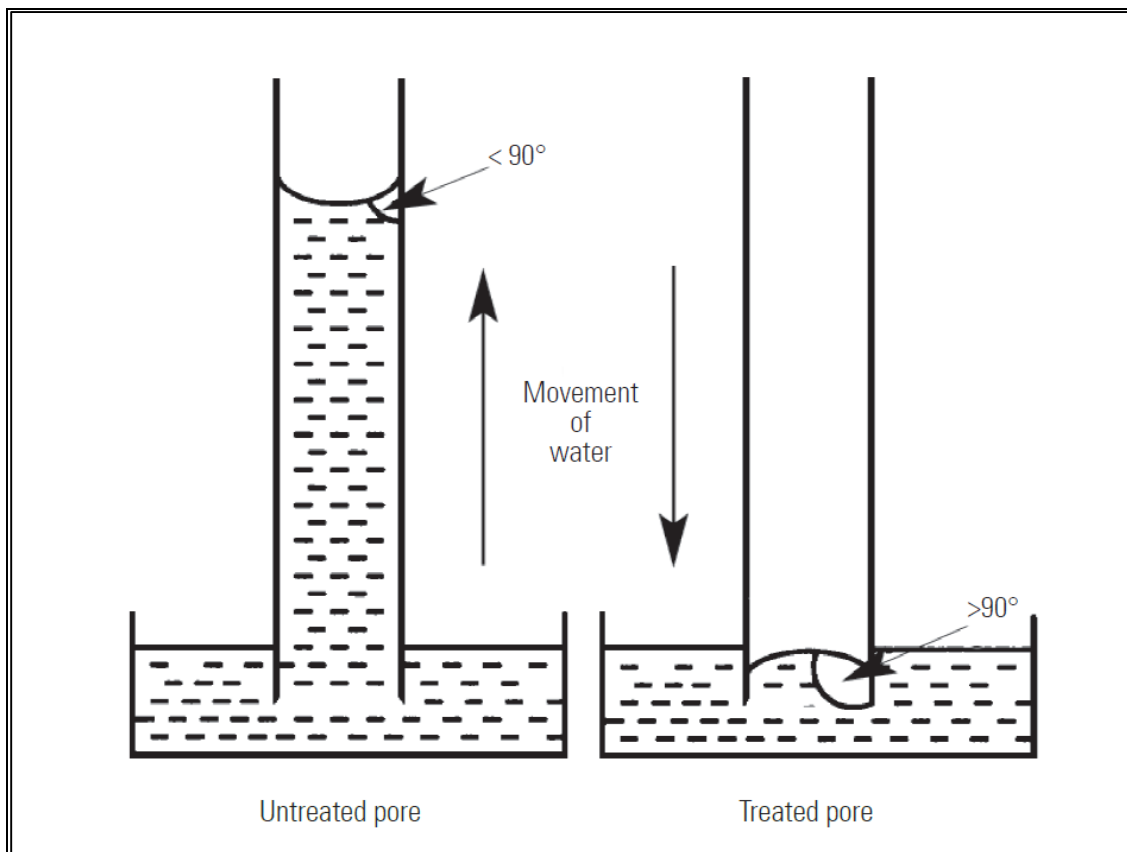
Figure 2: Untreated and treated pore (capillary) structure.

This graphic illustrates how in the treated pore the contact angle of the water with the sides of the capillary changes from less than 90°, which enables it to rise through interfacial tension, to an angle greater than 90°, altering the meniscus of the water in the capillary from concave to convex and thereby creating a downward pressure that depresses rising damp (Adopted from Safeguard Europe Ltd., 2007, p. 9).

The damp proofing cream technique is the contemporary method for retrofit damp proof courses and is the process that will be scrutinised in this project. Significantly, the damp proofing cream, the pressure injection methods that went before it, and indeed any other form of remedial damp proof course is just one part of a two-part system.

A damp proof course has a function: to prevent the upward rise of moisture from the ground. A physical (e.g. plastic) damp proof course built into a new wall will be very effective in this respect (Stationery Office, 2013, p. 29); yet, a chemical injection, retrofit damp proof course, installed in an old wall has inherent limitations and cannot be expected to stop rising damp completely (Burkinshaw, 2009, p. 83; Safeguard Europe Ltd., 2005, p. 1).

During the initial drying out period following installation of a remedial damp proof course, moisture that is present in the masonry wall needs to be effectively controlled, and in practice some residual moisture is likely to remain (Safeguard Europe Ltd., 2007). In addition, moisture sourced from the ground contains hygroscopic nitrate and chloride salts (Oliver, Douglas, & Stirling, 1997, p. 189; Oxley & Gobert, 1983, pp. 38-39). Rising damp brings these salts up into the walls and subsequent evaporation enables them to become highly concentrated in masonry, plaster, and other porous materials, overtime (Safeguard Europe Ltd., 2007, p. 5).

Construction materials do not typically contain nitrates, so their presence is a characteristic of rising damp that can be useful as an aid to diagnosis (Oliver, Douglas, & Stirling, 1997, p. 189; Oxley & Gobert, 1983, pp. 38-39). In addition, contamination from hygroscopic salts enhances the affected materials' ability to absorb moisture directly from the air and such moisture absorption can give rise to significant dampness despite the effectiveness of an installed damp proof course (Oliver, Douglas, & Stirling, 1997, p. 189; Oxley & Gobert, 1983, pp. 38-39; Safeguard Europe Ltd., 2007, p. 5).

It is for these above two reasons that in addition to the installation of a damp proof course the issues of residual moisture and hygroscopic contamination have to be addressed. This process has two stages: firstly, plasterwork contaminated with hygroscopic salts is removed, thus alleviating the initial problem; secondly, the plasterwork is reinstated using a specification designed to prevent hygroscopic salts and residual moisture present in the underlying masonry wall from affecting the wall surface (Safeguard Europe Ltd., 2007, p. 5; Triton Chemical Manufacturing Co. Ltd., 2011, pp. 3,4).

Reinstatement of plasterwork is typically undertaken using low-permeability cement renders (BRE Housing Defects Action Unit, 1986, p. 2; Safeguard Europe Ltd., 2005, pp. 1,2; Triton Chemical Manufacturing Co. Ltd., 2011, p. 29; Wykamol Group, 2013, p. 2). In essence, the damp proofing cream and the associated replastering work are inextricably linked as a single system (Safeguard Europe Ltd., 2007, p. 11).

Significantly, low-permeability cement renders are highly waterproof and even under conditions of positive water pressure will present a dry surface (Trotman, 2007, p. 9). Thus, the two-part nature of the chemical injection damp proof course system raises an important question: what precisely provides the damp proofing effect; is it the injected damp proof course or is it the applied, low-permeability render?

1.3. The damp proofing industry

Given the profusion of dampness problems in buildings, it is unsurprising that there is a well-established industry that provides surveying and remedial damp proofing services. This industry emerged from the practice of installing chemical injection damp proof courses into houses in the 1960s and is now an established profession that in 2009 was reported to be worth over £200 million per year (Hollis & Gibson, 2005, p. 421; The Architects' Journal, 2009).

The damp proofing industry has no barrier to entry. Anyone can obtain the necessary equipment and set themselves up as a specialist damp proofer, and damp proofing creams are readily available from on-line auction sites and DIY stores (Wickes, 2017). The industry does, however, have a trade organisation: The Property Care Association (PCA).

The PCA in its present form was established in 2006 following its separation from the Wood Preserving Association (WPA). However, although this recent relationship had only existed since 2003 when both associations were collective known as the British Wood Preserving and Damp Proofing Association (BWPDA), the BWPDA was created in 1989 from the merger of the British Chemical Dampcourse Association (BCDA), established in 1977, and the British Wood Preserving Association (BWPA), established in 1930 (Property Care Association, 2017a). Thus the PCA has a close to ninety-year history.

Contractor membership of the PCA, which is aimed at organisations who provide surveying and remedial treatment of dampness, is by application and necessitates a stringent vetting process that requires a minimum period of trading, the attainment of relevant qualifications, adherence to an ethical code of conduct, periodic inspection, and the payment of an annual subscription fee (Property Care Association, 2017b). At the end of 2015, the PCA had 402 contractor members, a 15% increase on the previous year (Property Care Association, 2015, p. 5).

The association is often featured in the media, and has forged relationships with the Construction Industry Training Board (CITB), Building Research Establishment (BRE), the Royal Institution of Chartered Surveyors (RICS), Sustainable Traditional Buildings Alliance (STBA), and Trustmark (Property Care Association, 2015, pp. 10,11). Essentially, the association has built an authoritative reputation for the care of houses and portrays itself as a credible organisation, its members as highly trained and trustworthy professionals, and it is prepared to demonstrate this commitment through the expulsion of contractor members who fail to maintain their standards (Property Care Association, 2015, p. 5; 2017a).

The PCA provides training for technicians and surveyors and through an examination process administers the mandatory qualifications of 'Certified Surveyor in Remedial Treatment' (CSRT) and 'Certified Surveyor in Structural Waterproofing' (CSSW) (Property Care Association, 2017c, 2017d, 2017e, 2017f). However, because membership is not a requirement to attend its training courses or to sit the CSRT and CSSW examinations, there are independent damp proofing businesses with staff who have attained these qualifications and provide similar services.

The PCA's mission statement is to "promote high standards of professionalism and expertise within the industry through training and other support services. To promote these standards outside the Association to ensure that members of the Property Care Association are perceived as the best providers in these specialist sectors" (Property Care Association, 2017a).

Perhaps it is unrealistic to suppose that such standards will extend across the entire damp proofing industry, and the association has no jurisdiction over non-member organisations, but it seems unjust to assume that organisations with an established track record and trading history, whether members of the PCA or not, would not deliver their services honestly and professionally. Nevertheless, this is not a view shared by critics of the industry.

1.4. Criticisms

From the foregoing, it seems reasonable to make three assumptions:

1. Capillary action is a mechanism that enables rising damp to occur in houses and although its incidence has fallen over the past twenty-five years this form of moisture continues to affect many hundreds of thousands of houses.

2. Rising damp can be successfully treated by injecting the affected walls with damp proofing cream and replacing plaster contaminated with hygroscopic soil salts with low-permeability cement renders.

3. There is a well-established damp proofing industry served by professionals who specialise in the surveying and treatment of dampness. This industry has a well-respected trade organisation, the Property Care Association, that provides training and support services and through an affiliation scheme endeavours to maintain high standards among its members.

All three of these assumptions have been challenged by critics.

The 1999 BBC programme 'Raising The Roof' carried out an investigation with respect to the identification and treatment of rising damp in houses by specialist damp proofing organisations. (BBC, 1999a, 1999b). Two commentators, Mike Parrett and Jeff Howell, were featured in this programme.

Parrett is a chartered scientist, building pathologist, co-author of 'Diagnosing Damp', an RICS publication, and producer of an award winning and well-reviewed six-part DVD series 'Building Pathology', all of which tend to support his claim as a leading expert on dampness in buildings (Burkinshaw & Parrett, 2003; Dampbuster.com, 2008; Hunt, 2006; M. Parrett, n.d.). In the BBC programme (1999a), Parrett maintained that while working for fifteen years as a surveyor for Lewisham council he had not found a single case of rising damp nor had recourse to install a chemical damp proof course, despite inspecting thousands of houses for dampness. He concluded that the damp proofing specialist's reliance on an electronic moisture meter caused widespread misdiagnosis and the unnecessary installation of chemical injected damp proof courses (BBC, 1999b).

Howell is a former bricklayer and senior lecturer of construction technology at South Bank University, where he researched dampness in buildings, and he writes a column for the Sunday Telegraph (Howell, 2008, p. inside back cover). The BBC programme featured his study of rising damp in brick pillars placed in tanks of water. Howell said that the pillars had to be constructed with a very weak mortar—essentially, a mortar containing no cement—and that this "allowed the damp to rise up a small way"; he concluded that "the normal British house in the normal British climatic conditions does not have rising damp. I would go so far as to say that rising damp is a myth; it does not exist" (BBC, 1999b).

Paul Kenyon, the presenter of 'Raising the Roof' ended the programme by arguing that householders waste millions of pounds each year on unnecessary damp proofing work and that the damp proofing industry is incompetent and fraudulent (BBC, 1999b).

In 2008, Howell published a book titled 'The Rising Damp Myth' (2008). In his book, as well as continuing to argue that rising damp was very rare or may not exist at all, Howell provides a damning review of the damp proofing industry, criticizing its sole reliance on the electronic moisture meter for diagnosis, its failure or indeed intent to see beyond rising damp as the cause of low level dampness, and its bias for the installation of

chemical injection damp proof courses as a cure all (Howell, 2008, pp. 27,40,59,103,109,122,125).

Howell contends that chemical injection damp proof courses do not work, that they may even exasperate rising damp, and that any damp proofing effect is attributable to the application of cement renders (Howell, 2008, pp. 95,102,104,105,125). Interestingly, he also claims that the term 'rising damp' did not come into common usage until the 1950s and that despite the commonly held belief that the installation of damp proof courses into houses became mandatory following the introduction of the Public Health Act 1875 that this is wrong and the act does not in fact mention damp proof courses at all (Howell, 2008, pp. 50,72).

In 2009, Howell appeared with Stephen Boniface, a former chair of the RICS Building Faculty, on a NBS video interview discussing rising damp (NBS, 2011). Howell reiterated the views he made in the BBC programme (1999b) and in his book (2008), described above. Boniface's comments, which were also reported in The Architect's Journal (2009; Waite, 2009, p. 5), aligned with Howells, contending that the effect of gravity and evaporation supresses rising damp to the extent that it is very rare and that chemical injection works undertaken by damp specialists are unnecessary and ineffective (NBS, 2011, p. 5; The Architects' Journal, 2009; Waite, 2009). Boniface's belief is such that he amended the RICS Dampness Factsheet (RICS, n.d.), placing references to 'rising damp' in inverted commas to indicate its ambiguity with respect to any form of dampness at low levels on walls (NBS, 2011, p. 5; Waite, 2009).

In the same journal article (The Architects' Journal, 2009; Waite, 2009, p. 5), Elaine Blackett-Ord, chair of the Register of Architects Accredited in Building Conservation, is quoted as saying "rising damp is as rare as rocking-horse shit" going on to criticize damp proofing treatments as ineffective, a waste of money, and inappropriate and damaging to historic buildings.

Other experts in dampness have also questioned the commonality of rising damp. Ridout (2001, p. 50) criticizes the presumption, typically arrived at through the use of an electronic moisture meter, that rising damp is always the cause of dampness, and that buildings must be treated with a damp proof course simply because they are old. Oliver et al (1997, p. 185), whilst identifying rising damp as a tangible source of dampness, suggest that there has been a steadily growing opinion that it is less significant than previously thought. Burkinshaw (2009, p. 13), although accepting that there is a mechanism for rising damp in buildings, argues that it is relatively rare, difficult to diagnose, and is often misdiagnosed.

The January 2012 edition of Which! magazine included an investigation of eleven damp proofing companies: six large and five smaller organisations (Which!, 2012, pp. 67-69). In their article, Which! concluded that although over 50% of these companies gave useful advice, four incorrectly diagnosed rising damp and recommended unnecessary chemical damp proof course and associated works. Which! were also critical of the knowledge and competence of the surveyors, the quality of the reports that they provided, and suggested that the issues identified in their investigation may be far more widespread (Which!, 2012, p. 69).

That rising damp is a myth has also not escaped the attention of the popular media. A 2011 edition of the BBC's QI programme, along with an accompanying synopsis on the 'Quite Interesting' website, discuss this topic, making specific reference to the comments of Parrett, Boniface, and Howell (BBC, 2011; Quite Interesting Ltd., 2011). Of course, nowadays, critics need not be limited to television or print media, anyone can provide their opinion on websites, on-line forums, social media sites, or via YouTube videos.

On his website, Konrad Fischer, a German architect, questions the existence of rising damp, providing examples of bridge parapets that he argues remain unaffected by moisture despite constant contact with water (Fischer, 2009, n.d.). This is a view shared by Summersgill, a chartered surveyor writing in the Yorkshire Times, who argues that

"Rising damp is almost non-existent - it rarely occurs naturally, and it certainly doesn't move a metre up the walls as "damp proofing' 'specialists' [sic] would have you believe", goes on to suggest that all damp proofing specialist surveyors are commissioned salespeople and their treatments ineffective (Summersgill, 2013).

The many pages of the Heritage House website contain a comprehensive and disparaging assault of the damp proof industry and 'The Fraud of Rising Damp' (Heritage House Building and Restoration, 2017c). The writer pulls no punches in accusing the industry of incompetent misdiagnoses and of conning home owners into unnecessary and ineffective remedial damp proofing work. They are particularly critical of the national damp proofing companies and of the Property Care Association and its members; in fact, of anyone remotely associated with the industry (Heritage House Building and Restoration, 2017a, 2017b). They maintain that rising Damp is a 'figment of building surveyors [sic] imagination' and does not exist (Heritage House Building and Restoration, n.d.).

It is not easy to determine the number of views a particular website may receive and therefore its popularity but YouTube do provide this information for all of their videos. Two of several videos uploaded to YouTube by Peter Ward of Heritage House Building and Restoration, which provide reviews of the damp proofing industry's activities that are in line with their website content, have received nearly 55,000 views (Ward, 2014a, 2014b).

Similarly, it is not practical to attempt to trawl the numerous social media sites for comments in respect of rising damp, its treatment, and of the damp proofing industry; however, a sample search of the LinkedIn forums 'Building Pathology' (5,928 members) and 'Diagnosis of dampness defects' (1,605 members) using the term 'Rising damp myth' found numerous posts (LinkedIn, 2017a, 2017b). Not all were relevant but opinion is typically split with respect to the frequency, cause, and appropriate treatment of rising damp.

The foregoing critique has highlighted issues and the significant criticisms of the damp proofing industry that extend beyond the practical existence of rising damp or of the effectiveness of contemporary damp proofing treatments. Questions have been raised over the competence of damp proofing specialists, their sole reliance on electronic moisture meters as a means of diagnoses, and of their integrity.

The opinions of Parrett, Howell, Boniface, and Blackett-Ord are scathing of the damp proofing industry and of the treatments they undertake, and it is difficult to ignore the comments of these professionals and those of renowned experts such as Ridout, Oliver et al, and Burkinshaw. It is perhaps easy to dismiss website blogs, forum posts, and YouTube videos as unsolicited opinions and to question their place in academic research; however, these and other popular media such as the BBC's entertainment programmes and Which! Investigations, in raising the profile of these issues, add further weight to these concerns.

1.5. My story

My involvement with the damp proofing industry began in the mid-1980s when I established my own business surveying, diagnosing, and treating dampness and timber decay in houses. Previously, I had trained as a civil engineering draughtsman, qualified as a civil engineering technician, and later worked as an engineer on building and civil engineering projects in the UK and Middle East, so I had amassed some useful experience in construction.

Over the following thirty years, this fledgling enterprise expanded into a small business that provides consulting, surveying, and contracting services, with respect to damp and timber decay in buildings, to the private and commercial property sectors. It currently employs ten people and is a contractor member of the Property Care Association (PCA).

I hold the PCA's CSRT and CSSW qualifications and untypical for a surveyor in this specialist industry I am a chartered building surveyor and chartered building engineer.

Essentially, I have endeavoured to become as qualified as I am able, and I consider that my business operates in an honest, ethical, competent, and professional manner.

It is acknowledged that businesses that provide combined services, which in the case of the damp proofing specialist are the recommendations of survey findings and the contracting works stemming from those recommendations, may well be accused of bias. Indeed, the critics argue that such specialist do not provide impartial advice but, instead, have a vested interest in selling damp proofing treatments (Burkinshaw, 2009, p. 3; Howell, 2008, p. 8; Oliver, Douglas, & Stirling, 1997, p. 3; Mike Parrett, 2009, p. 16).

Although I do not see this bias in my own organisation or personal work, it is naive to assume that the industry is beyond reproach. Whether the weight of criticism is an accurate reflection of the state of the damp proofing industry is another matter. Clearly, my involvement with this industry means that the criticisms levied apply to my business and to me personally. However, it is important to state that they extend well beyond my personal interest and have far wider implications.

For example, given the uncertainty regarding both the phenomenon of rising damp in houses, how can surveyors be confident in their diagnosis of rising damp as a cause of moisture affecting the base of ground floor walls? How may specifiers justify their recommendations for the use of damp proofing treatments if there is uncertainty with respect to their appropriateness and effectiveness? And how may damp proofing specialist contractors who issue long term guarantees be assured that the treatments they are using are proven to be effective?

In this modern era where access to opinion is instantly facilitated through internet searches, home owners are faced with the prospect of sifting through these conflicting claims. Does rising damp exist or does it not? Do damp proofing treatments work or do they not? Decisions taken to implement remedial works have financial implications. Indeed, should damp proofing treatments be unnecessary or ineffective then each year millions of pounds are wasted in remedial works that could be avoided. How are home

owners and other stakeholders to make informed choices in the light of such conflicting views?

These are the concerns that form the rationale for this research project. But, before elaborating that rationale, the following section identifies certain mitigating factors with respect to the diagnosis of dampness, the methods that can practically be used in this process, and for the justification in undertaking damp proofing works.

1.6. Mitigating factors

Precisely identifying the cause of dampness affecting the base of ground floor walls, and therefore, in diagnosing rising damp, is not straightforward (Burkinshaw & Parrett, 2003, p. 13). Yet, the critics argue that specialist surveyors are too quick to assume that any dampness affecting the base of a wall is a result of rising damp, maintaining that this inaccurate diagnostic conclusion is based on the flawed use of an electronic moisture meter.

Protimeters, which are described in detail in Chapter 4, are perhaps the most well-known of this type of meter. The criticisms stem from two issues: firstly, electronic moisture meters are calibrated for use on timber and, therefore, values obtained from masonry and plaster materials are not quantitative and can only be considered relatively (Burkinshaw, 2002, p. 165; Oliver, Douglas, & Stirling, 1997, p. 264); secondly, these meters measure electrical resistance and will respond to any form of moisture or any electrical conducting substance (Burkinshaw, 2002, p. 162; Oliver, Douglas, & Stirling, 1997, p. 264). It is a consequence of this latter issue that high values will be obtained from masonry or plasterwork contaminated with hygroscopic salts and on any materials that conduct electricity irrespective of how damp they may actually be (Burkinshaw, 2002, p. 171).

In my experience, a surveyor with experience of this instrument is likely to understand both its limitations and nuances and therefore be able to identify erroneous readings

that may be associated with, for example, the presence of silver foil beneath wall coverings. In practice, high readings returned from an electronic moisture meter when testing masonry materials typically indicates that dampness is present (Burkinshaw, 2002, p. 171). Nevertheless, Parrett (BBC, 1999a) argues that sample analysis is the only method that can be used to correctly determine the moisture content of masonry materials and thus to diagnose rising damp.[2] Given the nature of this method, which removes any doubt as to what is being measured, he is of course correct, but it is not practical to undertake sample analyses on every survey.

Many specialist surveys are carried out either free of charge or at relatively low cost, and I know from experience that it is difficult to persuade home owners that the costs of extensive investigation and sample analyses are justified. Furthermore, even in the mainstream area of building surveying clients may only be prepared to pay fees that in practice do not always cover the costs of the surveyors' time (Hollis & Gibson, 2005).

Another factor is the perceived correlation between remedial damp proofing works and long term guarantees (Mike Parrett, 2009, p. 16). Building surveyors, when undertaking surveys for home buyers, will typically recommend that such guarantees are obtained for any damp proofing works carried out, and this recommendation may ultimately become conditional to a mortgage offer, so the home owner has essentially no choice but to have remedial works carried out (BBC, 1999a). In effect, this demand has created a marketplace.

Thus from a practitioner's viewpoint, matters with respect to diagnosis of dampness, the practical methods that can be used in this process, and the undertaking of damp proofing works are complicated. In spite of this, I have investigated countless damp issues, diagnosed numerous cases of apparent rising damp (examples are illustrated in Figure 3 and Figure 4 below), and have used chemical injection damp proof course methods to treat rising damp many times with apparent success.

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[2] A discussion of methods of moisture analyses are provided in Chapter 4.

Figure 3: rising damp?

This photograph of damp staining affecting the base of a wall in an early nineteenth century, stone built house in Aberford, West Yorkshire aligns with the description of rising damp in BRE Digest 245, shown in Figure 4 below. I possess many similar photographs, some of which are provided in Chapter 2.

Figure 4: Staining to wall paper on a wall affected by rising damp (Adapted from Trotman, 2007, p. 1).

This photograph, Figure 1 from BRE Digest 245, shows a wall with staining that Trotman argues is rising damp (2007, p. 1) and which appears to be identical to that shown in Figure 3 above.

My experience is not isolated; surveyors and contractors involved in the specialist damp proofing industry recognise rising damp as a tangible source of moisture in buildings and make successful use of similar remedial damp proof course methods. And yet, is it rising damp that is being treated and, if so, what component of the two-part system provides the damp proofing effect?

In the real world, it has to be accepted that some businesses will place profit before client interest and therefore skew their advice; however, what if there is no malicious intent and, instead, that the industry has become habituated, spending so many years

repeating the same actions and using the same methods that it is no longer capable of objectivity (Jarvis, 1999, pp. 54-55)?

1.7. Research rationale

A number of criticisms have been highlighted and discussed in this chapter. These criticisms can essentially be split into two broad groups or domains: soft and hard. The soft-domain concerns the damp proofing specialist's knowledge, skill, and integrity with respect to their ability to correctly diagnose rising damp and their inclination to place their own interest before that of their clients. In contrast, the hard-domain concerns the actual phenomenon of rising damp, the instruments used to diagnose it, and the effectiveness of chemical injection damp proofing treatments; in other words, the hard-domain is to do with the mechanics of rising damp and its treatment.

As interesting as the issues in the soft-domain may seem, they are not to be the topic of this research project; instead, it is those in the hard-domain that are to be investigated; it is these matters that arguable should be of most concern to the industry and to building professionals, home owners, and other stakeholders that the industry serves. Is it conceivable that damp proofing specialists have been treating something that does not exist with something that does not work for tens of years? And, although damp proofing specialists would maintain that they understand the limitations of electronic moisture meters and consider them an indispensable tool, precisely how effective are these instruments as a mechanism to diagnose rising damp and to monitor the effect of damp proofing treatments?

In Chapter 2, a literature review concerning the history and science of rising damp, evaporation is identified as an important factor; in particular, because evaporation has a strong influence over the height to which damp may rise up a masonry wall (Massari & Massari, 1993, p. 75). Yet evaporation from damp masonry is said to be under-researched and there is disagreement among researchers with respect to its effect on environmental moisture (Hall & Hoff, 2007, p. 1875; I'Anson & Hoff, 1986, p. 195;

Trotman, Sanders, & Harrison, 2004, p. 68; Young, 1997, pp. 2-3; 2008, pp. 7-8). These matters are discussed in greater detail in Chapter 2. At this stage, it is sufficient to say that masonry has the potential to desorb and absorb moisture (Platten, 1989, p. 359). Because this is a property that impacts on rising damp, and by extension its treatment, the correlation of moisture in a wall affected by rising damp and moisture in the adjacent environment is significant to this study and is to be included in the hard-domain topics that provide the rationale for this project.

1.8. Research aims and objectives

This research project, which is to be undertaken to fulfil the requirements of a professional doctorate, has three connected aims:

> To establish whether contemporary remedial damp proof course treatments are (a) necessary (b) effective and (c) if evaporation from damp masonry affects moisture in the environment.

To inform the primary aim, the project has two operational objectives and four research objectives:

Operational objectives:

1. Develop a research methodology.

2. Evaluate the effectiveness of common and novel methods of moisture measurement.

Research objectives:

3. Examine the history and science of rising damp.

4. Determine the existence of rising damp.

5. Determine the effect that contemporary remedial damp proof course treatment has on the moisture in a wall affected by rising damp.

6. Determine if moisture in the environment and moisture in damp walls is correlated.

The project has been informed by issues perceived through practice. It will be undertaken by a practitioner-researcher and, as described in later chapters, will take a problem-solving approach consistent with this practical form of study.

1.9. Contents of thesis

Chapter 1 of this thesis is this introduction. It commences with a discussion of the types of moisture that typically affect domestic houses and makes explicit that rising damp is the primary topic of this practice-based research project. It describes the process of rising damp, the contemporary method of remedial treatment, and the industry that carries out this work before discussing the criticisms that all three of these matters attract. It concludes by presenting the research rationale, primary aim, underpinning objectives, and an outline for the remaining chapters.

Chapter 2 is a literature review, which describes in detail the historical perspective and science of rising damp, the Sharp Front model, evaporation and environmental moisture, perceived issues concerning laboratory-based research methods, and the implications of transitioning from the old fluid-based to contemporary cream-based damp proofing chemicals with respect to the appropriateness of BBA MOAT 39, the testing method intended for the former and not the latter.

Chapter 3 describes the research methodology: a quasi-experimental case study. These methods are discussed with respect to their role in theory testing, experimental designs,

the limitations of quasi-experiments, and of this combined methodology's suitability for this practice-based research project.

Chapter 4 is concerned with the research design. The first section describes the protocol employed in the selection of the case study house and how sources of moisture affecting its ground floor walls were identified, assessed, and systematically eliminated to arrive at the preliminary conclusion of rising damp. The second section outlines each of the moisture measuring and monitoring methods used in the project. The third and final section provides an outline programme and describes the types of data to be collected and methods chosen for data validation and presentation.

Chapter 5 first describes the two stage method employed to establish that rising damp did affect the base of the house's ground floor walls and then explains how these wall parts were allocated to the individual test panels used for the quasi-experimental work.

Chapter 6 is an account of the first part of the work involved in evaluating the damp proofing treatments. It describes the setting up of the test panels for the practical, quasi-experimental work: their design, the choice and application of specific treatments, the configuration of the apparatus used to monitor moisture change, and issues that were encountered during the data collection phase.

Chapter 7 is an account of the second part of the work involved in evaluating the damp proofing treatments. It describes the findings and, specifically, the effects of the applied treatments with respect to control of rising damp.

Chapter 8 presents the findings of the evaluation of each component of the moisture monitoring apparatus, explaining those factors that affected their operation and how effectively they tracked moisture change following damp proof course treatments. This chapter concludes with a discussion of the findings of data logging to determine if moisture in the environment is correlated with moisture in a wall affected by rising damp.

Chapter 9, the final chapter, provides conclusions drawn from the findings, sets out the unique claims to knowledge required of this doctoral level research project, and comments with respect to experience gained and future studies.

Chapter 2
History and Science of Rising Damp

2.1. Introduction

In Chapter 1, the criticisms of the damp proofing industry were identified. It was suggested that these criticisms could be separated into two distinct domains: soft and hard.

The soft-domain concerns the organisations and personnel directly involved in the industry: their alleged lack of knowledge and integrity, sole reliance on an electronic moisture meter for the diagnosis of rising damp, and bias for the use of chemical injection damp proof course methods for the treatment of dampness affecting the lower parts of ground floor walls.

In contrast, the hard-domain concerns the phenomenon of rising damp (i.e. its historical roots, its commonality in houses, the mechanics of capillary action, and evaporation), the method commonly used to diagnose rising damp (i.e. the operation and inherent limitations of an electronic moisture meter), and the effectiveness of chemical injection damp proof course methods.

This chapter, and indeed this research project, is interested in this second domain of criticism. Through a literature review, it will explore the historical perspective of rising damp and damp proof courses, reporting precisely what the Public Health Act 1875 has to say about these topics and when rising damp and the need for damp proof courses was first made explicit. It will consider the mechanics of rising damp, highlighting factors that may or may not have an influencing effect, including evaporation and gravity. Finally, it will assess prior research of both rising damp and of the chemical injection methods used for its treatment, identifying the perceived shortfalls of laboratory and

theoretical research methods. In essence, it will endeavour to answer five questions stemming from the criticisms:

1. Did the Public Health Act 1875 require the mandatory installation of damp proof courses?

2. When precisely were damp proof courses first installed in houses and, importantly, did this pre-date or post-date the Public Health Act 1875.

3. Does capillary action enable water to rise up masonry walls?

4. Does gravity counteract the effect of capillary action?

5. Do chemical injection treatment methods effectively control rising damp?

2.2. Rising damp: a historical perspective

2.2.1. The Public Health Act 1875

It is generally accepted that damp proof courses became mandatory following the introduction of the Public Health Act 1875. Statements to this effect appear in many reliable texts on dampness, in more general building surveying literature, and in articles on building conservation (Ashurst, 1990, p. 269; Douglas, 1998, p. 76; Mills, 1994, p. 219; Noy & Douglas, 2005, p. 24; Oliver, Douglas, & Stirling, 1997, p. 185; Trotman, Sanders, & Harrison, 2004, p. 151).

For example, Douglas (1998, p. 76) states that The Public Health Act 1846 [sic][3] introduced the concept of alleviating dampness in buildings, but that it was not until The Public Health Act of 1875 that the inclusion of damp proof courses in residential

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[3] The Public Health Act was introduced in 1848 not 1846 (UK Parliament, n.d.)

property became mandatory. Howell (2008, pp. 71-73) questions this assertion, suggesting, instead, that the 1875 Act is silent with respect to damp proof courses.

It has not been possible to gain access to the 1848 Act, but the 1875 Act is freely available on-line ("The Public Health Act, 1875 (38 & 39 Vict., ch. 55)," 1897). Surprisingly, the 1875 Act (1897) does not provide any direct references either to damp proof courses or to rising damp. This discrepancy was identified by Howell (2008, p. 72) who argues that the 1875 Act was passed to address unsanitary conditions rather than to serve as a mechanism for the introduction of measures to protect against rising damp and that damp proof courses were first mentioned in the Local Government Board Model By-laws of 1877.

The Public Health Act 1875, Part IV 'Regulation of Streets and Buildings', Section 157 'Powers to make byelaws respecting new buildings, & c' would seem to support Howell's claim as it states:

> "Every urban authority may make byelaws with respect to the following matters: ……
>
> (2)   With respect to the structure of walls foundations roofs and chimneys of new buildings for securing stability and the prevention of fires, and for purposes of health."
>
> ("The Public Health Act, 1875 (38 & 39 Vict., ch. 55)," 1897, p. 54)

This regulation clearly indicates that byelaws were to be the mechanism to deal with matters relating to the construction of buildings, including the walls. The comment 'for purposes of health' is, perhaps, open to interpretation. However, there is evidence that this would encompass measures to combat dampness, for, in 1842, Edwin Chadwick, who was secretary of the Poor Law Commission, prepared his 'report on the sanitary condition of the labouring population of Great Britain and on the means of

improvement' (Chadwick, 1842). Chadwick's aim was to improve the cleanliness of streets and homes, and in so doing to provide better drainage and water facilities to address the significantly shorter life expectancy of the poor in comparison to the wealthy (Golding, 2006, p. 475). This report ultimately became the basis of The Public Health Act 1848, which lead to the establishment of the General Board of Health, of which Chadwick was one of three commissioners, and subsequent improvements to public health (Golding, 2006, p. 475; Watkin, 1975, p. 35).

It seems, therefore, that the Public Health Act 1875, as its name suggests, was introduced primarily to address health concerns and, as Howell has recognised, it is indeed silent with respect to damp proof courses. Consequently, claims that the introduction of the 1875 Act resulted in the mandatory installation of damp proof courses in houses are incorrect.

2.2.2.   Rising damp and damp proof courses: historical references

In addition to identifying the discrepancy in the Public Health Act 1875, Howell also argues that the phrase 'rising damp' was not used until the 1950s and that damp proof courses were introduced through the Local Governments Model By-laws 1877, not as a means to prevent rising damp, but, along with sub floor ventilation, as a method of protecting ground floor timbers from contamination from street sewage (2008, pp. 50,71,73).

This section sets out to determine if these claims are accurate; namely, by endeavouring to establish the earliest dates when rising damp was used to describe the upward movement of moisture from the ground and when the need to install damp proof courses in houses to prevent rising damp was first identified.

Earlier, reference was made to the Chadwick report (1842). In his report, Chadwick (1842, p. 151) discusses contributory causes of damp in cottages in Lancashire and says "the stone…..sucks up the moisture of the ground"; he advises that a "foundation" must

be constructed of a material "calculated to resist moisture". He gives, as an example, "bricks be well laid with mortar comprising of sharp sand" and concludes by saying "the admission of damp will be entirely avoided." Chadwick then argues that materials such as stone, chalk, un-fired bricks, "impure" mortar, and wood allow moisture to "ascend" or "creep up", and "to avoid this "creeping up", builders are in the habit of placing a tire of slate in foundations above the surface mould." He criticizes this method as temporary on the basis that the damp causes the slate to fail, and he rejects the use of "Roman cement", which he infers is porous; instead, Chadwick recommends that "a course of well-burnt bricks set in asphalte [sic] would effectually prevent this absorption of surface water." (Chadwick, 1842, p. 151).

Chadwick's comments provide what is arguably an excellent description of both rising damp and methods of utilising impervious materials to create a damp proof course; specifically, to prevent the upward movement of moisture from the ground into the base of the walls above. His report was written in 1842 and six years later became the basis for The Public Health Act 1848, as described earlier.

Articles in The British Medical Journal in the period toward the end of the nineteenth century add further to the supposition that rising damp was a known phenomenon and that damp proof courses were a requirement to protect buildings from this form of dampness:

1. 25 May, 1872: "…the rising damp be arrested by what is technically called an impervious damp-proof course…. Attempts have been made to remedy the evil of porous bricks by the substitution of the hard blue bricks of Staffordshire; and then it may often be noticed that the wet has only struck, sailor-like, across the mortar-joints and chequered the inside walls like a tartan plaid." (British Medical Journal, 1872, p. 558).

2. 20 December, 1873: "If no damp course had been laid just above the ground-line, this wet would be continually striking up into the walls of the house above ground –

by capillary attraction [sic]……The cure would therefore consist in laying down 2,400 feet (superficial) of damp course on the top of the walls…… There are various kinds of suitable damp courses used by architects……double course of slates……Welsh slate bedded in cement……a layer of sheet-lead……asphalte [sic] or bitumen mixed with sand……asphalte [sic] damp-proof course sold in sheets ready for laying……a course or two of enamelled bricks, or ramped glazed bricks are also occasionally laid, in order to arrest the rising damp." (Eassie, 1873, p. 734).

3. 25 August, 1875: "The walls of a house should be built hollow, and protected from rising damp also by a proper damp-proof course." (British Medical Journal, 1875, p. 272).

4. 23 November, 1878: "Some very important by-laws have just been drawn up by the Metropolitan Board of Works, under the powers conferred upon them by the Building Act which was passed last session……A damp-proof course of asphalte [sic] or other impervious material is to be placed one foot above the base of the walls where there are basements, or one foot above the ground where there are no basements." (British Medical Journal, 1878, pp. 778-779).

5. 25 May, 1895: ""With respect to the prevention of dampness." This would cover the provision of subsoil drains, where necessary, of a damp-proof course, of a layer of asphalte [sic] or concrete under the house, and of rhones and rain-water conductors, as well as the construction of walls, in such a manner as to be impervious to moisture." (British Medical Journal, 1895, p. 1162).

The articles referred to in quotations 1 and 2 of the above list merit further comment:

In article 1, from the British Medical Journal, 25 May, 1872 (1872, p. 558), the author implies that Staffordshire Blue bricks were successful in controlling rising damp with respect to the brick units but that dampness continued to affect the, presumably, more porous mortar joints. Coleman (1990, p. 26) supports this notion, arguing that the damp

proof course should be incorporated in the mortar bed joint, thus preventing moisture migration up the joints or passing from one brick unit to the next. This is precisely the method outlined in the current British Standard for the installation of damp proof courses (British Standards Institution, 1991, p. 3).

In article 2, from the British Medical Journal, 20 December, 1873, Eassie (1873, p. 734) not only refers to damp proof courses and rising damp but identifies "capillary attraction" [sic] as the process through which rising damp is said to occur, and he states that "dampness from this source has several times been traced up thirty feet in height above ground". In addition, Eassie provides an extensive list of materials along with methods that can be used to create a damp proof course. He suggests that a damp proof course can be installed retrospectively, utilising what he considers to be the best method: "a vitrified stone-ware tile, made in thicknesses from one to one-and-a-half inches, and perforated in order to ventilate the space between the ground and the joists of floor, and also to prevent dry rot in the timbers." (Eassie, 1873, p. 734). He provides an illustration of his preferred method, shown in Figure 5 below, that would not appear out of place in modern text books.
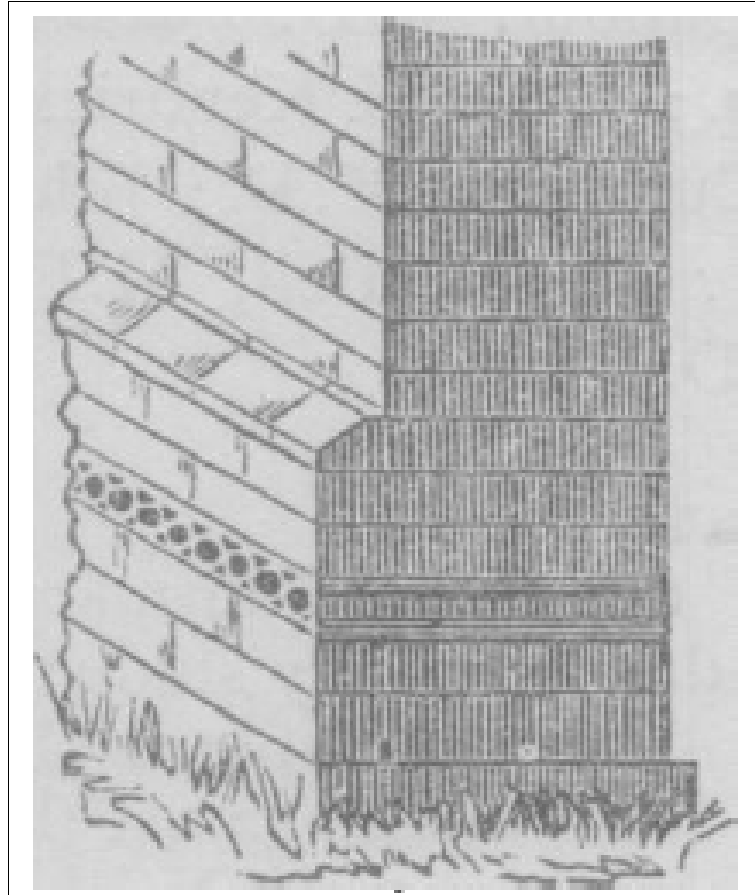
Figure 5: vitrified, stoneware, tile damp proof course (Adapted from Eassie, 1873, p. 734).

A similar detail to that of Eassie's, shown in Figure 5 above, appears in a paper written by John Taylor , published in The Transactions of the Royal Institute of British Architects 1862-63 (1863, p. 79) and reproduced in Figure 6 below. Taylor's solution is essentially identical to Eassie's but preceded it by ten years. What is particularly interesting about Taylor's damp proof course is that it was installed in Victoria Church, in the Isle of Dogs, specifically to prevent perceived unhealthy condition and damage to the walls. Taylor had this to say in his paper:

"I found the soil a deep bog, while the cottages of the poor in the neighbourhood showed fearfully the effect of damp rising up the walls to the height of six or seven feet. The wretched inhabitants, as is too frequently the case, excluded as much air as possible, and so kept up the temperature that the evaporation filled

the rooms with foul vapour…As for the building itself, the frost, acting upon the damp walls, had destroyed the mortar and injured the bricks, and the ruin of the building was evident. In this [Victoria] church my damp-proof course was introduced, and the damp so effectually cut off, that an observer looking through any part of the walls, at the height of a foot above the ground, could see the traffic on the other side." (Taylor, 1863)
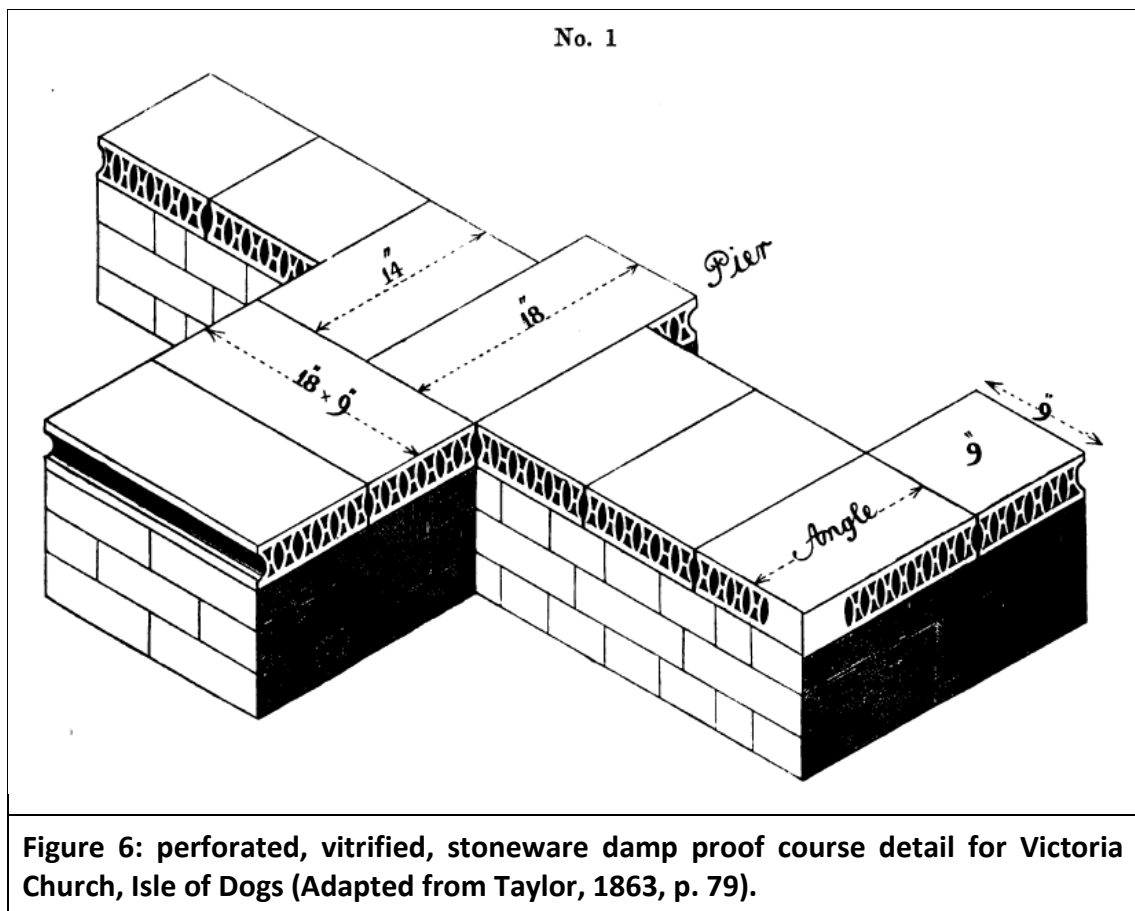
Figure 6: perforated, vitrified, stoneware damp proof course detail for Victoria Church, Isle of Dogs (Adapted from Taylor, 1863, p. 79).

The earliest reference to rising damp and damp proof courses found through this literature review, albeit neither being specifically named, appeared in The Lancaster Gazette and General Advertiser on Saturday, 22 September 1832:

"Damp houses are, to those who inhabit them, a certain source of numerous diseases…If, therefore, through unavoidable necessity, a dwelling-house must be built upon damp ground…To prevent the damp rising up the walls, a few courses

may be built with Roman Cement, and the last course thus built, which should be below the floor, ought to have a coat of about ¾ or 1 inch thick, all over it." (The Lancaster Gazette and General Advertiser, 1832).

Finally, if there is any remaining doubt with respect to its historical roots, William Charlton Forster filed a patent for a damp proof course on the 20 September, 1841 (Newton, 1846, p. 36). In the patent Forster states: "This material for preventing damp from rising in walls…This compound is to be formed into slabs, and placed at the foundation of walls and buildings, by which means the damp or moisture will be prevented from rising from the earth to the wall or building above." (Newton, 1846, p. 36).

Ashurst (1990, p. 269) maintains that the installation of damp proof courses was on the increase during the mid to late Victorian period, gaining momentum in response to The Public Health Act, 1875. Because their widespread use was subject to individual local government bye-laws and the building regulations were not applied nationally until the mid-1960s (Douglas, 1998, p. 76), it is unsurprising that buildings constructed in the late nineteenth or early twentieth centuries may not incorporate damp proof courses. Nevertheless, the findings of this literature review support Ashurst's assertion and confirm that rising damp was a mechanism known to cause dampness in buildings that could be alleviated through the installation of a damp proof course by the mid-nineteenth century. Therefore, claims that the term rising damp was not used until the 1950s or that damp proof courses were required exclusively to protect timbers from sewage rather than as a mechanism to alleviate rising damp are incorrect.

2.3. The mechanics of rising damp

In Chapter 1, the criticisms that rising damp is very rare or that it may not occur at all in masonry walls were presented (BBC, 1999a, 1999b; Fischer, 2009, n.d.; Heritage House Building and Restoration, n.d.; NBS, 2011; Quite Interesting Ltd., 2011; Waite, 2009). By extension, such criticism implies that capillary action as a mechanism to cause rising

damp must be flawed. In fact, Howell argues that capillary action and thus rising damp cannot be replicated in a laboratory without resorting to the use of very weak mortars and that bricks placed in trays of water are either unaffected by rising damp or only exhibit modest water uptake because the size and distribution of their pores does not facilitate this mechanism (BBC, 1999b; Howell, 2008, p. 21). Additionally, both he and Boniface (NBS, 2011) contend that gravity counteracts the effect of capillary action in masonry walls.

To establish if there is validity to these claims, the mechanism of capillary action in masonry will be examined; in particular, whether its pore structure can support rising damp, how this process is affected by evaporation and gravity, and how the theory underpinning rising damp compares to real world examples.

2.3.1. *Capillary action*

In specialist texts on dampness, general building surveying books, British Standards, and other similar sources, capillary action is described as the mechanism that enables moisture in the ground to rise up a wall and therefore to be the cause of rising damp (British Standards Institution, 1991, p. 1; Marshall, Worthing, & Heath, 2003, pp. 273-274; Trotman, Sanders, & Harrison, 2004, p. 150).

Capillary action is a natural phenomenon, allowing water to rise up a tube through the forces created by the surface tension of the liquid (Oliver, Douglas, & Stirling, 1997, p. 186). According to Jurin's Law, the maximum height that water can attain in a capillary is inversely proportional to the capillary's radius; in other words, the narrower the pores in a material, the higher the liquid will rise (Alfano, Chiancarella, Cirillo et al., 2006, p. 1060). This theoretical maximum capillary rise height can be calculated from Equation 1 (Oliver, Douglas, & Stirling, 1997, p. 187; Rirsch & Zhang, 2010, p. 1):

Equation 1

$$h = \frac{2y\cos\theta}{r\rho g}$$

Where:

h = capillary rise height.

y = surface tension.

θ = contact angle.

r = capillary radius.

ρ = liquid density.

g = gravity.

Oliver et al (1997, p. 188) suggest that the pore size of capillaries in bricks and mortar lie within the range of 0.001-0.01 mm and which, applying the above formula to pores with these radii[4], equates to a theoretical capillary rise height of between 1.5-15.0 m. In practice, the author's argue that the height attained by the water is influenced by flow resistance within the pores, evaporation, the position of the water table, and the moisture content of the soil, which is required to be in excess of 20.0% (Oliver, Douglas, & Stirling, 1997, p. 188).

Karoglou et al (2005, p. 261) use a simplified formula to calculate the equilibrium capillary moisture rise from the mean capillary pore radius, which when adjusted for radius in millimetres and height in metres is shown in Equation 2:

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[4] In their text, the author's use pore size, diameter, and radius interchangeably and appear to confuse these three properties; however, the calculations are correct for pore radius.

Equation 2

$$He = \frac{15 \times 10^{-3}}{r}$$

Where:

He = equilibrium height in metres.

r = capillary mean radius in millimetres.

(Adapted from Karoglou, Moropoulou, Giakoumaki, et al., 2005, p. 261).

Entering the typical pore size radii for brick and mortar proposed by Oliver et al (1997, p. 188) into Equation 2 provides a capillary rise height that concurs with the figures they suggest.

Mercury Intrusion Porosimetry is a technique employed by researchers to ascertain the pore sizes of masonry materials (Beck, Al-Mukhtar, Rozenbaum et al., 2003, p. 1161; Somsim, Zsembery, & Ferguson, 1985, p. 3; Vanhellemont, De Clercq, & Pien, 2006, p. 129). Using this method, Karoglou et al (2005, p. 262) determined the average pore size radii of samples of brick, plaster, and stone to be 0.45-2.01 μm, 0.51-2.42 μm, and 2.83-39.80 μm, respectively. They concluded that the brick pore sizes, which convert to the range of 0.00045-0.00201 mm would support an equilibrium capillary rise height of 6.7-33.3 m (Karoglou, Moropoulou, Giakoumaki, et al., 2005, p. 262).

Alfano et al (2006, p. 1060) suggest that a capillary pore size radius of 1.00 μm (0.001 mm) "is typical for many construction materials"; Trotman (2007, p. 2) agrees but claims that the capillary pore radii may be as small as 0.50 μm (0.0005 mm) in older buildings; and Mason (1974, p. 227) argues that the pore size diameter of brick walls is in the range of 5.0-0.1 μm (0.005-0.0001 mm) and 10.0-1.0 μm (0.01-0.001 mm) for the cement mortar and brick units, respectively.

Thus, capillary pore sizes can be sufficiently narrow to support a significant head of water. However, although factoring a pore size radius of 0.001 mm into Equation 2 provides a capillary rise height of 15.0 m, in reality, evaporation limits the maximum height to 4.0-5.0 m (Alfano, Chiancarella, Cirillo, et al., 2006, p. 1060). Nevertheless, this is still significant moisture rise.

As highlighted earlier, not everyone agrees with this theory: Howell (2008, p. 20) while maintaining that a pore size diameter of 0.025 mm is required to achieve a capillary rise height of 0.6 m, argues that capillaries are unconnected, do not necessarily enable water to move upwards, and that the explanations for this mechanism to enable rising damp to occur in a wall are unsatisfactory.

Pores and hence the porosity of any inorganic material are essentially the empty spaces that are created by the particles from which it is comprised. In this sense, the porosity governs the total quantity of water that any inorganic material may contain. Using the same Mercury Intrusion Porosimetry technique, Karoglou et al (2005, p. 262) found the porosity of brick, plaster, and stone samples to be 32.6%-49.2%, 32.4%-42.1%, and 22.0%-35.2%, respectively; in practice, it is rare for the total porosity of any inorganic material to be greater than 35.0% (Hall & Hoff, 2012, p. 2).

Nevertheless, as Howell (2008, p. 20) suggests, these pores are not a discrete system that extend through masonry materials from one side another; instead, the pore structure may be discontinuous. Hall and Hoff (2012, pp. 6, 7) describe this arrangement of 'connected' and 'unconnected' pores by comparing the differing compositions of a mass of sand to that of a solid material such as mortar of brick.

Sand particles do not fit perfectly together but, instead, abutting grains create the three dimensional space or void that is its porosity; importantly, this porosity is connected and, therefore, each part of the void space links to another (Rose, 1963, p. 256). In contrast, the cementation and firing processes associated with the production of mortar

and bricks, for example, inevitably closes off some of the pores, isolating them from others (Hall & Hoff, 2012, p. 7).

Thus, the passage of moisture through construction materials is determined by their porosity and the capillarity of individual pores (Hall & Hoff, 2012, p. 1). Movement of moisture by capillary action in masonry materials is therefore more complex than the theory suggests, and this is the reason why sorptivity is the property increasingly used to quantify the capillary uptake of porous materials (Culligan, Ivanov, & Germaine, 2005, p. 1010; Lockington & Parlange, 2003, p. 760).

2.3.2. Sorptivity

Sorptivity is essentially the property of a material to absorb and desorb water (Philip, 1957, p. 257). It is said to be of particular value where complete information of the subject material is unknown (Hall & Hoff, 2012, p. 102). This is clearly useful with respect to the ground floor walls of an older building that comprise a composite of masonry units and mortar; indeed, the sorptivity of many brick, stone, mortars, and plaster type building materials has been measured and values for composite materials such as plastered brickwork evaluated (Hall & Hoff, 2007, pp. 1879-1880; Wilson, Hoff, & Hall, 1995).

A wall is typically constructed of masonry units, for example bricks, bonded with mortar joints. Rirsch and Zhang (2010, p. 4) found that in walls of such construction the more sorptive of the two materials will, rather logically, contain the most moisture. Furthermore, Wilson et al (1995, p. 217) determined that the absorption rate of a two-layer composite is governed by the less sorptive of the two materials. This suggests that the mortar and masonry unit combination used to construct a masonry wall will have a significant influence on rising damp.

Research undertaken by Rirsch et al (2011) on samples of mortar taken from a variety of houses across the UK that had been treated for rising damp determined that the

sorptivity of the mortars varied significantly: ranging from 0.2 to 14.0 mm min$^{-1/2}$; the houses varied with respect to the age and construction, and mortars from the older houses tended to have higher sorptivity (Rirsch, MacMullen, & Zhang, 2011, p. 2849).

Variations in sorptivity provides one potential reason why walls that do not incorporate a damp proof course, even in close proximity to liquid water, do not exhibit rising damp (Massari & Massari, 1993, p. 25). In addition, because of the tendency for the lower sorptive material to govern the moisture uptake of composites, highly sorptive materials close to but above the base of a wall may remain unaffected by rising damp if low sorptivity materials were incorporated in the construction beneath. This arrangement essentially describes a damp proof course, but such low sorptivity may well be a property of wall materials that are not explicitly identifiable as a damp proof course, yet do not support rising damp.

Despite the criticisms, the theory underpinning capillary action as a mechanism that enables rising damp to occur in masonry walls is compelling. The size of individual pores in brick, stone, and mortar materials has been determined to be sufficiently narrow to support significant capillary rise height and despite suggestions that the discontinuity of the pore structure of inorganic building materials may hamper this process, their sorptivity does enable these materials to absorb water. There are, however, other factors that influence how rising damp may affect a masonry wall such as the rate of evaporation from the wall surface, its thickness, and the quantity of water present in the ground (Rirsch & Zhang, 2010, p. 2).

2.3.3. Evaporation from damp masonry

Evaporation is essentially a drying process. Drying can be defined as the transfer of liquid water from the pores in a material to the surrounding air and is generally considered to have two distinct phases: stage 1 and stage 2 (Hall & Hoff, 2012, p. 203). However, as will be shown below, the Building Research Establishment (1974, p. 1) argues that there is an additional third stage of drying.

A saturated material initially undergoes stage 1 drying. During this phase, moisture at the outermost layers of a porous material changes from liquid to vapour and transfers to the surrounding air (Hall, Hoff, & Nixon, 1984, p. 13). The rate of transfer is equivalent to evaporation from the surface of open water, provided that the specific environmental conditions are the same (Hall, Hoff, & Nixon, 1984, p. 14; Rose, 1968, p. 1780).

Importantly, stage 1 drying is not dependent on the inherent characteristics of the porous material but, instead, is governed solely by its surface area, the properties of the evaporative substance–in this case water–and environmental conditions (Hall, Hoff, & Nixon, 1984, p. 14; Phillipson, 1996, p. 8). Stage 1 drying occurs relatively rapidly and at a uniform, linear rate: it is a period when the rate of evaporation is constant (Building Research Establishment, 1974, p. 1; Hall, Hoff, & Nixon, 1984, p. 14).

As stage 1 drying completes, all moisture on the surface of the material has evaporated; that is, it has transferred to the surrounding air. For stage 2 drying to occur, the moisture present within the material must first transport to the surface; only then can further evaporation take place (Phillipson, 1996, p. 8). This moisture transport process is a result of 'unsaturated flow' and 'vapour flow' within the porous material, and movement of water within the capillaries resulting from the suctional differential of hydraulic tension, a process that causes the water to migrate from the wetter to the drier parts of the material (Hall, Hoff, & Nixon, 1984, p. 13; Platten, 1989, p. 360). Because moisture dissipates during stage 1 drying, construction materials are not permanently saturated and neither is the moisture distributed uniformly (Hall, 1977, p. 117; Hall & Hoff, 2012, p. 64). Thus, in contrast to stage 1, stage 2 drying is the period when the rate of evaporation falls (Rose, 1968, p. 1780), and this is why stage 1 is referred to as the constant drying rate period and stage 2 as the falling drying rate period (Hall & Hoff, 2012, p. 203).

The Building Research Establishment (1974, p. 1) argues that the second stage of drying can itself be divided into two parts: stage 2 drying involving the transport of moisture from the larger capillaries of the material, which, by definition, facilitates a larger

quantity of water than the fine capillaries, and stage 3 drying the transport of water from very fine capillaries, a process that is extremely slow and takes many years to complete.

In practice, some moisture is always present in construction materials. Figures suggested by the BRE (1974, p. 1) are 1% and 3% respectively for brickwork and concrete protected from moisture, but rising to 5% if the material is subject to rain. Given that houses typically affected by rising damp are constructed with solid walls, there is clearly a potential for rainwater to contribute to dampness present in external walls.

Importantly, evaporation is argued to have a profound effect with respect to the height attained by rising damp. Massari and Massari (1993, p. 75) found rising damp affecting the walls of the Farseni in Rome to have risen to 3.1 m on its north side but only to 1.5 m on the south side, an affect that they attributed to enhanced evaporation caused by solar gain.

In addition, because thicker walls require a larger surface area to attain a rate of evaporation equivalent to that of thinner walls, damp will rise higher in the former than it will in the latter (Rirsch & Zhang, 2010, p. 1816). This phenomenon is demonstrated by Massari and Massari with respect to the church of San Bernardo in Rome (1993, p. 77), shown in Figure 7 below, its 4.0 m thick walls enabling moisture to rise to the considerably height of 5.3 m (Massari & Massari, 1993, p. 77).

Figure 7: Church of San Bernardo (Français Wikipedia, 2010).

The church walls are 4.0 m thick. Rising damp is reported to have reached a height 5.3 m (Massari & Massari, 1993, p. 77).

To explain the relationship between wall thickness and the height attainable by rising damp, Massari and Massari developed a 'climb index' (1993, pp. 78-79). This index is essentially a ratio that enables a prediction of the probable height of rising damp relative to the thickness of a wall for three different types of evaporative conditions: freestanding walls allowing for evaporating on all sides (height to thickness ratio of 1:1); walls with one external face (height to thickness ratio of 1.5-4:1); and internal walls (height to thickness ratio of 2-5:1) (Massari & Massari, 1993, p. 79).

Thus both evaporation and wall thickness are significant. With respect to this latter variable, the Sharp Front model, described in the next section, suggests that the theoretical rise height is equivalent to the square of the wall's thickness (Hall & Hoff, 2007, p. 1876; Rirsch & Zhang, 2010, p. 1816).

2.3.4.   The Sharp Front model

Hall and Hoff argue that rising damp is a complex process that cannot be precisely represented by mathematical formula; however, they have endeavoured to produce a simple model to represent rising damp in real walls (Hall & Hoff, 2007, p. 1871). This Sharp Front model is represented by Equation 3 below.

Equation 3

$$h_{ss} = S(\frac{b}{2e\theta_w})^{1/2}$$

Where:

h_{ss} = rising damp 'steady state'.

S = sorptivity of the wall material.

b = wall thickness.

e = evaporation rate.

θ_w = the moisture content of the wet region of the wall.

(Hall & Hoff, 2007, p. 1875)

Significantly, the Sharp Front model aligns with the heights of rising damp found in houses investigated by the BRE and with Massari and Massari's climb index and 'field observations' (Hall & Hoff, 2007, pp. 1876,1878). Furthermore, in a laboratory-based research project undertaken by Rirsch and Zhang (2010, pp. 1819-1820), the results predicted by the Sharp Front model were broadly similar to the height that water actually rose up brick test pillars.

I have seen many instances of dampness affecting the bases of the ground floor walls of houses that align with the characteristics claimed to be representative of rising damp (BRE, 1997, p. 2; Trotman, 2007, p. 1; Trotman, Sanders, & Harrison, 2004, p. 149). Clearly, in the absence of important factors such as the wall component's sorptivity, porosity, and the quantity of moisture that the porosity contains, it is not possible to say categorically that such examples align with the theoretical Sharp Front model. However, Rirsch et al (2011) determined the sorptivity of mortars removed from actual houses. A sample taken from a 110 year old brick walled terraced house was found to have a sorptivity of 1.3 mm min$^{-1/2}$ (Rirsch, MacMullen, & Zhang, 2011, p. 2849).

If it were assumed that this value represented the typical mortar sorptivity of a Victorian terraced house with 225 mm, one-brick thick walls, then entering these data into the Sharp Front model to represent the variables S and b and using the figures recommended by Hall and Hoff (2007, pp. 1874,1876) for the annual UK evaporation potential (e) of 0.001 mm min^{-1} and moisture content of the wet part of the wall (θ_w) of 0.85, respectively, equates to a rise height (h_{ss}) of 860 mm.

Admittedly, this result is underpinned by a number of assumptions; yet, if the product of the calculation is representative of the height that rising damp may attain in the walls of Victorian terraced houses, then the Sharp Front model aligns with rising damp that I have seen many times in houses of this era, as illustrated in the examples shown in Figure 3, Figure 9, and Figure 10 below.

Figure 8: Wall base dampness aligning with the Sharp Front model (example 1).

Damp staining affecting the base of this wall of an early twentieth century, brick built house in York, North Yorkshire aligns with the characteristics describing rising damp and the Sharp Front model.

Figure 9: Wall base dampness aligning with the Sharp Front model (example 2).

Damp staining affecting the base of this late nineteenth century, brick built house in Howden, East Yorkshire aligns with the characteristics describing rising damp and the Sharp Front model.

Figure 10: Wall base dampness aligning with the Sharp Front model (example 3).

Damp staining affecting the base of this early twentieth century, brick built house in Selby, North Yorkshire aligns with the characteristics describing rising damp and the Sharp Front model.

Clearly, there is some speculation that these three real world examples, and many comparable cases that I have witnessed, are categorically rising damp; nevertheless, given their seeming correlation with the Sharp Front model and similarity with the characteristics describing rising damp, that it may be the cause of this dampness cannot be ignored.

Before moving on to discuss the effect that gravity has on rising damp—another reason postulated by the critics for its non-existence—an additional matter relating to evaporation requires further comment. This issue, which is concerned with the potential effect that evaporation of water from a damp wall may have on moisture in the environment, has been identified through this literature review.

2.3.5. *The environmental effect of evaporation*

Hall and Hoff (2007, p. 1875) maintain that incorporating the evaporation component in mathematical models is very difficult because it is affected by variables that are site specific and subject to change. The Sharp Front model therefore uses a value approximated from the UK average over a year. Factoring this value into the calculation indicates that the total quantity of water rising up and evaporating from a limestone wall with a thickness of 150 mm is 0.88 litres per day, per metre length (Hall & Hoff, 2007, p. 1876). Similar rates of evaporation were claimed by Rirsch and Zhang (2010, p. 1820): 0.69 litres per day, per metre length from a 110 mm, half-brick thick wall constructed with high permeability mortar.

Assuming an arbitrary length of 4.0 m, the typical width of a Victorian terrace house (i.e. a house of an age and type susceptible to rising damp), these figures suggest that the total quantity of water passing into the environment from that wall is in the range of 2.76-3.52 litres per day. Households produce around ten litres of moisture through normal living activities each day (Trotman, Sanders, & Harrison, 2004, p. 68), so evaporation of this order occurring inside a dwelling is adding approximately one third more moisture vapour to the internal air. Furthermore, because evaporation is proportional to the surface area of the damp affected region, for a house with extensive dampness, these figures could potentially be far higher. Evaporation from a damp wall appears to be a significant source of moisture vapour.

The moisture content of air is expressed as the relative humidity, which is the ratio of the vapour pressure of air at a given temperature relative to the amount of vapour it would contain when saturated at the same temperature (Oliver, Douglas, & Stirling, 1997, p. 148). Because relative humidity is a function of temperature, it is a value that increases as its temperature falls and vice versa. When the relative humidity reaches 100% (i.e. saturation), a temperature referred to as the dew point, the moisture vapour it contains is released as liquid water in the form of condensate (Garratt & Nowak, 1991, pp. 5-6). Thus moisture vapour evaporating from a damp affected wall has the potential

to increase the vapour pressure of the air and therefore to cause or aggravate condensation in a dwelling.

This notion is supported by I'Anson and Hoff (1986, p. 195) who cite rising damp as a "significant source of water vapour". Other authors make similar comments with respect to evaporation of moisture. Young (1997, pp. 2-3; 2008, pp. 7-8) suggests that "musty smells are common in poorly vented rooms" as a consequence of the evaporation of moisture from walls affected by rising damp. He goes on to suggest that as a consequence of high humidity, mould growth is encouraged (Young, 2008, p. 8).

Simpson (2005, p. 1) provides a comparable opinion, suggesting that, in some cases, evaporation of moisture from a concrete floor can increase relative humidity and the risk of condensation. Simpson's comments are contained in guidance notes relating to the design and specification of concrete floors, and it is not clear if he is considering construction moisture because, as described in section 2.3.3 above, construction moisture evaporates during stage 1 drying and, therefore, is quite different to the subsequent stage 2 drying of residual moisture. However, Simpson outlines various mechanisms, including rising damp, through which moisture can penetrate into concrete and there are clear implications that such moisture sources are considered problematic (Simpson, 2005, p. 2).

Guimarães and de Freitas (2009, p. 191) show that their 'wall base ventilation' system, to control rising damp in ancient buildings, produced a measured evaporation rate of 80 litres (80 kg) during the five month test period between February and March 2006. By extrapolation, this equates to 192 litres per year. Their method utilises a fan operated ventilation system installed at the base of a damp wall; although, the authors conclude that the rate of evaporation is determined by the external weather conditions and not by the air speed (Guimaraes & de Freitas, 2009, p. 191).

In contrast, research undertaken by the BRE determined that the rate of evaporation from a saturated concrete floor was insufficient to contribute to condensation in a

dwelling (Trotman, Sanders, & Harrison, 2004, p. 68). The BRE's study was carried out using the MATCH software model to establish the amount of moisture evaporating from the surface of a 100 mm thick concrete floor in an area of 8.0 m² under differing environmental conditions (i.e. at varying relative humidities and temperatures). The worst case scenario was concluded to allow just 35 ml (0.035 litres) of water to evaporate from the concrete per day. This quantity of moisture was considered to be insignificant when compared to the ten litres per day typically produced through living activities (Trotman, Sanders, & Harrison, 2004, p. 68).

It would seem reasonable to assume that moisture affecting a wall or floor must ultimately evaporate from the surface and therefore contribute to moisture within a dwelling. Hall and Hoff (2007, p. 1875) make clear that the evaporation rate is subject to environmental conditions and can therefore vary considerably. Furthermore, evaporation from masonry has an important influence on the height to which moisture will rise up a wall and it is therefore a factor that is influenced by surface coatings, temperature, and humidity (Hall & Hoff, 2007, pp. 1875, 1877, 1878, 1881). Paradoxically, decreasing surface evaporation causes water to rise higher up the wall which, conversely, provides a larger surface area from which evaporation can take place (Hall & Hoff, 2007, p. 1876).

From the foregoing, it can be construed that for evaporation to occur at a sufficiently fast enough rate for moisture to influence environmental conditions within a dwelling, a masonry wall is required to be in a state of saturation. In other words, in a condition for stage 1 drying to take place. Saturation is defined as the condition when the pores in a porous material are completely filled with water (Sereda & Feldman, 1970, p. 4). Indeed, Hall et al (1984, p. 13) claim that prolonged periods of water absorption through capillary action can result in total saturation of the masonry at the base of a wall and a consequence of such saturation is the evaporation of significant quantities of water.

So, on the one hand is the argument that damp walls have the potential to release large quantities of moisture into the environment within a dwelling, potentially giving rise to condensation, but on the other hand is the argument that evaporation, even from masonry that is saturated, is so small to be insignificant. Which of these opposing arguments is correct?

There is, in addition, a further concern. Platten (1989, p. 359) argues that excess moisture will evaporate from saturated walls into the environment but that dry walls will absorb moisture from the air as a result of suctional forces. Thus the moisture content of the walls in a building may be prone to change as they endeavour to reach a state of equilibrium with their environment. In practice, this means that through absorption, moisture vapour in the air has the potential to affect the moisture content of a wall. So, do houses with higher internal vapour pressures have walls containing a greater quantity of moisture?

Nearly thirty years ago, Platten (1989, p. 359) stated that there was much work to do with respect to the relationship between moisture in the environment and moisture in the fabric of a building. More recently, Hall and Hoff suggested that research to more accurately determine the evaporation rate from damp masonry was "a high technical priority" (Hall & Hoff, 2007, p. 1875).

This issue is to be explored in research objective 6, which is to determine if moisture in the environment and moisture in damp walls is correlated. It has two goals: firstly, it will endeavour to measure the evaporation from a masonry wall known to be affected by rising damp to determine if this is significant (i.e. if such evaporation increases the vapour pressure of the surrounding air); and, secondly, to determine if the moisture content of masonry walls changes in response to changes in the moisture content of the surrounding air.

2.3.6.   The effect of gravity

This final sub-section returns to the question of how gravity affects capillary action and therefore if it may supress rising damp.

It seems logical to assume that as water moves in an upward direction through the capillaries of a masonry material that gravity would exert a downward pull and therefore depress rising damp. This is the reason argued by some critics as to why capillary action cannot occur in masonry walls and therefore why rising damp is not an actual phenomenon (NBS, 2011).

Technically, capillary action is very strong when compared to the effect of gravity (Lockington & Parlange, 2004, p. 406). This is why moisture can move upwards in a wall against the forces of gravity, a phenomenon that has been known for over three hundred years (Coussy, 2010, p. 107); however, there is a caveat: it depends on the size of the pores (Zhang, 2010, p. 1).

In large diameter pores, suction is the primary mechanism that enables water movement to take place and gravity has an effect; in contrast, for fine pores, 0.01-0.00001 mm in diameter, capillary forces dominate (Hanzic, Kosec, & Anzel, 2010, p. 84; Phillipson, 1996, p. 5). In section 2.3.1 above, it was found that the typical pore size radii of construction materials is 0.001 mm (i.e. 0.002 mm diameter), which falls within this dominant capillary force range. Indeed, common masonry building materials typically support capillary action (Hall, Hamilton, Hoff et al., 2010, p. 2)

As an example of this phenomenon, research carried out at the Foscari University in Venice found damp to have risen to eaves height of the building. This happened because in applying an impermeable coating to the external face of the wall, not only was evaporation inhibited, but the capillary pore size sufficiently reduced to facilitate capillary action against the forces of gravity (isurv, 2017).

Another important factor that plays a part in the gravity effect is the degree of saturation of the masonry. Rising damp does not result in capillaries full of water, but, instead, they are incompletely wetted; it is this unsaturated flow that allows capillary forces to prevail (Hall & Hoff, 2007, p. 1872; Unesco, 1969, pp. 172-174).

Hall & Hoff demonstrate the weak effect of gravity in the Sharp Front model by considering conditions that enable capillary rise heights of 500 mm and 1000 mm when gravitational forces are ignored. Factoring in the effects of gravity reduces these rise heights by just 12 mm and 49 mm, respectively (Hall & Hoff, 2007, p. 1878).

Many other researchers concur that gravity has a modest effect and can be excluded from calculations of capillary rise height; for example, (D'Agostino, 2013, p. 125; De Freitas, Abrantes, & Crausse, 1996, p. 107; Kropp & Hilsdorf, 1995, p. 142). And Vos (1971, pp. 129,140), while arguing that it is relative humidity and its effect on evaporation that is most significant with respect to the heights attained by rising damp, agrees the gravity is unimportant.

As concluded at the end of section 2.3.2, there is overwhelming evidence to support the argument that the pore size of common building materials is sufficiently narrow to support capillary action. This section has presented additional information to support the premise that gravity does not play a significant role in depressing rising damp in masonry materials. In 'Diagnosing Damp', Burkinshaw and Parrett (2003, p. 217) provide this definition for rising damp: "where moisture travels upwards through the pore structure, or via small fissures or cracks, or as water vapour, against the forces of gravity, typically up a wall or through a floor from a source below the ground". In the light of the foregoing, it would seem a fair description.

2.4. Research methods

Although this literature review was undertaken primarily to inform the criticisms identified in Chapter 1, it has highlighted other issues concerning laboratory research

techniques. This final part of Chapter 2 considers the methods used in these studies to evaluate rising damp and the effectiveness of chemical injection damp proof courses; in particular, the applicability of these protocols with respect to real house walls and of contemporary damp proof course systems.

2.4.1. Laboratory test pillars

Despite Howell's claim (2008, p. 22) that moisture does not rise upwards by capillary action in bricks placed into trays of water, a more general consensus among researchers is that it is difficult to create rising damp in a laboratory (Hall & Hoff, 2007, p. 1877; Rirsch & Zhang, 2010, p. 2). This difficulty stems from the effect of aging on mortars (Mason, 1974, pp. 229,230).

Newer mortars, and especially those that are cement based, have an inherent resistance to rising damp (Hall & Hoff, 2007, p. 1877). However, water moving through the mortar gradually increases its sorptivity, an effect enhanced through the removal of lime by acids present in the water (Hall & Hoff, 2007, p. 1877; Mason, 1974, pp. 229,230; Rirsch & Zhang, 2010, p. 1816). But it is not just acidic water that has an effect; water originating from the ground is contaminated with various minerals including soluble salts of nitrates and chlorides (Oxley & Gobert, 1983, p. 33).

These ground salts are carried up into the masonry in solution and become concentrated over time; water diffusing from areas of low salinity to high increases capillary moisture rise (Feilden, 2003, p. 101). To compound this effect, the salts obstruct capillaries, which not only inhibits evaporation, but enables those of a hygroscopic nature to absorb moisture directly from the air (Rirsch & Zhang, 2010, p. 2).

The mortar aging effect is significant. Over a one-hundred-year period, the height of damp rise in a wall can increase by seven-fold (Mason, 1974, p. 229). The church of San Bernardo, discussed earlier in this chapter and illustrated in Figure 7 above, is an example of rising damp reaching heights of 5.3 m (Massari & Massari, 1993, p. 77). The

Massari's claimed this extraordinary height to be a result of the considerable wall thickness of 4.5 m, but the church was constructed in 1598 and changes to the sorptivity of its walls over the intervening 400 years are arguably a factor (Ferluq, 2010; Panoramic Earth, 2010).

In 1974, Mason (1974) maintained that it was simply not possible to construct test apparatus that matched the properties of an older masonry wall. Yet, the problem of how to replicate older masonry walls in the laboratory, and thus to undertake research into the phenomenon and treatment of rising damp, ultimately led to the practice of constructing test pillars from specially prepared, low-strength mortars (Sharpe, 1978, p. 261). These low-strength mortars are described in detail in 'MOAT No. 39', the British Board of Agrément method for the assessment of damp-proof course systems in existing buildings (BBA, 1988, p. 5).

MOAT 39 requires the test pillars to be constructed with mortar comprising 40-parts washed sand, 3-parts Snocal 6 ML (Whiting), 3-parts slaked lime, 10-parts Fossasil No 6 (diatomaceous brick dust), and 17-parts water (BBA, 1988, p. 5). This is an extremely weak mix that would not be suitable for general construction purposes (Chudley & Greeno, 2006, p. 330). In essence, artificially created, porous masonry used in the construction of laboratory test pillars do not replicate the conditions of a real building (Burkinshaw, 2009, p. 85).

2.4.2. Laboratory research protocol: an example

A great deal of research has been undertaken on the movement of moisture in porous materials. Some of which have already been discussed in this chapter. These and other studies demonstrate that water rises up masonry walls and that chemical injection damp proof courses are an effective method of controlling this form of moisture.

Take as an example the work of Alfano et al (Alfano, Chiancarella, Cirillo, et al., 2006). Their project, 'Long-term performance of chemical damp-proof courses: twelve years of

laboratory testing' made use of robust methods and provided useful results with respect to the performance of the damp proof course chemicals under test (Alfano, Chiancarella, Cirillo, et al., 2006, p. 1069); yet, under scrutiny, there are concerns with respect to how applicable this and other similar studies may be with respect to UK houses and of the remedial treatment methods currently used.

Alfano et al's study made use of test walls constructed of locally sourced stone and clay brick; the stone, Tufa, being a building material commonly used in southern Italy (Alfano, Chiancarella, Cirillo, et al., 2006, p. 1062). As discussed earlier, the composition of masonry materials has an important influence over their sorptivity and, notwithstanding the concerns raised in 2.4.1 above regarding the use of high sorptivity mortars, did these test pillars truly represent building materials typically used for the construction of UK houses?

The climatic conditions are also problematic. The twelve-year project was based in Bari, Italy and, significantly, undertaken in a shed that was not air conditioned (Alfano, Chiancarella, Cirillo, et al., 2006, p. 1062). Bari is in southern Italy's Puglia region and, as illustrated in Figure 11 below, it has far higher external temperatures and vapour pressures than those found in, for example, York[5] in the UK.

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[5] York has been used as an example because it is the city closest to the location of this research project.

Figure 11: Average monthly outside temperatures and vapour pressures for Bari, Italy and York UK.

The two charts illustrate the difference in climatic conditions between Bari in southern Italy and York in the UK; the average monthly outside temperatures and vapour pressures being far higher in Bari (Adapted from World Weather Online, 2017a, 2017b).
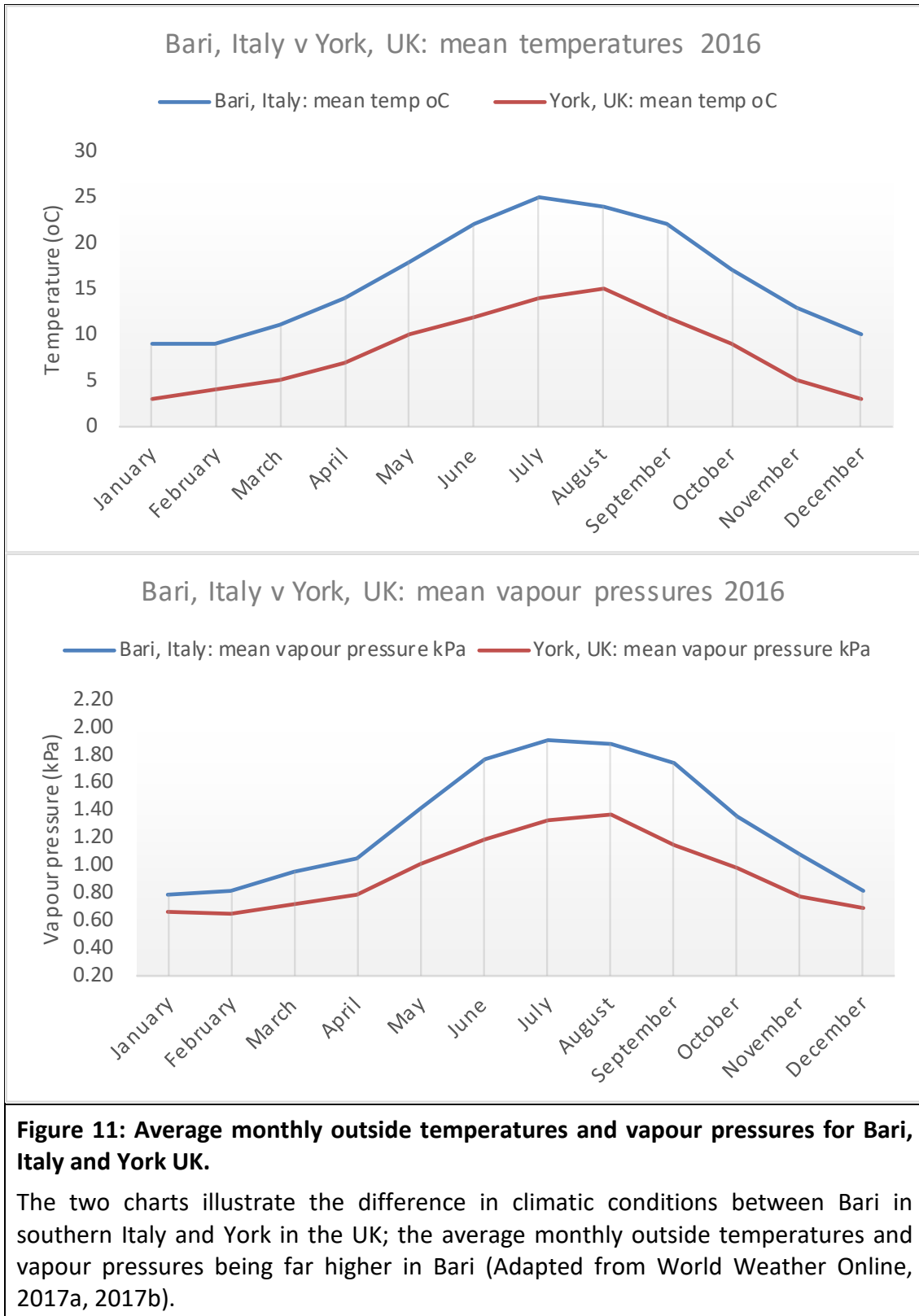
Temperatures and vapour pressures influence evaporation, and evaporation is one of the most important factors with respect to the height to which damp may rise up a wall

(Hall & Hoff, 2007, p. 1881; Rirsch & Zhang, 2010, p. 1). Comparing meteorological data from London and Athens in the Sharp Front model, and a more comprehensive 'Unsaturated-flow' model, Hall et al showed that for the Athens' conditions, changes in the rate of evaporation caused a three-fold increase in the total quantity of water passing through the wall and a reduction in the height attained by rising damp (Hall, Hamilton, Hoff, et al., 2010, pp. 14,15). How representative of the UK, therefore, is research undertaken in climates that are significantly different?

Finally, it is common practice for test pillars to be placed in trays of liquid water to produce rising damp. Alfano at al used this method, wetting their test walls by immersing the bases in tanks of 'brackish' water that contained high concentrations of sodium chloride and controlling the rate of evaporation by enclosing the test walls and the tanks in polythene (Alfano, Chiancarella, Cirillo, et al., 2006, p. 1063). This method of wetting is quite different to the walls of actual buildings, which are built into the ground and subject to variable soil and water conditions (Mason, 1974, p. 229).

From the foregoing, is clear that there are differences in the conditions applied in laboratory research in comparison to those that may be found in actual houses in the UK. Not only through the practice and indeed the necessity of constructing test pillars using high sorptivity mortars to recreate rising damp in the laboratory, but also by way of variable climatic and test conditions. But, there is arguably a more significant issue and that concerns the type of chemical injection systems used in the studies.

2.4.3. Chemical injection systems

Alfano et al's project investigated fluid methods of chemical injection; specifically pressure injected silanes, siloxanes, and silicates, and gravity fed siliconate-silicates, silanes, and siloxanes (Alfano, Chiancarella, Cirillo, et al., 2006, p. 1063). These fluid-based chemical injection damp proof course methods have largely been replaced by damp proofing creams, which were first introduced in the UK in 2000 (Safeguard Europe Ltd., n.d.). Essentially, all research undertaken prior to this date has become outdated.

In recent years, research has been undertaken in the UK on the effectiveness of damp proofing creams by Burkinshaw (2010), Richardson, (2008), and Rirsch and Zhang (2010); nevertheless, a number of the aforementioned concerns remain.

Burkinshaw (2010, p. 9) made use of a brick test pillar constructed with mortar comprising 1-part lime to 3-parts sand. This mortar specification is argued by the author to be representative of that found in nineteenth century terraced houses (Burkinshaw, 2010, p. 9). For the experiment, the test pillar was allowed to stand in water for two months before the damp proofing cream was installed, thereby reproducing, in principal, the conditions of a real wall (Burkinshaw, 2010, pp. 10,15).

Despite the methods and the protocol used, Burkinshaw contends that his study did not necessarily replicate true rising damp (Burkinshaw, 2010, pp. 2,17). For example, the test pillar had been carefully constructed and the damp proofing cream meticulously installed, both factors that the author suggests may not be representative of a real world scenario (Burkinshaw, 2010, p. 18).

Burkinshaw's test did yield impressive results and demonstrated that the damp proofing cream arrested the rise of moisture up the test pillar (2010, p. 17). But this experiment does not replicate those conditions found in a typical house: real walls are unlikely to be standing in water and the masonry from which they are built may be poorly constructed or contain voids (Burkinshaw, 2010, p. 18); thus, in practice, the effectiveness of the damp proofing cream could be compromised by site conditions or the method of installation.

In common with the study undertaken by Alfano et al (2006), Burkinshaw's experiment (2010, p. 9) was carried out in an unheated workshop. The environmental conditions within an unheated workshop and those of a typical dwelling, heated and subjected to moisture vapour produced through the occupants' living activities, will be dissimilar and evaporation, which has a strong effect on the height attained by rising damp, is influenced by these environmental conditions.

Richardson's work was essentially aimed at comparing Safeguard Europe Ltd.'s Dryzone damp proofing cream with products manufactured by their competitors. His study involved the use of 'brick burgers'; each of these burgers comprised two thin pieces of common Fletton bricks sandwiching a centre filling of high porosity mortar. The damp proofing cream was injected into two 12 mm diameter holes, spaced at 120 mm centres, that had been formed in the mortar filling during construction (M. Richardson, 2008, p. 3). The treated brick burgers were subsequently placed in trays containing a shallow depth of water, as shown in Figure 12 below, and weighed at periodic intervals to measure the amount of water absorbed (M. Richardson, 2008, p. 4). From these results, the relative effectiveness of the damp proofing creams was determined.
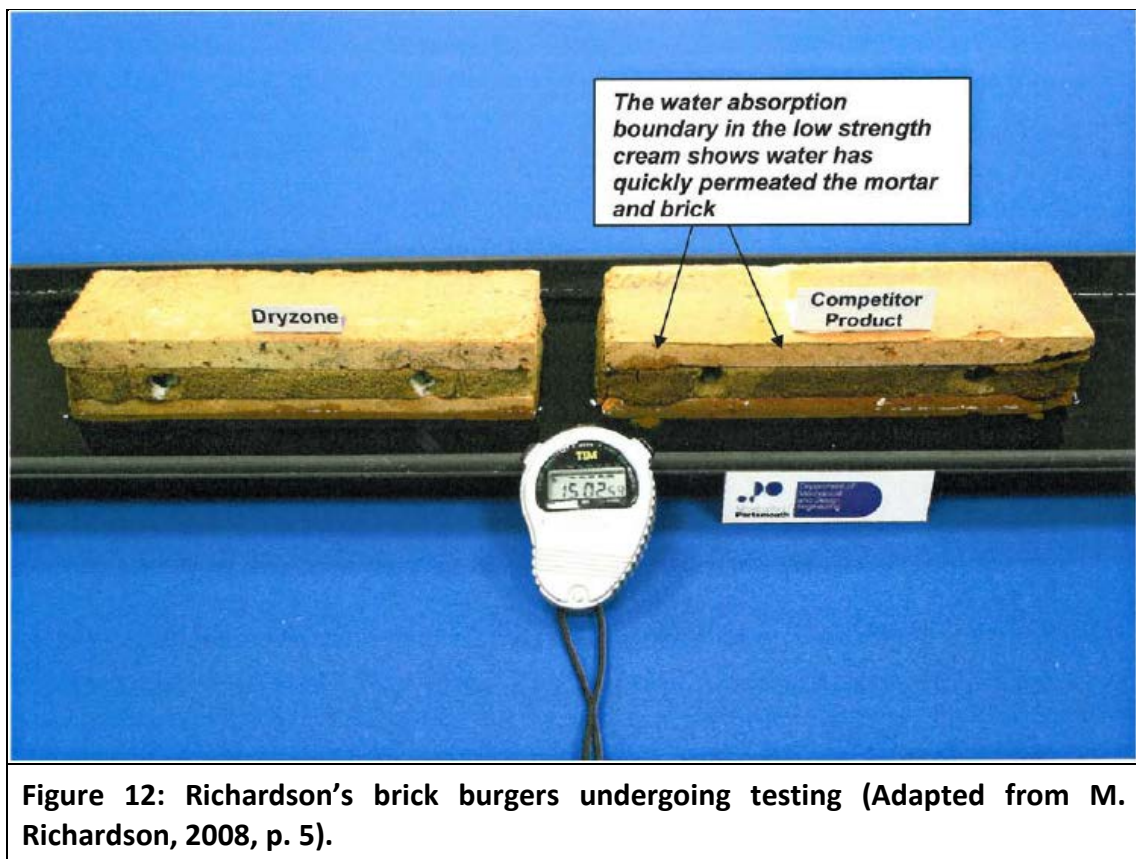
Figure 12: Richardson's brick burgers undergoing testing (Adapted from M. Richardson, 2008, p. 5).

Irrespective of how well one injection cream performed against another, the experimental methods used in Richardson's experiment raises two concerns with respect to their applicability to the walls of actual houses affected by rising damp.

Firstly, the brick burgers were placed in trays of liquid water for a maximum period of 42.5 hours (M. Richardson, 2008, p. 8). As argued earlier, this differs from the way that real walls, which are built into the ground, become wet; yet, short term wetting is common practice in research of this type.

Secondly, Richardson's study commenced with dry bricks that were subsequently treated with the damp proofing cream and then placed in conditions that caused rising damp to take place (M. Richardson, 2008, pp. 3,4). This is very different from real walls with no effective means of preventing the rise of moisture from the ground that may have been affected by rising damp for many years before receiving damp proof course treatments.

Rirsch and Zhang's project (2010), which has been cited in earlier parts of this chapter, was primarily aimed at establishing how mortar of differing sorptivity influences rising damp in test walls; however, the author's make reference to one of their test walls that had been successfully treated using Safeguard Europe Ltd.'s 'Dryzone' damp proofing cream (Rirsch & Zhang, 2010, pp. 1815,1819). Yet, despite this claim to success, Rirsch and Zhang caveat their findings by stating that "the study is limited to one-year old test walls with an artificial water source rather than the field condition of a wall that may be many years old with natural ground water as the source" (2010, p. 1820).

2.4.4. Damp proofing creams and MOAT 39

The British Board of Agrément (BBA) method of testing, MOAT No. 39, was developed to evaluate and test the following chemical injection methods (BBA, 1988, p. 1):

1. Silicone water repellents suspended in white spirit.
2. Polyoxo aluminium stearate suspended in white spirt.
3. Aqueous sodium or potassium methyl siliconates.
4. Injection mortars.

Of the above lists, items 1 and 2 are installed by pressure injection and item 3 by pressure injection or gravity feed (BBA, 1988, p. 1). Item 4, Injection mortar, is installed using a proprietary caulking gun and unlike the pressure injection or creams systems that are pore liners it is a pore blocking system that is not of interest to this project (Oliver, Douglas, & Stirling, 1997, pp. 200,212; Safeguard Europe Ltd., 2007, p. 9).

The foregoing means that the testing procedure described in MOAT No. 39 (BBA, 1988) is effectively out of date. Yet, many damp proofing creams in current use have been issued with BBA certificates using the former method of testing. This specific concern was addressed in a consultation involving the BBA, the Property Care Association (PCA), and the major manufacturers of damp proofing products. The consultation culminated in the BBA releasing two statements: the first in October 2013 and the second in April 2014.

The BBA's October 2013 statement and a letter from the PCA to the BBA with respect to the consultation, dated 25 October 2013, can be found via an internet search. However, unsure if either of these documents were in the public domain, I contacted the PCA (S.Hodgson, personal communication, 13 April 2017) and the BBA (M. Wiseman, personal communication, 20 April 2017; S.Wroe, personal communication, 20 April 2017) to clarify this matter.

The BBA subsequently advised that the October 2013 statement is not in the public domain (M.Wiseman, personal communication, 21 April 2017). For this reason, and despite the information from this statement and the PCA to BBA letter technically being retrievable from the internet, I have opted not to quote from these two sources. However, the second of the BBA's statements, dated 14 April 2014, is confirmed to be in the public domain (M.Wiseman, personal communication, 21 April 2017) and freely available to download from the their website (BBA, 2014). This statement contains five bullet points, the third of which reads:

"Following the consultation it was decided not to implement anything from the consultation paper, but to further consult with manufacturers/holders of BBA Certificates for Dampproofing [sic] Creams and the PCA on test methodology for these products with a view to updating MOAT 39: 1988, which was issued in that year, long before the advent of creams. (BBA, 2014)"

Thus, the BBA identified concerns with respect to the differences between the former fluid-based and the contemporary cream-based chemical injection damp proof course methods and the applicability of the MOAT 39 testing method. Consequently, not only may questions be raised over the use of specially constructed, high porosity mortar test pillars with respect to how they may compare to the walls of actual buildings, but also to their appropriateness as a method of testing contemporary damp proof course creams.

2.4.5. Low-permeability renders

In Chapter 1, it was explained that the chemical injection method for remedial damp proof courses is in fact a two-part system: the installed damp proof course (i.e. the damp proofing cream) is one component of that process and the reinstatement of plasterwork, typically, using a low-permeability cement render overlaid with a finish coat of plaster, is the other. Together, these two parts control, respectively, rising damp and hygroscopic salts and residual moisture remaining in the masonry wall (BRE Housing Defects Action Unit, 1986, p. 1; Safeguard Europe Ltd., 2005, p. 1; Wykamol Group, 2009, p. 2).

Research by the BRE showed that a typical low-permeability render, mixed at the ratio of 3-parts sand to 1-part cement and finished with gypsum plaster, can withstand water under positive pressure without exhibiting any evidence of dampness on the internal surface (Trotman, 2007, p. 9). Indeed, it is for this very reason that critics argue that it is the low-permeability cement render that provides the damp proofing effect rather than the chemical damp proof course itself (Howell, 2008, p. 104; B. A. Richardson, 1995, pp.

126-127). Additionally, because low-permeability renders reduce surface evaporation, their application will force moisture to rise higher up a wall (Hall & Hoff, 2007, p. 1877).

Alfano et al's test pillars were not rendered; instead, they received a 15 mm thick coat of plaster, comprising four layers of increasing porosity, presumably designed to encourage evaporation from the surface (Alfano, Chiancarella, Cirillo, et al., 2006, p. 1062). Similarly, neither Burkinshaw's (2010) nor Rirsch and Zhang's (2010) test pillars or Richardson's (2008) brick burgers received any form of plastering at all.

Arguably, there is good reason why none of the above testing apparatus received a surface coating: all were specifically intended to investigate rising damp and the effect of installing a chemical damp proof course. However, given the importance of correct plaster reinstatement in the two-part system that comprises a remedial damp proof course and the potential for low-permeability renders to be providing the damp proofing effect independently of the installed damp proof course and yet, at the same time, to drive uncontrolled rising damp to greater heights up a wall, none of these effects are being tested.

2.5. Summary and closing comments

In the introduction to this chapter, five questions were posed that related, respectively, to the powers of the Public Health Act 1875, the date when damp proof courses were first installed in houses, capillary action in masonry, the effect of gravity in supressing rising damp, and the effectiveness of chemical injection damp proof courses.

This literature review has determined that, contrary to established opinion, the Public Health Act 1875 did not require the mandatory installation of damp proof courses in ground floor walls. Notwithstanding this fact, there is a great deal of historical evidence to support the notion that rising damp, the upward movement of moisture from the ground by capillary action, was a recognised phenomenon from the mid-nineteenth

century and that measures to prevent rising damp through the installation of appropriate damp proof courses were clearly being used at that time.

The theory underpinning capillary action in masonry, and therefore its role as a mechanism to enable moisture to rise up walls, is compelling. The structure of common building materials with respect to the diameter and distribution of their pores provides a satisfactory explanation for the role of capillary action in rising damp; yet this process is complex and is better explained through sorptivity. Results from the Sharp Front model, which uses sorptivity, align well with real world examples of rising damp.

The height attained by rising damp is influenced by a walls' thickness and on the rate of evaporation from its surface, two properties that are intertwined; however, gravity has only a weak effect, which, in practical terms, can be ignored. This is because the capillaries are only partially wetted and their typical size, around 0.001 mm radius in masonry materials, enables capillary forces to overcome gravity.

Of research undertaken to test chemical injection damp proof courses, the available results suggest that they are effective in controlling rising damp. For example, Alfano et al's twelve-year project found that silane-based fluids injected into their test walls reduced water uptake by nearly 50% (Alfano, Chiancarella, Cirillo, et al., 2006) and, in their independent tests, Burkinshaw (2010), Richardson, (2008), and Rirsch and Zhang (2010) claimed that damp proof course creams successfully controlled rising damp.

But Alfano et al's and other similar overseas-based research has been carried out in climates dissimilar to that in the UK and makes use of local construction materials that are not the same as those found in UK houses. Furthermore, because of the difficulties in replicating rising damp in the laboratory, test pillars are constructed of specially prepared low-strength, high-porosity materials that in the UK comply with MOAT No. 39 (BBA, 1988). Not only is MOAT 39 outdated with respect to damp proofing creams, the contemporary method widely used in remedial work, but so is prior research that tested the effectiveness of fluid-based chemical injection damp proof courses.

The rate of evaporation from masonry walls is claimed by some researchers to be significant but by others to be inconsequential. Additionally, evaporation is an important factor with respect to rising damp and the height that it may attain. It is for this reason that measurement of evaporation rates is argued by Hall and Hoff (2007, p. 1875) to be a research priority. Given the differing opinions with respect to evaporation rates and the potential for this moisture to increase vapour pressure within a dwelling and therefore to promote condensation this would seem a sensible recommendation. Furthermore, the inverse, that of the potential for moisture to be absorbed from the air by suctional forces into a masonry wall, would appear worthy of investigation to determine if it is a tangible cause of dampness.

A remedial damp proof course is a two-part system, which, nowadays, comprises a damp proofing cream and plastering reinstatement using low-permeability cement renders. Prior research tended to test the efficacy of the damp proof course independently of the render; yet, this render is clearly an important component, not only with respect to its role in controlling hygroscopic salts and residual moisture but also because it may be the primary mechanism of damp control and, in the absence of an effective damp proof course, has the potential, by limiting evaporation, to drive rising damp higher up a wall.

This chapter has endeavoured to address those criticisms that fall into the hard-domain identified in Chapter 1. Arguably, with respect to the phenomenon of rising damp and the mechanics of capillary action, these questions have been satisfactory answered. However, not only have some criticisms not been investigated—for example, the effectiveness of an electronic moisture meter with respect to the diagnosis of rising damp—but others such as the efficacy of chemical injection damp proof courses systems have only been partially resolved. Ironically, this literature review has highlighted additional concerns regarding the testing methods used to evaluate injection damp proof courses, the type of systems studied, and both the effect and correlation of environmental and wall moisture.

EMERISDA 'Effectiveness of Methods against Rising Damp in Buildings' a three-year mainland Europe based project, established in 2013 with the objective of finding a solution to rising damp (EMERISDA, n.d.-a, n.d.-b), had this to say in their first newsletter, dated April 2015: "the scarce and fragmented scientific information on the effectiveness of the methods [for treating rising damp], make it difficult (even) for the professionals working in the field to choose a suitable intervention on a sound basis." (EMERISDA, 2015, p. 1).

It is clear that a research project to investigate these matters is warranted. In Chapter 1, the aim of this project was made explicit. The additional concerns identified in this chapter do not change that aim but are sufficiently significant to warrant their incorporation. Precisely how the practical work that will inform this study is to be undertaken is explained in Chapter 3.

Chapter 3
Methodology

3.1. Introduction

Chapter 1 provided the background to this research project. It explored the criticisms of rising damp, the damp proofing industry, and the methods used to treat rising damp. These so-named hard-domain criticisms can essentially be summarised as follows:

a. Rising damp is rare or may not occur at all.

b. The electronic moisture meter, which is typically used to diagnose rising damp, is not reliable for this purpose.

c. Chemical injection damp proof courses do not work.

d. Low-permeability cement render, applied as a necessary component of the two-part remedial damp proof course system, provides the damp proofing effect.

The literature review that is Chapter 2 demonstrated that masonry walls can support capillary action and therefore that rising damp is a real phenomenon; however, in undertaking that review several, additionally issues were identified with respect to laboratory research that, as a continuation of the above list, can be summarised as follows:

e. Real walls may be poorly constructed, and their sorptivity results from aging and contamination with hygroscopic ground salts; laboratory test walls are well constructed from highly sorptive materials to replicate aged masonry, and the effects of hygroscopic contamination are not tested.

f. Real walls are built into the ground and subject to varying soil and water conditions; laboratory test walls are inevitably placed in containers of liquid water.

g. Real walls are treated with chemical damp proof courses after being subject to rising damp for many years; laboratory test walls are treated with chemical damp proof courses after short periods of wetting and in some cases before wetting takes place.

h. Real walls in the UK are subject to a climate that differs from the conditions where research has been undertaken in warmer countries.

i. Real walls in the UK are constructed from materials that differ from those used to construct test walls for research in other countries.

j. Prior research of fluid-based chemical damp proof course injection systems has been superseded through the transition to damp proofing creams.

k. Evaporation has a significant effect on the height attained by rising damp; evaporation from rising damp affected walls and the absorption of moisture from the atmosphere by masonry walls (i.e. the correlation of environmental and wall moisture) is under-researched.

l. The application of low-permeability cement render is a significant component of the remedial damp proof course system; it has the potential to both provide a damp proofing effect and to force uncontrolled rising damp to greater heights, yet it is not incorporated into studies of damp proof course chemicals.

In Chapter 1 the aim of this research project was described as follows:

> To establish whether contemporary remedial damp proof course treatments are (a) necessary (b) effective and (c) if evaporation from damp masonry affects moisture in the environment.

To inform this primary aim, two operational and four research objectives were made explicit:

Operational objectives:

1. Develop a research methodology.

2. Evaluate the effectiveness of common and novel methods of moisture measurement.

Research objectives:

3. Examine the history and science of rising damp.

4. Determine the existence of rising damp.

5. Determine the effect that contemporary remedial damp proof course treatment has on the moisture in a wall affected by rising damp.

6. Determine if moisture in the environment and moisture in damp walls is correlated.

Of this list of objectives, the third has been satisfied through the literature review undertaken in Chapter 2. Of the remaining five, they, and therefore the criticisms and

concerns summarised above in items a-l, and indeed the primary research aim, are to be met using the methodology described in this chapter.

The nature of this project and, therefore, the research methodology to be employed is not typical of practice-based enquiry. A perusal of authoritative practitioner and management research texts reveals a bias in professional practice studies for qualitative, social science-based methods (Gill & Johnson, 2010; Robson, 2002; Saunders, Lewis, & Thornhill, 2009). This is not to imply that quantitative methods of enquiry are not used—research in construction management, for example, has a strong positivist tradition and typically employs a quantitative methodology (Knight & Ruddock, 2008, pp. 4,10)—nevertheless, these projects are typically grounded in the social sciences.

In contrast, this project is essentially concerned with the phenomenon of rising damp: a mechanism for moisture movement that falls within the remit of the physical sciences. Through necessity, the study will not to be undertaken in a laboratory, but, instead, will be placed in the real world and, therefore, use the ground floor walls of an actual house affected by rising damp.

Unlike laboratory test pillars that are carefully constructed of high porosity materials and subject to artificial means of wetting, it will evaluate damp proofing treatments against rising damp occurring naturally, in real walls that may have imperfections and nuances of construction. In addition, the study will endeavour to establish if the electronic moisture meter and other common and novel methods can be relied upon as a method of measuring moisture and moisture change in masonry walls and if moisture in the environment and in a damp wall are correlated.

Clearly, to undertake such a project requires a house with walls affected by rising damp to which damp proofing treatments can be applied and subsequently assessed in the form of a long term moisture monitoring exercise. The processes involved in sourcing and selecting a suitable house, designing and applying damp proofing treatments, and the protocol for moisture measurement and monitoring are described in later chapters.

This chapter is concerned with the methodology chosen to facilitate this research project; a methodology that combines case study and quasi-experimental methods. In the context of the primary research aim, the latter method evaluating the effectiveness of the applied damp proofing treatments and the former method how this effect was achieved (Yin, 2014, p. 221).

3.2. The case study method

Yin[6] (2014, p. 16) defines a case study as "an empirical inquiry that investigates a contemporary phenomenon (the 'case') in depth and within its real-world context, especially when the boundaries between phenomenon and context may not be clearly evident". He proceeds to argue that case study research methods are appropriate for "descriptive" or "explanatory" research questions to determine, respectively, "what is happening or has happened?" or "how or why did something happen?" (Yin, 2012, p. 5).

Given the aim and objectives of this project and the protocol in which it is to be implemented, Yin's definition appears to be an excellent fit and his argument justification for the choice of the case study method: it favours data collection in real-world settings—the setting in this instance being an actual house—and the study seeks to determine if rising damp is occurring (i.e. what is happening) and if moisture change results from the application of relevant damp proofing treatments (i.e. why did something happen) (Yin, 2012, p. 5).

The protocol for the house selection and justification of its suitability for this research project is described fully in Chapter 4. Technically, this house will comprise the case and thus the project will be a single case study for which five rationales may be applied: critical, unusual, common, revelatory, and longitudinal (Yin, 2014, p. 51).

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[6] Yin is arguable the acknowledged authority in the field of case study research methods; consequently, material used in this discussion draws predominantly from his work.

Within the constraints of its geographical location and vernacular form, and given its age and construction, the house selected will be representative of the type typically affected by rising damp and thus to fall within the remit of the 'common' rationale. However, moisture in the wall parts under test and the surrounding environment, and any changes affected by the applied treatments, will be determined through analyses and measurements taken at the start, end, and periodically throughout the data collection phase: thus this part of the study falls within the remit of a 'longitudinal' rationale (Yin, 2014, p. 53). In practice, this will be both a common and longitudinal case study.

One criticism of single case designs is that the issue intended to be investigated by the study may ultimately be found not to apply (Yin, 2014, p. 53). For this project, it would therefore be essential to establish at the outset that the ground floor walls were affected by rising damp and not some other form of moisture. To achieve this important requirement the house will be carefully surveyed and sources of moisture systematically eliminated until only rising damp remains as a potential cause.[7]

Next, preliminary moisture analyses[8] will be undertaken using the gravimetric analysis method[9] to confirm that excess capillary moisture is present in the base of the ground floor walls. In the absence of other explanations, this capillary moisture would strongly suggest rising damp as the cause.

Finally, the preliminary analyses will be followed by more extensive moisture profiling[10], again using the gravimetric method, mapping the characteristics of the moisture profiles found against those of the established model of rising damp described by Kyte (1987, p. 312), Coleman (1990, pp. 15-22), Trotman (2007, pp. 5-6) Hall & Hoff (2012, pp. 256-257), and others, thereby confirming this moisture source. A careful investigation will

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[7] See Chapter 4, section 5. 'Potential sources of moisture other than rising damp'.
[8] See Chapter 5, section 3. 'Stage 1 moisture analysis: procedure' and section 4. 'Stage 1 moisture analysis: results'.
[9] See Chapter 4, section 7.2. 'Gravimetric analysis method'.
[10] See Chapter 5, section 5. 'Stage 2 moisture analysis: procedure' and section 6. 'Stage 2 moisture analysis: results'.

therefore be undertaken to confirm rising damp and thus to justify the case study method at the outset of this project (Yin, 2014, p. 53).

3.3. Embedded, single case design

The foregoing suggests that this project will be a single case study. Yet, the house itself is not technically the unit of analysis; on the contrary, the units of analysis will be five individual test panels that will be allocated to parts of the ground floor walls.[11]

Other than their applied treatment[12], each of the five panels will be identical, comprising a section of internal, half brick thick, masonry wall with apparatus installed to measure moisture[13]. Thus, moisture and any changes that may occur over the data collection phase is to be monitored; these data may be considered either with respect to each individual test panel or collectively across all five panels.

This arrangement lends itself to an 'embedded, single case design' (Yin, 2014, p. 50) in which the test panels, comprising five separate units of analysis, will effectively be placed beneath the umbrella of the house—the single case. In practice, and as discussed later, the embedded cases will be undertaken as quasi-experiments; regardless, this five case method will ultimately add robustness to the findings and support to the claims in comparison to what may have been possible using only a single case study (Yin, 2012, p. 9).

If further justification is required, there are four additional reasons why a single case study that makes use of a single house rather than multiple houses is appropriate for this practitioner research project: availability, practicality, costs, and confounds.

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[11] See Chapter 5, section 2. 'Allocation of test panels to ground floor wall parts'.
[12] See Chapter 6, section 1. 'Stage 3: test panel set up introduction'.
[13] See Chapter 4, section 7. 'Moisture monitoring and measurement methods' and Chapter 6.

3.3.1. Justification 1: availability

With respect to availability: it took time to find a suitable house[14] because not only was it required to be of a type susceptible to rising damp, and thus of a particular age and construction, but it needed to be located geographically close to the my base to facilitate the many data collection visits required during the monitoring phase; under normal occupation (i.e. representative of its real world setting); and to have an owner willing to engage in the project for a nominal period of eighteen months. On reflection, it was extremely fortuitous to source a house that met all of these requirements.

3.3.2. Justification 2: practicality

With respect to practicality: at design stage, the time required to setup the five test panels and undertake the data collection phase could only be estimated. Hindsight revealed that work involved in site setup was time consuming but not necessarily too onerous that the same study could not have been undertaken simultaneously in two or even three houses provided that suitable buildings could have been sourced. Yet, this was certainly not the case with respect to data collection.

Gravimetric analyses, necessary to establish the starting and ending moisture contents of the test panels, required the processing of hundreds of samples. In addition, data collection visits, which were undertaken at nominal ten-day intervals throughout a fifteen-month monitoring period, were extremely time consuming. Initially, each of these visits required the recording and subsequent processing of 227 instrumental readings but because of the inclusion of additional measuring apparatus[15], this number rose to 269 readings per visit over the monitoring phase. Furthermore, equipment

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[14] See Chapter 4, section 2. 'Selection criteria for the case study house' and section 3. 'The case study house'.
[15] See Chapter 6, section 6. 'Stage 4: data collection'.

failure and the necessity to continuously test and verify the accuracy of some of the moisture measuring instruments[16] caused additional, unplanned work.

In practice, the study produced a large quantity of data; with the benefit of reflection, it would have been impractical for a single researcher to have attempted to undertake this case study employing more than a single house.

3.3.3.   Justification 3: costs

With respect to costs: these were envisaged to be significant. Costs incurred in setting up the test panels and in applying relevant treatments, although to be met by my business, were estimated to be in the order of £2,000.00. Some of the apparatus required for moisture analyses and measurement were already owned but some new items of equipment were needed. For example, the Protimeter Hygrostick electronic thermo-hygrometers, of which forty-five were ultimately required, incurred a total cost in excess of £2,000.00. For self-funded research, these are not trivial amounts.

3.3.4.   Justification 4: confounds

With respect to confounds: additional variables would be introduced if the project spanned multiple houses.

For the single case house, all five test panels were located in the same dwelling and thus could be confidently reasoned to comprise the same materials and thus be of identical construction (ignoring the applied treatments). Furthermore, the occupation and environmental conditions, even if varying overtime, would be similar for all test panels located in a single house. Clearly, this would not be the case for cross comparisons because a second or third house may differ in construction, occupation, and environmental conditions.

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[16] See Chapter 6, section 6.2. 'Issue 2: Hygrostick equilibration time and calibration drift'.

To illustrate this issue, the case study house had just one or two occupants over the duration of the monitoring phase. Subsequent analyses of environmental data revealed its internal vapour pressure to have remained relatively low throughout the study period.[17] In contrast, in a house occupied by, for example, a large family with a different lifestyle, thereby producing greater quantities of moisture vapour through normal living activities, would provide dissimilar environmental conditions (Garratt & Nowak, 1991). Thus comparison of results across what, in effect, would be different house types, would involve additional layers of complexity.

3.4. Multiple v single cases

Yin (2014, p. 57) argues that multiple case studies may provide additional rigour but that the penalty with respect to time and resources prohibits their use for self-funded individuals; however, he adds that single case rather than multiple case methods are appropriate where the rationales, which in this case are common and longitudinal, have been met (Yin, 2014, p. 57).

For these reasons and in view of the foregoing, it is contended that the embedded, single case design employed for this project is a suitable method. It meets the feasibility constraints of research funded and undertaken by an individual researcher while at the same time applying an appropriate design, given the dual rationale, mitigating the shortfalls of a single case, and thus providing the desired outcome of satisfying the research aim.

3.5. Data types and the necessity for experiment

For case study research, there are six common sources of data that may be used: interviews, documents, archival records, physical artefacts, participant-observation, and

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[17] See Chapter 6, section 6.5. 'Issue 5: vacant house' and Chapter 8, section 8. 'Environmental and wall moisture: evaluation of correlation'.

direct observation (Yin, 2014, p. 106). In practice, the important requirement is for these data to be appropriate and sufficient to meet the aims of the research; thus, any data type may be used (Gerring, 2007, p. 68). However, given the specific nature of this project, direct observation was selected.

Yet, this will not be passive observation. Instead, the moisture content of four of the test panels will be manipulated through applied treatments. This manipulation process is commonly referred to as an experiment (Cox & Reid, 2000, p. 1). Thus, an experiment enables influencing factors, variables, to be purposely manipulated and the result of this intervention to be observed (Field & Hole, 2003, p. 5). And it is this difference, the manipulation of variables by experimenters, that distinguishes experiments from the passive observation of case studies (Cohen, Manion, & Morrison, 2007, p. 258).

Thus, although this project is primarily a case study, and therefore benefits from the wealth of detail characteristic of this method, the field work is an evaluation facilitated through experiment, a technique more appropriate for this purpose than the case study method in isolation (Yin, 2012, p. 5).

3.6. Experiments and the scientific method

Experiments are underpinned by the scientific method; also referred to as empirical research, quantitative research, and positivist or post-positivist research (Creswell, 2003, p. 7). Essentially, these methods involve the gathering of data that are subsequently analysed to confirm or refute a problem, theory, or hypothesis (Leedy & Ormrod, 2005, p. 33; Oxford English Dictionary, 2010).

Scientific investigation involving experiment typically starts with an expectation of the outcome that is postulated through hypotheses: the process is a priori (Garson, 2002, p. 141; Phillips & Pugh, 2005, p. 50). Indeed, a primary aim of this study it to establish whether contemporary remedial damp proof course treatments are necessary and effective and, through experiment, to satisfy research objectives 4 and 5.

Operational objective 2 and research objective 6, evaluating methods for moisture measurement and the correlation of environmental and wall moisture, could, arguably, be categorised as simple observations that do not require manipulation and therefore to fall solely within the remit of the case study method. Yet, undertaking these tests using wall parts for which the moisture content is intended to change through manipulation (i.e. through applied damp proofing treatments) provides far more comprehensive and robust assessment than passive measurement. Furthermore, ascertaining the effect of environmental conditions with respect to moisture present in the test panels is important in the identification of confounding variables. It is for these reasons, that objectives 2 and 6 are part of the same experiment.

Fundamentally, the scientific method seeks to explain phenomena (Griffiths, 2004, p. 715), and it is often portrayed as objective and outside the influence of actors (Gill & Johnson, 2010, p. 193). Clearly, it would be useful if experiments could be approached from a strictly objective position; however, they cannot be truly independent of reality and are susceptible to influence by, and open to interpretation from, the researcher (Shadish, Cook, & Campbell, 2001, p. 30). Consequently, robust experimental design and adherence with guidelines appropriate for the scientific method of research are essential.

3.7. Experimental variables, validity, and reliability

Before discussing experimental designs, it is first necessary to define independent, dependent, and confounding variables, and validity, and reliability.
A variable is an attribute (i.e. a factor of the person, object, or situation under investigation) that can have more than one possible value (Leedy & Ormrod, 2005, p. 218).

Variables may be independent or dependent. An independent variable is an attribute that can be manipulated and which has an effect on the dependent variable (Leedy & Ormrod, 2005, p. 218). In the context of this study, the independent variables are the

specific damp proofing treatment applied to a particular test panel—for example, the installation of the damp proofing cream or the application of low-permeability cement render—and the rate of evaporation from the panel's surface. The dependent variable is, essentially, the quantity of moisture present in the wall and which is presumed to be affected by the applied treatment. In effect, this is a cause (independent variable) and effect (dependent variable) relationship (Leedy & Ormrod, 2005, p. 218).

Confounding variables are those that may influence the dependent variable but that were not considered during the experimental design (Field & Hole, 2003, p. 224). One such confounding variable is environmental moisture that could potentially affect the moisture content of the test panels (Platten, 1989, p. 359). If this factor was not taken into consideration, claims that the moisture content of a wall fell consequent to the application of a particular damp proofing treatment, or conversely that the treatment failed to have this effect, could be challenged. In essence, this highlights the importance of validity in the research and in ensuring that what is being measured is what is supposed to be measured (Field & Hole, 2003, p. 44; Leedy & Ormrod, 2005, p. 28).

There are various interpretations of validity types applicable to research projects; however, for this study two types are of particular importance: internal validity and external validity. Internal validity seeks to show that any effects claimed to have occurred were indeed caused by the applied treatments, and it is therefore a requirement of exploratory studies (Campbell & Stanley, 1963, p. 5; Yin, 2014, p. 46); external validity is the extent to which generalisations can be claimed from the research findings (Campbell & Stanley, 1963, p. 5).

Reliability is essentially the capacity for an experiment to be repeatable; that is, for someone else to be able to obtain the same results using the same techniques and with the same equipment (Field & Hole, 2003, p. 47).

Thus, the choices used to obtain data and the robustness of those methods is very important. One crucial factor in this process is the selection of an appropriate experimental design.

3.8. Experimental designs

Experimental designs are typically based around the philosophy of logical positivism and can be broadly placed into four distinct categories: non-experimental, pre-experimental, true-experimental and quasi-experimental (DePoy & Gitlin, 1998, p. 29).

Fundamentally, a cause and effect design is the ideal method for this study (Field & Hole, 2003, pp. 21, 66). Each test panel will be monitored to determine how its dependent variable (the moisture content) is affected by manipulation of its independent variable (the action of the applied treatment).

Given the cause and effect nature of the experiment, two of the experimental designs can be discounted at the outset: non-experimental designs because, as their description suggests, they do not involve direct experimentation but instead are concerned with statistical analysis of existing data; and pre-experimental designs because they do not encompass cause and effect studies (DePoy & Gitlin, 1998, p. 120; Leedy & Ormrod, 2005, p. 229). Therefore, this research project is only interested in true-experimental and quasi-experimental designs.

As described above, in a true experiment the researcher manipulates an independent variable and observes the effect of that manipulation on a dependent variable (Leedy & Ormrod, 2005, p. 222). A classic true-experimental design considers two distinct groups; a treatment is applied to one of these groups (i.e. an independent variable is manipulated) but not to the other. This second, un-treated group is subsequently used as a control to allow comparisons to be made with the first group and thereby to determine the effect of the treatment on the dependent variable (Campbell & Stanley, 1963, p. 13; Locke, Silverman, & Spirduso, 2010, p. 101). However, and of particular

importance in true-experimental design, the subjects or objects of the study are randomly assigned to the groups (DePoy & Gitlin, 1998, p. 109).

The foregoing method is perhaps typically associated with medical research where volunteers will be allocated to one of two groups. Members of one of the groups are given a treatment—for example, a new drug—and the other group a placebo. The effect of the treatment is determined by collecting relevant data and through analyses to identify potential causal differences between the treated group and the control group (Locke, Silverman, & Spirduso, 2010, p. 102). In addition, knowledge of the persons who have been allocated to either group can be kept from both the participants and the observers in what is referred to as a double-blind experiment (Campbell & Stanley, 1963, p. 14).

Thus, with true-experimental designs, the researcher essentially has full control over the selection of subjects or objects; how the groups may be allocated; and how the method of treatment will be applied to the chosen groups. Furthermore, a true experiment allows for a high degree of randomisation to all parts of this process (Locke, Silverman, & Spirduso, 2010, p. 102).

Quasi-experimental designs are, in many respects, very similar to true experiments but with one major difference: for a quasi-experiment the researcher is not able to employ randomisation in the selection process or have control over one or more variables that may be important to the outcome of the experiment (Field & Hole, 2003, p. 66; Locke, Silverman, & Spirduso, 2010, p. 109; Tharenou, Donohue, & Cooper, 2007, p. 36). With this in mind, is the experiment proposed for this research project a true or quasi-experiment?

Given that the experiment will, by design, be undertaken outside of a laboratory and inevitably involve walls that are damp affected, it could be construed that such walls are likely to be located in a particular type of property with respect to construction and age. Furthermore, it is envisaged that the subject house will be identified through enquiries

to my business[18] and, therefore, will be located in a particular geographical area and of a specific vernacular type. Moreover, when the experiment is in progress, it will not be possible to control environmental conditions within the house; in fact, this would be undesirable as the sixth research objectives is to determine if moisture in the environment is correlated with moisture in damp affected walls.

It is acknowledged that a field experiment, which by necessity is essentially to be undertaken in someone's home, cannot replicate the rigour of similar studies taking place in the controlled environment of a laboratory. This being the case, the validity of this research project may well be undermined if the onsite work was claimed to be a true experiment. For this reason, both the onsite work and the results derived from it are categorised as a quasi-experiment.

Despite this quasi classification, it remains essential that the experimental design allows adequate control of extraneous variables so that the effect of specific independent variables (i.e. the applied treatments) can be identified (Leedy & Ormrod, 2005, p. 217). This important requirement will be met by keeping some elements of the experiment constant through the use of a 'non-treatment' control panel and, as far as constraints will allow, through random assignment of both the test panels to the subject walls[19] and the treatments that will be applied to those panels[20] (Leedy & Ormrod, 2005, p. 220).

3.9. Proposed quasi-experimental design

Many of the commonly used experimental designs are based on the work of Campbell and Stanley (1963). Leedy and Ormrod (2005, p. 222), in referencing Campbell and Stanley, provide an appraisal of sixteen different designs, categorising them in groups as pre-experimental, true-experimental, quasi-experimental, ex post facto, and

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[18] The business provides surveying and treatment services with respect to dampness and timber decay in buildings.
[19] See Chapter 5, section 2. 'Allocation of test panels to ground floor wall parts'.
[20] See Chapter 7, section 1. 'Stage 3: test panel set up introduction'.

factorial. It is not the intention to discuss all of these designs but, instead, to review methods that are considered suitable for this project and that take account of the particular issues that have been highlighted. Of these designs, two have been identified as appropriate: pre-test / post-test control group design and factorial design.

The pre-test / post-test control group design, which Cook and Campbell (1979, p. 103) refer to as the 'Untreated Control Group Design with Pretest And Posttest' utilises two groups: a control group and a treatment group; both of these groups are observed before the treatment is undertaken; the treatment is applied to the treatment group; observations are made of both groups after treatment; and through comparison with observations made at the pre-treatment stage, the difference, and therefore the effect of the treatment, can be identified (Field & Hole, 2003, p. 78). This is the design that was used in the clinical trial example discussed earlier.

The pre-test / post-test control group type design can be utilised as both a true experiment and a quasi-experiment; however, in the latter case, the groups are, essentially, non-random (Campbell & Stanley, 1963, pp. 13,47). Nevertheless, as outlined above, in setting up the test panels a degree of randomisation with respect to allocation to specific wall parts and application of treatment will be possible.

The above design has one independent variable, the moisture content of the subject walls. This design can be extended to account for different treatment types—in this study, there are four treatment types—while maintaining the single independent variable and thus providing a multiple level design (Field & Hole, 2003, p. 83).

Factorial designs can be employed where there is interest in studying more than one independent variable (Leedy & Ormrod, 2005, p. 233). Logic would suggest that in a study where a number of different factors could affect an outcome that it would be sensible to carry out an experiment that separated and therefore tested each of these variables independently. Montgomery (2001, p. 4) suggests that there is a distinct disadvantage with this strategy because, he argues, it does not account for the typical interaction between variables that may be overlooked if they are considered in isolation.

This scenario can be illustrated through the example of a test panel that receives both a damp proof course and low-permeability render. A change in the moisture content of the wall or plasterwork may be identified, but it would be difficult to conclude which element of the combined treatment provided the damp proofing effect.

Montgomery's recommendation is to utilise a fractional factorial experiment—the use of fractional in the description referring to the number of factors (i.e. variables) that are involved. Importantly, a scientific approach must be used for this type of experiment (Montgomery, 2001, p. 11) and this corroborates the decision to employ a scientific research methodology. In practice, the precise form of the quasi-experiment's design will combine the above methods, utilising the pre-test / post-test approach and a fractional factorial design.

3.10. Putting it all together

A fundamental requirement of this practice-based research project is for the study to be undertaken in an actual house and not in a laboratory; hence, the effect of damp proofing treatments can be appraised in the context of their real world application. This method supplements the theoretical studies and the strict, controlled conditions applied to laboratory research by exposing itself, and thus has to account for, real world variables such as fluctuating environmental conditions and nuances of actual house construction that may not be present outside of practical applications. This study is not attempting to outdo laboratory research but by undertaking this project in the setting of a real house in as controlled a manner as possible aims to compliment this work and the theory underpinning the phenomenon and treatment of rising damp.

This chapter has described the research methodology and the protocol for the on-site quasi-experimental work. Subsequent chapters will, as the case study methodology demands, provide detailed accounts of the case study house selection, the moisture measuring methods to be used, the design and construction of the test panels, the data collection process, and, importantly, the results ultimately found.

Flyvberg (2001, p. 87) argues that "a discipline without a large number of thoroughly executed case studies is a discipline without systematic production of exemplars, and that a discipline without exemplars is an ineffective one." It is hoped that in closely examining all significant factors, using appropriate and robust evidence, and considering alternatives explanations that this project will produce a significant and interesting piece of work. In other words, that it will be an exemplar (Yin, 2014, pp. 200-206).

Chapter 4
Research Design

4.1. Introduction

As described in the previous chapter, this project will employ a quasi-experimental case study methodology to establish whether contemporary remedial damp proof course treatments are necessary and effective and if evaporation from damp masonry affects moisture in the environment. In practice, the study will take the form of a field experiment undertaken in an actual domestic house.

This chapter has three parts. The first part discusses the case study house: the process of selection, the method and findings of an initial survey, and the potential sources of moisture that were identified and systematically eliminated until only rising damp remained as a probable cause. The second part describes the techniques and apparatus used to measure and monitor moisture change in the test panels. The third and final part is primarily concerned with data and, specifically, the types collected, methods of validation, and mechanism for processing and presenting the results; it also includes a summary programme in the form of project milestones.

Subsequent chapters will provide details of the method used to confirm rising damp, the specific damp proofing treatments applied to the four active test panels, and the results achieved by these treatments with respect to each panel's moisture content.

4.2. Selection criteria for the case study house

The rationale underpinning this study is practice-based research; specifically, it was to be a project to mirror, as closely as possible, the real world and therefore be a study carried out in an actual house affected by rising damp. However, a completely random

choice of house was not possible because, through necessity, six constraints had to be applied.

Firstly, the ground floor walls needed to be affected by rising damp.

Secondly, rising damp had to be an inherent defect of the wall construction and therefore align with the technical description of this form of dampness: the upward movement of moisture from the ground by capillary action in a masonry wall (Oxley & Gobert, 1983, p. 47). This criterion meant that rising damp occurring, for example, as a result of leaks from plumbing, ingress of rain water, or bridging—a consequence of construction defects where plasterwork or solid floors enable ground water to bypass a damp proof course (Parnham & Rispin, 2001, p. 113; Property Care Association, 2009, p. 1)—was unsuitable because the action of removing these primary defects would essentially alleviate the rising damp; in such scenarios, rising damp is a symptom of some other building defect rather than an intrinsic fault in itself.

Thirdly, the house was required to be of a suitable era and most probably constructed of masonry bonded with lime-based mortar. This is because the mechanism of rising damp is related to the sorptivity of masonry (Hall & Hoff, 2012, p. 102) and this sorptivity to the type and age of the mortar used in the construction of the walls: lime-based mortar is more sorptive than cement-based mortar and older mortar more sorptive than newer mortar (Hall & Hoff, 2007). House styles tend to the vernacular with geographical areas having their own characteristics and older buildings typically constructed from locally sourced materials (Emmitt, 2002, p. 4). The need for a house constructed with ground floor walls that did not incorporate an effective damp proof course and that comprised lime mortar of a sufficient age to provide the required sorptivity for rising damp to occur essentially narrowed the range of suitable properties to an era prior to the 1920s (Marshall, Worthing, & Heath, 2003, pp. 334-337).

Fourthly, because the study required a monitoring period of fifteen months, during which time regular visits would be made to collect instrumental data, for practical reasons, a viable house had to be located close to my base in North Yorkshire.

Fifthly, to enable an extended monitoring period required the house owner's cooperation and their permission to set up the experiment, install moisture monitoring equipment, and to gain access at regular intervals to take instrumental readings. Therefore, not only had a suitable house to be sourced but its owner needed to be willing to participate in the study.

Sixthly, and finally, there had to be some mechanism to put the owner of a suitable house in contact with me. Given that I operate a business that investigates and treats rising damp, a logical method was to monitor normal business enquiries with the intention of identifying a suitable candidate property.

Putting these six requirements together suggested a late Victorian era, brick built house, located within my area of business activities.

4.3. The case study house

In August 2012, my business received an enquiry with respect to dampness reported to affect the base of the ground floor walls of a late Victorian house in Selby, North Yorkshire, which is just a few miles from my base.

The house, shown in Figure 13 below, had ground floor living accommodation that comprised a small entrance lobby, a front living room, an understairs cupboard, a kitchen, and attached outbuildings. It was of a type that is susceptible to damp problems and for which surveys relating to dampness are often commissioned.

Figure 13: The case study house.

The initial survey revealed damp staining to affect the base of the ground floor walls in the entrance lobby, living room, and kitchen that extended to heights of between 250 mm and 800 mm above internal floor level, as shown in Figure 14, Figure 15, Figure 16, Figure 17, Figure 18, Figure 19, Figure 20, Figure 21, and Figure 22 below.

Figure 14: Entrance lobby right-hand side wall.

Damp staining extends to 550 mm above floor level.

Figure 15: Living room dividing wall with entrance lobby.

Damp staining extends to 800 mm above floor level.

Figure 16: Living room left-hand side (party) wall.

Damp staining extends to 300 mm above floor level.

Figure 17: Living room rear wall.

Damp staining extends to 250 mm above floor level.

Figure 18: Living room right-hand side (party) wall; rear alcove.

Damp staining extends to 400 mm above floor level.

Figure 19: Living room right-hand side (party) wall; fireplace.

Damp staining extends to 650 mm above floor level.

Figure 20: Kitchen left-hand side wall.

Damp staining extends to 350 mm above floor level.

Figure 21: Kitchen front wall, nib wall to side of door.

Damp staining extends to 250 mm above floor level.

Figure 22: Understairs cupboard left-hand side and right-hand side walls.
Damp staining extends to 800 mm above floor level.

A Protimeter MMS meter was used to obtain measure-mode readings from the ground floor walls of the house. The distribution of high to low readings essentially aligned with the damp staining visible on the wall bases. For example, on the living room rear wall, illustrated in Figure 17 above, the following profile of measure-mode readings was recorded:

- Plaster surface from a vertical position in excess of 300 mm above floor level (i.e. above the stained region): 12% WME.

- Plaster surface to a height of 250 mm above floor level (i.e. within the stained region): 100% WME[21].

- Skirting board: 15-100%.

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[21] WME (Wood Moisture Equivalent) is a scale devised by the manufacturers of the Protimeter instruments to assess moisture in materials other than timber. An in depth discussion of this meter's function, operation, and limitations is provided later in this chapter.

This profile of measure-mode readings, falling rapidly to low values above the visibly damp stained wall parts but high in the wall base and skirting boards, was consistent throughout the ground floor. The extent of the damp affected ground floor walls are illustrated on the annotated ground floor plan, shown in Figure 23 below.
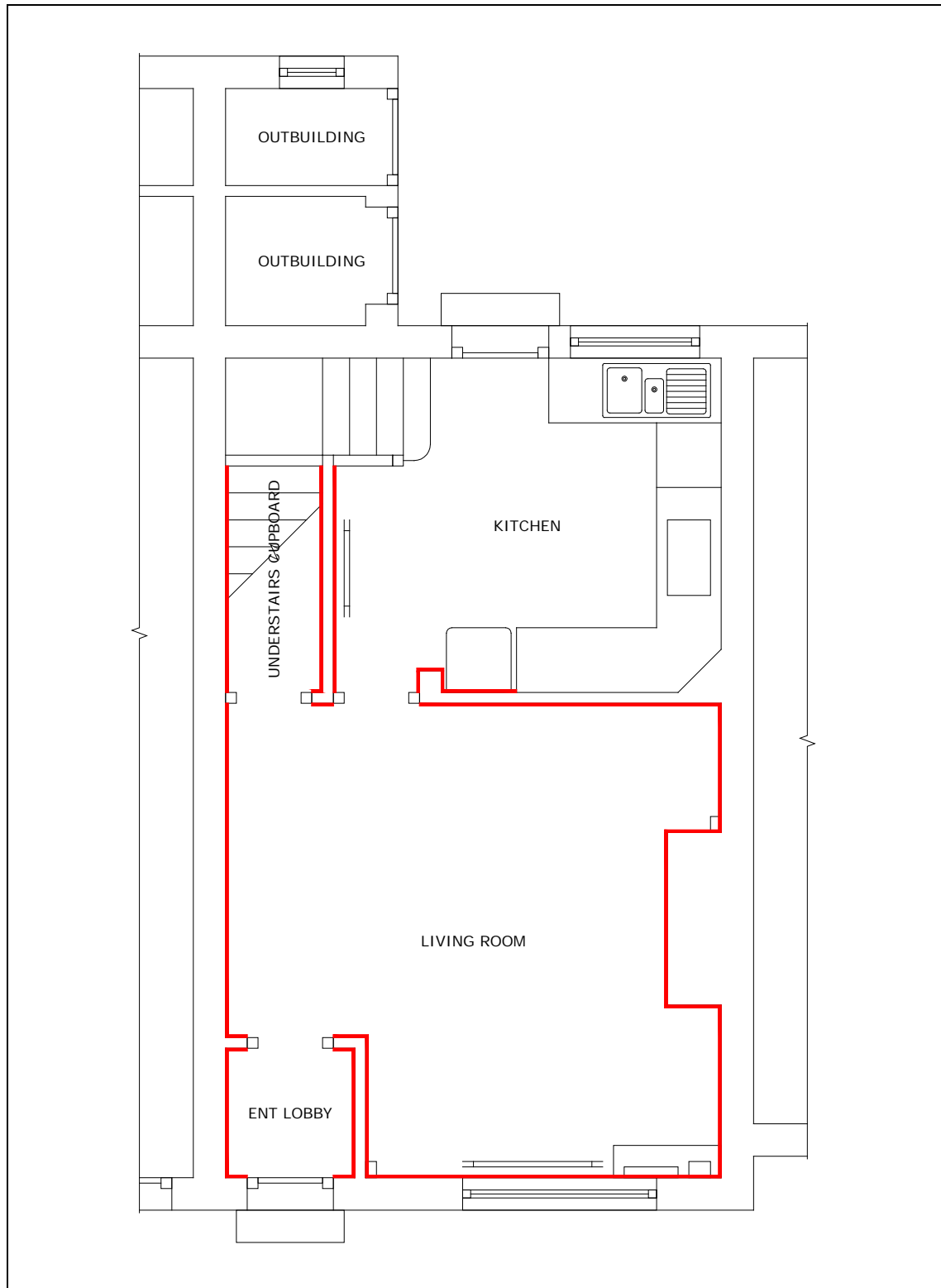
Figure 23: Ground floor plan illustrating location of damp affected walls.

The walls highlighted in red are those that had bases affected by dampness and on which high Protimeter measure-mode readings were recorded.

The profile of Protimeter measure-mode readings and the visible staining affecting the base of the ground floor walls suggested a distribution of moisture characteristic of rising damp (Coleman, 1990, pp. 26-27; Parnham & Rispin, 2001, pp. 114-115). And, significantly, the rapid change in the appearance of the staining at its upper edge and a corresponding abrupt fall in the Protimeter measure-mode readings at this location were entirely consistent with the Sharp Front model for rising damp (Hall & Hoff, 2007, p. 1873).

Given the limitations of electronic moisture meters, it was not possible to conclude at this stage that the ground floor walls were affected by rising damp but only that this form of moisture could be the cause of damp staining and the profile of Protimeter measure-mode readings that had been recorded. To confirm rising damp, three further steps were required: firstly, to systematically eliminate sources of moisture other than rising damp; secondly, to carry out analyses to establish the precise quantity, nature, and distribution of moisture present in the ground floor walls; and, thirdly, to verify that the moisture profile provided by these analyses aligned with the rising damp model.

The following sections first discuss the implications should the house have an existing damp proof course and then proceed to describe how sources of moisture were considered and systematically eliminated until only rising damp remained.

4.4. Existing damp proof course

The house is estimated to have been constructed in the early twentieth century and more precisely around 1910. It is generally acknowledged that the installation of damp proof courses was mandatory following the introduction of the Public Health Act 1875 (Douglas, 1998, p. 76; Oliver, Douglas, & Stirling, 1997, p. 185; Trotman, Sanders, & Harrison, 2004, p. 151). However, Howell (2008, p. 72) has challenged this claim, and a literature review, described in in Chapter 2, did find the 1875 Act to be silent with respect to damp proof courses.

Despite this anomaly, it would be reasonable to anticipate that a house built in the early 1900s may be constructed with a damp proof course (Marshall, Worthing, & Heath, 2003, p. 334). Furthermore, because of the potential influence that the presence of a damp proof course may have on this study, it was prudent to assume that one existed until proven otherwise.

In practice, neither the initial survey nor subsequent investigation undertaken when skirting boards and plaster were removed during test panel setup revealed any signs of an original damp proof course. There was, however, evidence that a remedial damp proof course had been installed in the house, in recent years. Specifically, and as shown in Figure 24 and Figure 25 below, a pattern of drill holes visible in the base of the ground floor walls consistent with the installation of a chemical injection damp proof course commonly used in the 1970s, 1980s, and 1990s (British Standards Institution, 1985, pp. 3-5; 2005, pp. 6-8; Oxley & Gobert, 1983, p. 51; B. A. Richardson, 1995, pp. 119-120).

This technique typically entailed the pressure injection of organic solvent or water based silicone or aluminium stearate water repellents into the bricks to form the damp proof course (British Standards Institution, 1985, pp. 3-5; 2005, pp. 6-8). In recent years, this method has become less popular and has essentially been replaced by chemical injection using damp proofing creams (Burkinshaw & Parrett, 2003, p. 81).

Figure 24: Front wall evidence of chemical injection damp proof course.

Drill holes in a pattern consistent with the installation of a chemical injection damp proof course were visible in the third brick course of the front wall (arrowed). Similar holes were found to have been drilled internally in the base of the walls.

Figure 25: Living room rear wall evidence of chemical injection damp proof course.

Drill holes in a pattern consistent with the installation of a chemical injection damp proof course were visible in the horizontal mortar bed joint above the first brick course (arrowed). Note that the vertical row of holes is not associated with this damp proof course but was formed when the walls were drilled to obtain samples for gravimetric moisture analysis.

The installation of a chemical injection damp proof course is usually carried out in conjunction with the removal of plaster from the bottom one metre of the ground floor walls and its reinstatement using a cement rich render containing a salt inhibitor, finished with a coat of gypsum plaster, to alleviate dampness associated with hygroscopic salts (BRE Housing Defects Action Unit, 1986, p. 1; Safeguard Europe Ltd., 2005, pp. 1-2; Wykamol Group, 2009, p. 2).

Constructed early in the twentieth century, this house would originally have been plastered with lime, a relatively soft and porous material (Marshall, Worthing, & Heath, 2003, pp. 334-337). But, the plaster on the base of the ground floor walls was found to

be a hard, dense material and when parts were subsequently stripped during test panel setup revealed its backing coat to comprise cement render.

In practice, that the house had previously been treated with a remedial damp proof course was not a concern, for three reasons: firstly, the ground floor walls were damp and thus this damp proof course was ineffective; secondly, the damp proof course treatment to be used in the study would differ from the existing because it employs a cream that is inserted into a mortar bed joint; and thirdly, many older properties in the United Kingdom have been treated at some time for rising damp using chemical injection methods (Parnham & Rispin, 2001, p. 115). It is this latter point that is particularly relevant to this practice-based research project because if the existence of some previous form of remedial damp proof course treatment is typical, then this house is the norm rather than the exception.

4.5. Potential sources of moisture other than rising damp

During the initial survey, the following defects were identified that had the potential to be the cause or a contributory cause of dampness affecting the ground floor walls:

1. Penetrating damp via the chimney stack caused by eroded pointing and damaged flaunchings.

2. Penetrating damp via defects to the guttering above the right-hand end of the front elevation.

3. Penetrating damp via perished brickwork at the base of the front wall.

4. Rising damp as a consequence of plumbing leaks (i.e. defects to the hot and cold water or heating systems).

5. Bridging of a damp proof course by solid floors.

6. Bridging of a damp proof course by plasterwork.

As described in the following sub-sections, each of these defects was investigated to either eliminate it as a potential source of moisture or to ensure that it would not impact on the study.

4.5.1. Penetrating damp via the chimney stack

Damage to the flaunching and eroded pointing of the chimney stack, shown in Figure 26 below, could have allowed rain water to penetrate into the flue and to seep downwards and affect the living room chimney breast and fireplace.

Figure 26: Chimney stack.

The pointing of the stack was eroded and the mortar flaunching damaged; both defects that could allow rain water to penetrate into the flue and seep down into the base of the chimney breast below.

Hygroscopic salts, which are released from fossil fuels during combustion, are typically present in chimney flues and the masonry of fireplaces (Oxley & Gobert, 1983, p. 37).

Rain water entering the flue and penetrating downwards into the base of the chimney breast would therefore provide a mechanism, through evaporation, for these salts to migrate into the plasterwork, as shown in Figure 27 below, and be a contributory cause of dampness.

Figure 27: Living room fireplace and alcove walls.

Damp affects the living room fireplace, chimney breast, and adjacent alcove walls. Rain water ingress via defects affecting the chimney stack could potentially be the cause of this moisture.

Yet, identical damp staining was apparent on other ground floor walls remote from the chimney breast and which therefore could not be associated with defects to the chimney stack.

Ultimately, whether or not the chimney stack was a contributory factor with respect to dampness affecting the living room party wall was academic because these wall parts were not chosen for inclusion in any of the test panels.

4.5.2. Penetrating damp via defects to the guttering

The front guttering comprised a half-round, grey plastic type, connected to a fall pipe at its left-hand end, as shown in Figure 13 above. However, the right-hand end of this gutter had sagged, as shown in Figure 28 below, and stains visible on the fascia board directly behind suggested that rain water had been discharging from it or from the roof.

Figure 28: Gutter above right-hand end of front elevation.

The right-hand end of this gutter had sagged. Visible staining suggested that rain water had been discharging from this gutter or from the roof onto the fascia board behind.

Damp related staining was not apparent on the external parts of the front wall below the gutter, and although dampness did affect the base of the living room front wall on the inside, as shown in Figure 29 below, this matched the characteristics of dampness visible on the base of other ground floor walls.

Figure 29: Living room front wall.

The damp staining apparent on the base of the living room front wall was no different to dampness affecting other ground floor walls.

Given the absence of dampness externally and the similarities of the dampness affecting the base of the living room front wall internally and on other ground floor walls, it seemed reasonable to conclude that defects to the rain water goods were not a contributory cause. However, as was the case with the living room chimney breast wall, the precise cause of dampness affecting the living room front wall was to be academic because no parts of it were used for the test panels.

4.5.3. Penetrating damp via perished brickwork

Externally, the fourth and fifth brick courses at the base of the front wall were noticeable more perished and affected by greater deposits of efflorescent salts than the bricks in the adjacent courses, as shown in Figure 30 below.

Figure 30: Front wall perished masonry.

This type of masonry deterioration is associated with dampness and in particular moisture originating from the ground: the bricks become damp, the moisture freezes in winter, and the brick faces spall and perish (Hall, Hamilton, Hoff, et al., 2010, pp. 1-2).

Significantly, the erosion and accumulated salt deposits corresponded with the uppermost position of dampness evident on the external face of the front wall. But, rather than a result of rain water penetration, the distribution of salts at the highest point of damp rise is a characteristic of rising damp (Alfano, Chiancarella, Cirillo, et al., 2006, pp. 1060-1061; Trotman, 2007, pp. 5-6). Furthermore, it is this region, the salt band, where masonry damage typically occurs (Hall, Hamilton, Hoff, et al., 2010, p. 13).

The locations of the fourth and fifth brick courses, externally, corresponded with the second and third brick courses on the internal side of the walls. In other words, the external erosion precisely aligned with the horizontal position of the damp stained

plasterwork at the base of the ground floor walls, whether comprising external or internal parts, and rain water penetration seemed an unlikely cause of dampness to affect internal walls.

Again, the precise cause of the eroded brickwork or of dampness affecting the internal side of the living room front wall is somewhat academic because neither this wall nor any other external wall parts were used for test panels.

4.5.4.   Rising damp as a consequence of plumbing leaks

It was not possible during the initial inspection to verify the integrity of the plumbing or drainage systems and therefore to rule out the potential for such a defect to be the cause of dampness affecting the ground floor walls. However, the owner of the house was made aware of the potential for dampness to be related to a plumbing fault. Later they arranged for the systems to be checked and no faults were discovered. In addition, as will be demonstrated when discussing the results, moisture levels in the wall sections incorporated in the study responded in a manner that would be inconsistent with an escape of water from plumbing services.

4.5.5.   Bridging of a damp proof course by solid floors

Despite clear evidence of prior remedial damp proof course work being discovered during the initial survey, and later when skirting boards and plaster were removed from the base of the ground floor walls, no signs of an original damp proof course were found.

The survey established that the ground floors were concrete and a relatively recent addition to the house, yet sub floor air grates, visible externally in the base of the front and rear walls, suggested that the house had been built with ground floors of suspended timber construction. Assuming that this was the case then an original damp proof course, if present, would typically be located beneath the floor joists and timber wall

plate, as illustrated in Figure 31 below (Clay & Davis, 1977, p. 97; Oliver, Douglas, & Stirling, 1997, p. 144).
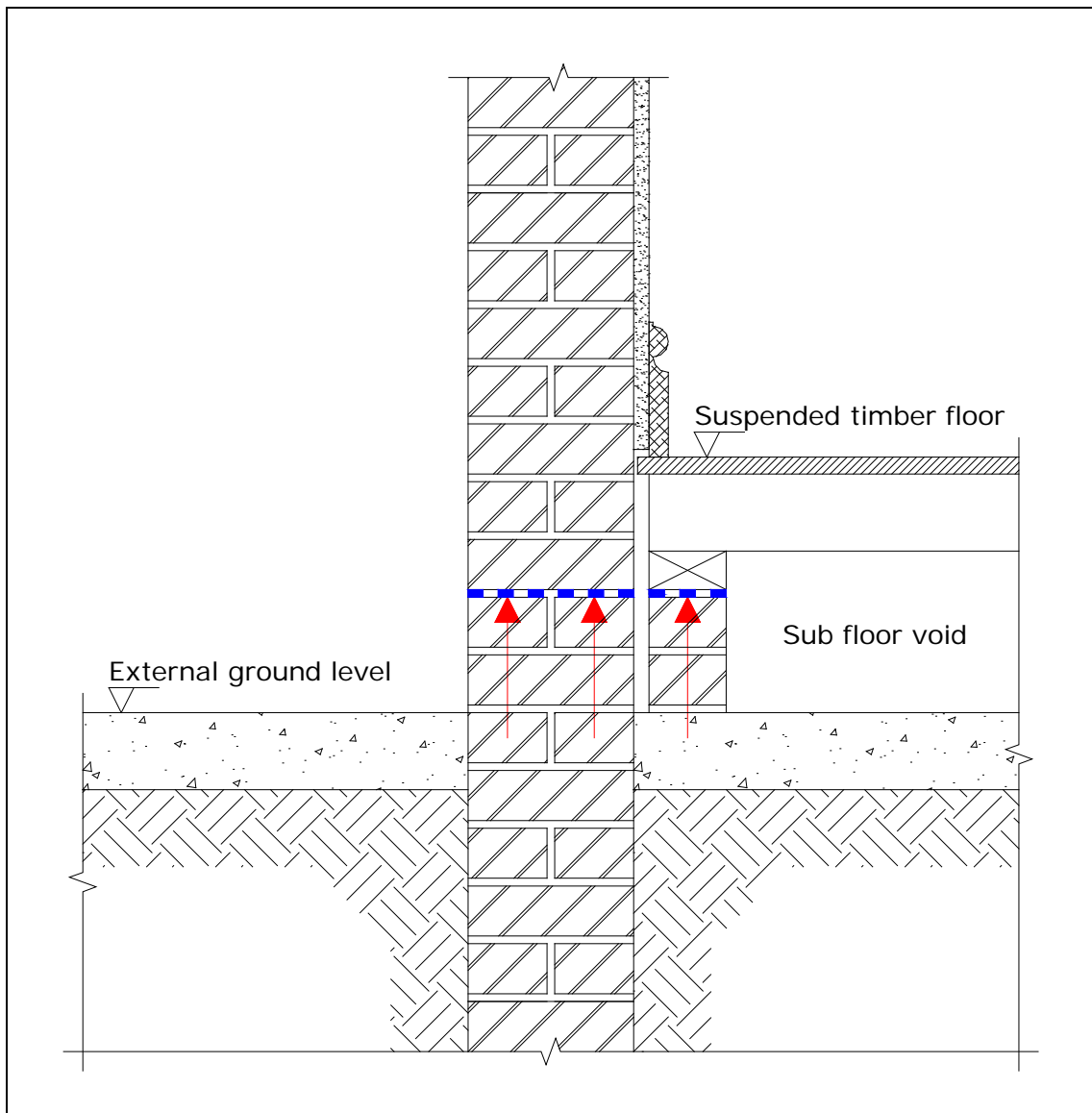
Figure 31: Indicative section through a solid external wall of a house with suspended timber floors.

Cross section illustrating a typical configuration for a solid walled house that incorporates a physical damp proof course and has suspended timber ground floors. A damp proof course located beneath the floor timbers would control rising damp and prevent moisture in the ground from passing up into the wall above.

Removing an original suspended timber floor and replacing it in concrete effectively bridges a damp proof course positioned beneath the floor timbers: the solid floor

construction providing a mechanism that enables ground water to bypass the damp proof course and rise up into the walls above, as illustrated in Figure 32 below.
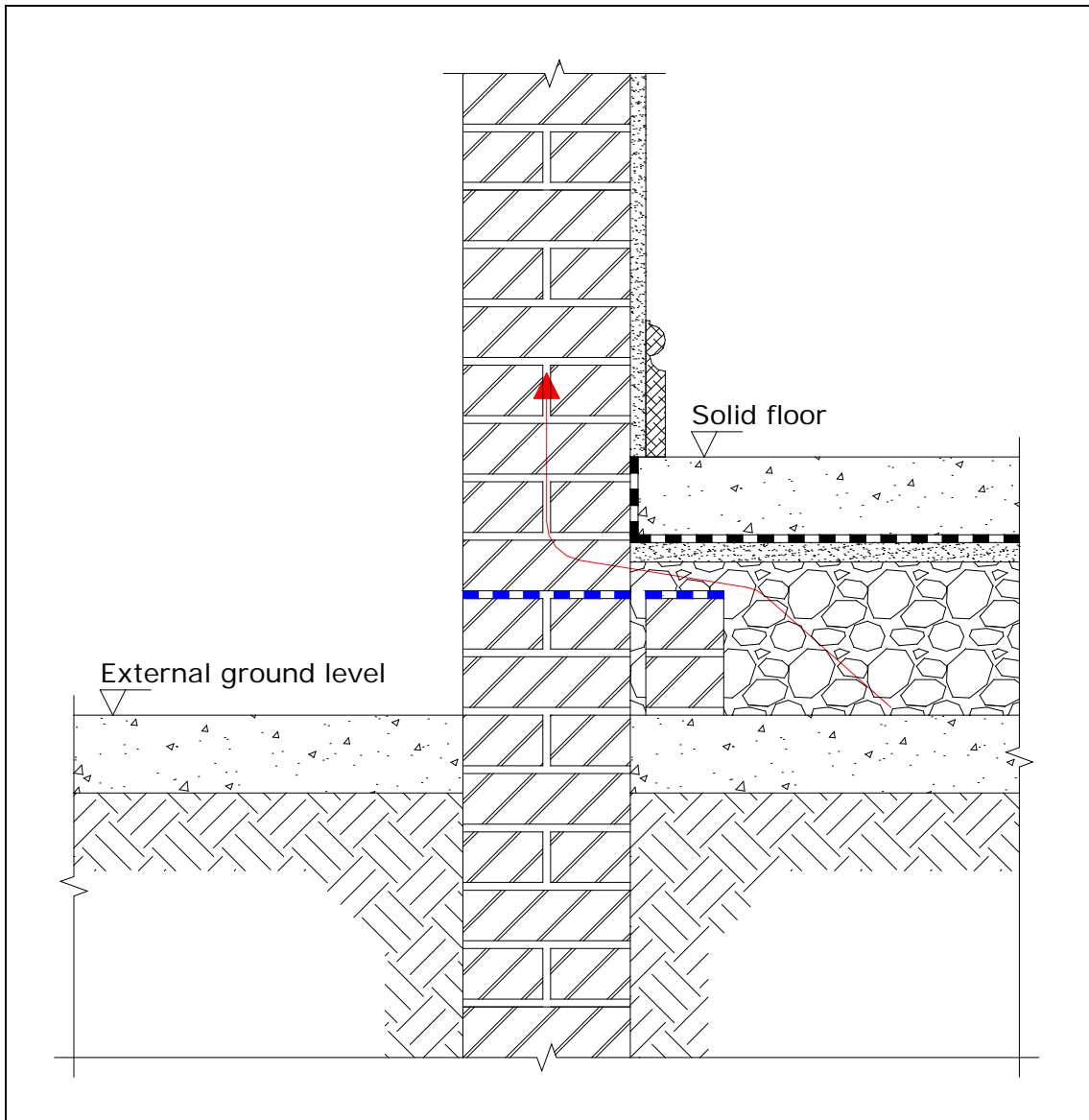
Figure 32: Indicative section through a solid external wall of a house with replacement concrete floors.

Cross section illustrating a typical configuration for a solid walled house that incorporates a physical damp proof course where the suspended timber ground floors have been replaced in concrete. A damp proof course located beneath the floor timbers is bridged by the solid floor construction allowing moisture from the ground to by-pass it and rise up into the wall above.

It was not possible to verify if a damp proof course had been built into the ground floor walls when the house was constructed or if the ground floors had been materially

altered from suspended timber to solid concrete or, indeed, if these solid floors happened to bridge that damp proof course. In practice, and significantly for the purposes of this study, these matters are not a concern: no original damp proof course was found and even if such a damp proof course existed in the walls below the floor it was essentially redundant as a result of bridging.

4.5.6. Bridging of a damp proof course by plasterwork

A chemical injection damp proof course had been installed in the ground floor walls. At the time of the initial survey, the only signs of this work were characteristic holes drilled into the bricks at the base of the external face of the front wall, along with evidence that the internal sides of the ground floor walls had been replastered with a cement rich render to a nominal height of one metre. Works undertaken at later stages of this study revealed the bottom edges of this render to have been taken down to meet the solid floors, as shown in Figure 33 below.

Figure 33: Base of the living room rear wall: plaster bridges the existing chemical injection damp proof course.

Allowing the internal plasterwork to touch the solid floor, or more explicitly to pass over the chemical injection damp proof course, provides a bridging mechanism that enables moisture in the masonry below the damp proof course to pass up into the wall above, as illustrated in Figure 34 below.
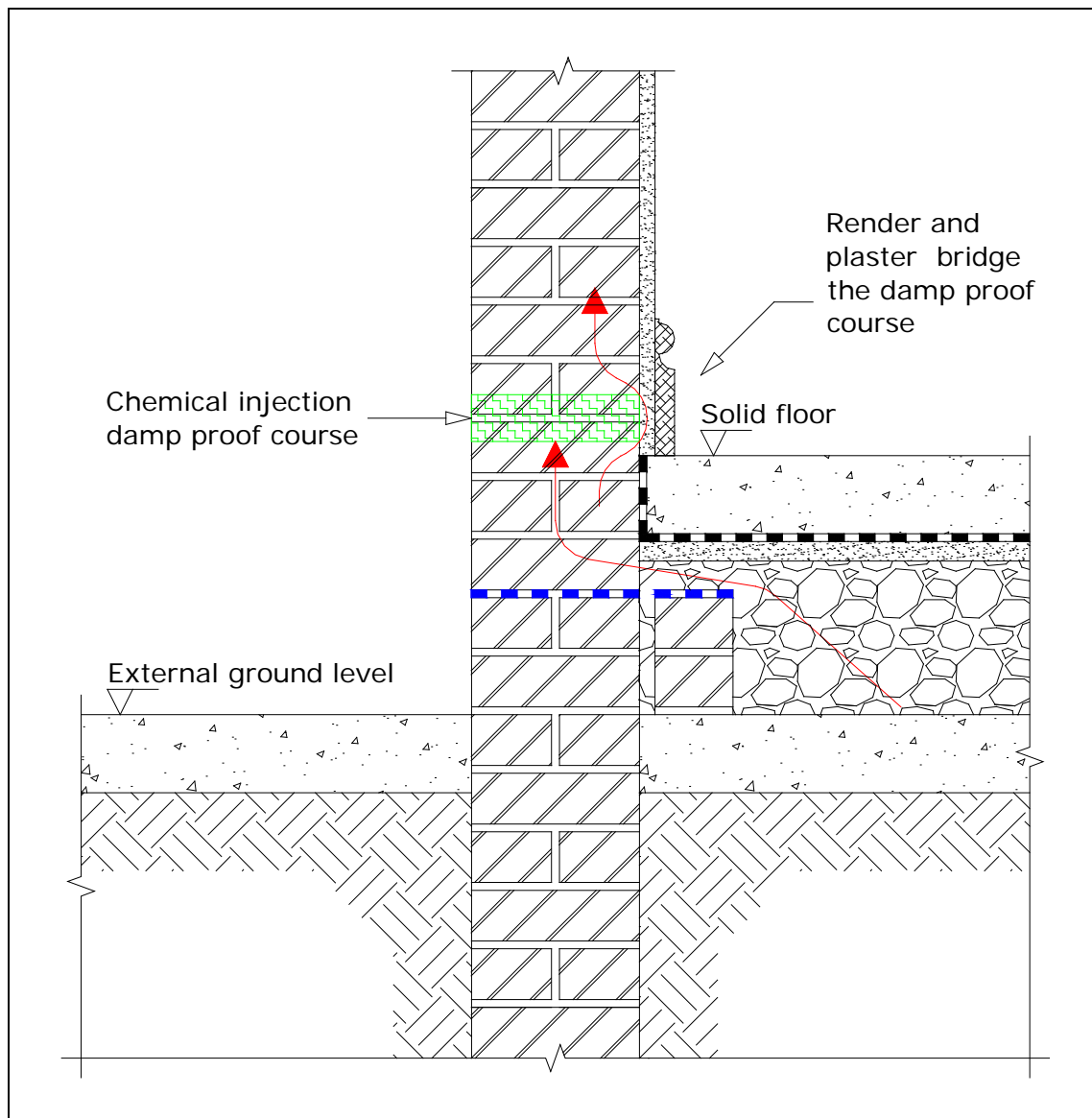
Figure 34: Indicative section through a solid external wall of a house with replacement concrete floors and a chemical injection damp proof course bridged by internal plasterwork.

Cross section illustrating a typical configuration for a solid walled house that incorporates a physical damp proof course where the suspended timber ground floors have been replaced in concrete and a chemical injection damp proof course installed into the wall above this floor. The original damp proof course located beneath the floor timbers is bridged by the solid floor construction. The plasterwork extends down to meet the solid floor, effectively bridging the chemical injection damp proof and enabling moisture from the ground to by-pass it and rise up into the wall above.

To prevent bridging requires the bottom edge of the plasterwork to be cut back or otherwise terminated above the damp proof course, as illustrated in Figure 35 below.

Chemical injection
damp proof course

Bottom edge of
render and plaster
terminated above
the damp proof
course to alleviate
bridging

Solid floor

External ground level
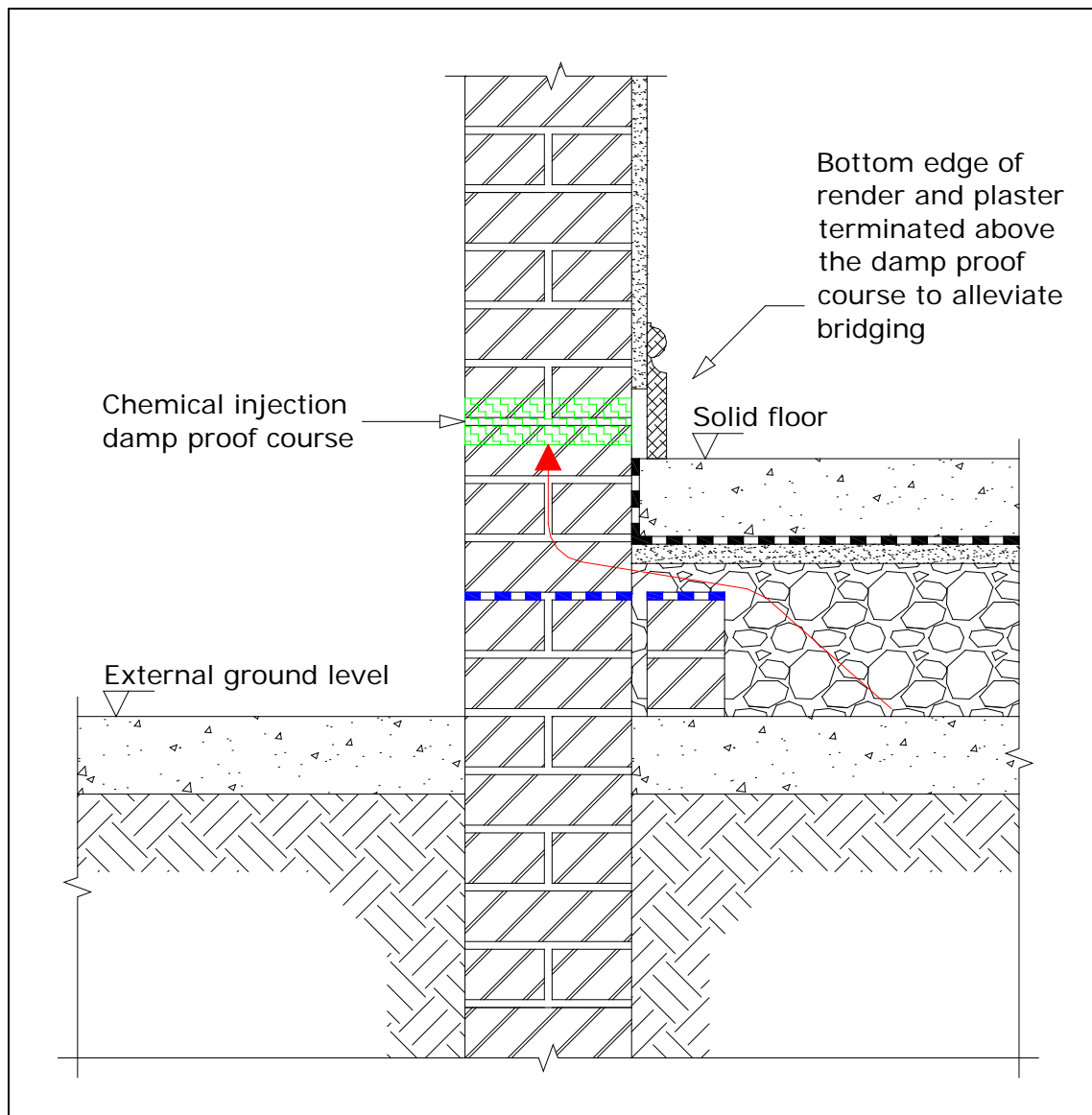
Figure 35: Indicative section through a solid external wall of a house with replacement concrete floors and a chemical injection damp proof course not bridged by internal plasterwork.

Cross section illustrating a typical configuration for a solid walled house that incorporates a physical damp proof course where the suspended timber ground floors have been replaced in concrete and a chemical injection damp proof course installed into the wall above this floor. The original damp proof course located beneath the floor timbers is bridged by the solid floor construction. The plasterwork terminates above the solid floor and thus does not bridge the chemical injection damp proof course.

The concern with respect to this study was whether bridging by the plasterwork had actually been the cause of the dampness that affected the ground floor walls rather than a defect to the existing remedial damp proof course. The works in setting up of the test

panels would require this existing render to be removed or for its bottom edge to be trimmed. Thus, if rising damp stopped and the wall parts dried, it would be unclear if this was an effect of the applied treatments or simply because bridging of the existing chemical injection damp proof course was alleviated.

Consideration was given to this conundrum. For consistency, because it would not be possible to apply the required damp proofing treatments to the test panels without disturbing the existing plasterwork, it was decided that the bottom edge of existing plasterwork should be trimmed to expose the bottom course of brickwork and that any newly applied render[22] and plasterwork should be similarly detailed. Ultimately, the results provided by this study confirmed that this decision was justified: bridging of the existing damp proof course, even if occurring, was not the primary cause of dampness within the depth of the walls.

4.6. Case study house selection: closing remarks

The preceding text has described the selection process for the case study house and demonstrated why it was suitable for this project, not only given its age, construction, and location, but most importantly because the bases of its ground floor walls displayed characteristic evidence of rising damp, following the elimination of other potential sources of moisture.

Despite this outcome, rising damp had yet to be confirmed. The preferred method of confirmation is to determine the characteristic profile of moisture affecting the base of the ground floor walls using the gravimetric analysis method (Trotman, 2007, pp. 11-12). This technique requires the removal of plasterwork and masonry samples, which is both invasive and time consuming.

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[22] In practice, low-permeability cement render applied to one of the test panels was extended down to meet the solid floor. The reasons for this decision are described in Chapter 6.

On the one hand, it was essential to employ a suitably robust method to confirm rising damp, but on the other hand considerable time and resources may well be wasted if rising damp was not in fact occurring. A sensible compromise was to make use of the gravimetric method to undertake an initial, less complex analysis to broadly establish if significant quantities of capillary moisture affected the base of the ground floor walls and therefore that a liquid source of moisture, namely rising damp, was present. If these initial results showed promise and supported the findings of the preliminary, non-invasive inspection then a full moisture profiling exercise would be undertaken.

An agreement was reached with the owner for samples to be removed from the ground floor walls to facilitate this initial moisture analyses. Assuming that this exercise confirmed suitability of the house, the owner also gave consent for the remainder of the project to proceed. The moisture analyses and their results are discussed in Chapter 5; the remaining parts of this chapter are concerned with the apparatus and protocols that were used in this project to measure and monitor moisture.

4.7. Moisture monitoring and measurement methods

This is fundamentally a practice-based research project; consequently, for practical and economic reasons and through a desire for the techniques used to be accessible and easy to replicate by others, only moisture measurement and data collection methods generally available to building surveyors were to be included. Microwave, nuclear magnetic resonance, radar, thermographic, ultrasonic, and other similarly exotic methods of moisture measurement were purposely excluded (Dill, 2000); instead, this project makes use of the following, widely available and essentially affordable equipment:

1. To quantify moisture:

    1.1. Carbide meter.

    1.2. Gravimetric analysis method.

2. To monitor changes in moisture over the monitoring period:

    2.1. Protimeter electronic moisture meter.

    2.2. Timber probes.

    2.3. Protimeter Hygrosticks.

3. To monitor environmental conditions

    3.1. Lascar ELB-USB-2+ electronic thermo-hygrometer data loggers.

Each piece of apparatus along with its specific application, advantages, and disadvantages are described below.

4.7.1. Carbide meter

A carbide meter, which is shown in Figure 36 below, comprises a metal flask with a pressure gauge attached to its base. To use this meter, a sample of the mortar, plaster, or masonry to be tested is typically obtained by drilling. This sample is carefully weighed, placed in the flask with a measured quantity of calcium carbide reagent and the flask is then sealed and shaken to mix the contents (Hollis & Gibson, 2005, p. 411). The calcium carbide reagent reacts with moisture in the sample and this reaction produces acetylene gas (Burkinshaw & Parrett, 2003, p. 80). The gas increases the pressure within the flask and this pressure is converted into a percentage moisture content that can be read directly from the analogue dial of the gauge attached to is base. The reading obtained is therefore proportional to the amount of moisture present in the sample: the wetter the sample, the higher the reading (Hollis & Gibson, 2005, p. 411).

Figure 36: Carbide meter.

The carbide meter is supplied as a kit containing scales to facilitate careful weighing of the sample under test, a container of reagent, and a small, proprietary measuring cup that is used to place the correct quantity of reagent in the meter. The moisture content is read from an analogue gauge fitted to the base of the meter.

Many practitioners advocate the use of a carbide meter as a preferred method to accurately determine the moisture content of masonry on site (Burkinshaw & Parrett, 2003, p. 79; Coleman, 1990, p. 14; Dill, 2000, pp. 43-47; Trotman, Sanders, & Harrison, 2004, p. 44).

Technically, drilling into a wall to obtain samples could result in some evaporative loss of moisture caused by the friction of the bit (Dill, 2000, p. 44). However, this is a potential limitation of the sampling method and not an inherent flaw of the carbide meter. In any case, such moisture loss is not considered significant if the material tested is not too hard and the drill bit used is sharp (Trotman, 2007, p. 11).

The appendix to BRE Digest 245 (Trotman, 2007) provides a protocol for the use of a carbide meter for quantitative moisture analysis. This method shares similarities with the gravimetric method and, hence, is discussed in more detail in the following section.

Given the accuracy of the carbide meter, it would seem a good choice for quantifying the moisture content of the ground floor walls at the start and end of this study; nevertheless, for the reasons presented in the next section, the alternative, gravimetric method of moisture analysis is to be used. Yet, in practice, neither the carbide meter nor the gravimetric method are suitable techniques for monitoring purposes where far more frequent values are required. Later sections of this chapter will describe other methods that this project will use to fulfil that requirement.

4.7.2. *Gravimetric analysis method*

The majority of construction materials are hygroscopic and absorb moisture directly from the air (Trotman, Sanders, & Harrison, 2004, p. 63). Therefore, they will contain some moisture, which can be as high as 16-20% in timber, 1% in plaster, 3% in brick, 2% in cement mortar, 5% in lime mortar, and in excess of 5% in lightweight concrete without causing adverse effect (Oliver, Douglas, & Stirling, 1997, p. 269; Trotman, Sanders, & Harrison, 2004, p. 1).

The tendency for construction materials to absorb atmospheric moisture is enhanced as a result of hygroscopic contamination (Coleman, 1993, p. 3). Significantly, moisture sourced from the ground contains hygroscopic nitrate and chloride salts (Oliver, Douglas, & Stirling, 1997, p. 189). Therefore, these salts are a characteristic of rising damp and will be present in walls affected by this form of moisture (Oliver, Douglas, & Stirling, 1997, p. 189). Hygroscopic moisture is not only a tangible source of moisture but can enable a construction material to exhibit dampness independently of other moisture sources (Oxley & Gobert, 1983, p. 38).

From the foregoing, it can be reasoned that the total moisture content of any construction material is comprised of two components: a hygroscopic moisture portion and a capillary moisture portion. The hygroscopic moisture content is the quantity of moisture that it could contain by absorbing moisture directly from the air, and it is a value that is influenced by the presence of hygroscopic contaminants such as common ground salts of nitrates and chlorides, for example. Capillary moisture content is the quantity of moisture that the material contains in excess of its hygroscopic moisture content. Essentially, this is unwanted or free moisture and is a value that needs to be determined to establish if masonry is affected by an active source of moisture such as rising damp. Thus, the total moisture content—the sum of its hygroscopic and capillary moisture contents—is the quantity of moisture that the material contains as found.

The procedure to determine the total moisture content (TMC), hygroscopic moisture content (HMC), and capillary moisture content (CMC) of masonry walls is well documented in the appendix to BRE Digest 245 (Trotman, 2007, pp. 11-12). It requires samples of plaster and masonry to be removed by drilling, placed in sealed, air-tight containers to prevent moisture loss, and taken off-site for laboratory processing which, if employing the gravimetric method, follows these steps (Adapted from Trotman, 2007, pp. 11-12):

1. Weigh a watch glass (onto which the sample is placed) and record the value as W_0.

2. Shake the container holding the sample, remove the top, place around 2 g of the sample onto the pre-weighed watch glass, weigh, and record the value as W_w.

3. Place the W_w sample into a sealed container at a controlled relative humidity of 75.0% for twelve hours (overnight), weigh, and record the value as W_{75}.

4. Place the W_{75} sample into the drying oven at 100°C, remove, allow to cool, weigh, and record the value as W_d.

5. Calculate the hygroscopic moisture content (HMC) of the sample expressed as a percentage of the wet weight using Equation 4:

Equation 4

$$HMC = (100W_{75} - W_d) / (W_{75} - W_0) \text{ \%wet weight}$$

6. Calculate the total moisture content (TMC) of the sample expressed as a percentage of the wet weight using Equation 5:

Equation 5

$$TMC = (100W_w - W_d) / (W_w - W_0) \text{ \%wet weight}$$

7. Calculate the capillary moisture content (CMC) of the sample expressed as a percentage of the wet weight using Equation 6:

Equation 6

$$CMC = HMC - TMC \text{ \%wet weight}$$

Thus, the gravimetric method comprises the following apparatus:

1. Watch glasses to hold the samples.

2. Sealable vessel providing an enclosed environment of 75.0% relative humidity.

3. Electronic milligram balance.

4. Electric drying oven.

Figure 37 below illustrates items 1 and 2 of the above list after a sample on a watch glass has been weighed and placed in a desiccator above a saturated solution of sodium chloride. When sealed, the air inside the desiccator equilibrates to 75.0% relative humidity (BSI, 2013a, pp. 4,5; Trotman, 2007, p. 11).

Figure 37: 75% humidity chamber.

Samples are conditioned by placing them in a sealed vessel above a saturated solution of common salt, thereby providing a controlled, 75% relative humidity environment. Once equilibrated, the moisture content of the sample is determined either using the gravimetric method or with a carbide meter to obtain its hygroscopic moisture content.

Items 3 and 4, the electronic milligram balance and laboratory drying oven, are illustrated in Figure 38 below.

Figure 38: Drying oven and balance

Although the gravimetric process undertaken for this study essentially aligned with BRE 245, certain modifications described in BS EN ISO 12570:2000+A1:2013 'Hygrothermal performance of building materials and products—determination of moisture content by drying at elevated temperature' and BS EN ISO 12571:2013 'Hygrothermal performance of building materials and products—determination of hygroscopic sorption properties', were applied (BSI, 2013a, 2013b)

Firstly, rather than a single weighing to determine the W_{75} value, an initial W_{75} weight was obtained after twenty-four hours of conditioning in the 75.0% relative humidity vessel. This value was checked against a second weight taken a few hours later and repeated until the weights had stabilised (i.e. when two consecutive weights were the same).

Secondly, Trotman (2007, p. 11) suggests that samples should be dried for one hour at 100°C arguing that lower temperatures simply prolong this process. In contrast, British Standard BS EN ISO 12570:2000+A1:2013 (2013b, pp. 7-8) states that lower drying temperatures should be used for certain materials: for example, gypsum where high temperatures can cause loss of 'water of crystallisation' and where drying temperatures should not exceed 40°C. For similar reasons, Hall and Hoff (2012, pp. 73,139) recommend a "gentle heating regime", arguing that high temperature can affect cement based materials.

The samples removed from the house comprised brick; mortar, that in addition to sand could contain lime, cement, or a combination of these materials; render, which was assumed to be a mixture of cement and sand but which might also contain lime; and finish plaster (i.e. gypsum). This finish plaster comprised a relatively small part of the samples and loss of water of crystallisation from it was unlikely to compromise the results. Nevertheless, given this knowledge and the uncertainty regarding the precise composition of other materials, it would be best to avoid high temperature that might produce erroneous results. Thus, offering a sensible compromise that mitigated the potential damage of high temperatures while not excessively prolonging the drying process, 50°C was used for the oven drying temperature.

Thirdly, like the protocol used for the W_{75} weights, the dry weights were not determined by a single weighing; instead, an initial W_d value was obtained after a few hours in the drying oven, checked against a second weight taken a few hours later, and this process repeated until the weights had stabilised (i.e. when two consecutive weights were the same).

Fourthly, the desiccator containing the saturated salts solution can accommodate approximately twenty samples at any one time. For this project, establishing the starting and ending moisture contents of the test panels required the processing of several hundred samples. Undertaking this processing in batches of twenty would not only necessitate a great deal of time but it risked moisture loss from samples awaiting

conditioning. In contrast, the drying oven can accommodate eighty-two samples in a single batch. Thus, a larger 75.0% relative humidity chamber was constructed using a large plastic container with a sealable lid, as shown in Figure 39 below, in which up to eighty-two samples could be processed above a saturated salts solution at the same time.

Figure 39: 75.0% relative humidity container for large batch processing.

Samples are placed on trays above a saturated salts solution in the base of this large, plastic container for batch processing at 75% RH. This container can accommodate eighty-two samples at the same time.

At each stage of the gravimetric process, the respective sample weights were recorded and entered into a results spreadsheet. In the case of W_{75} and W_d values, it was their final (i.e. stable) values that were used in the calculations.

The results spreadsheet was configured to determine the Total Moisture Content (TMC), Hygroscopic Moisture Content (HMC), and Capillary Moisture Content (CMC) of each sample using the formulas described in Equation 4, Equation 5, and Equation 6 above.

BRE Digest 245 provides a protocol for the carbide meter that differs from the gravimetric method. Two samples are removed from the same location of the wall. One of the samples is tested immediately to determine its TMC. The second sample is conditioned in the 75% relative humidity container and on completion of this process, is tested to determine its HMC. Then, like the gravimetric method, the CMC value is calculated from Equation 6 above using these derived TMC and HMC values.

From the foregoing, it can be construed that all moisture analyses require two distinct steps to determine the TMC, HMC, and CMC values of the samples. However, because the technique used in the gravimetric method does not materially affect the materials, a single, two-gram sample is all that is required for each test: multiple check weights of this single sample can to be recorded at each stage of the process. The gravimetric method uses a scientific balance that has a digital readout which displays values to three decimal places and thus offers precision, particularly when comparing samples with very similar moisture contents. And it is a method that enables multiple samples to be processed at the same time.

In contrast, for each single test, the carbide meter necessitates a minimum of two, separate, six-gram[23] samples because they are destroyed when the reagent is added. To obtain check values, requires additional samples and all values are read from an analogue gauge attached to the base of the meter, limiting its accuracy to around 0.5%. It is not possible to batch test samples in a carbide meter.

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[23] Technically, a three-gram sample can be used for carbide meter tests by using a proportional test technique. For this method, the value displayed on the meter's dial is doubled (Amphenol Advanced Sensors, 2014, p. 4)

So, in comparing these two techniques, the gravimetric method, although invasive, is less disruptive, potentially more accurate, and is far quicker than the carbide meter, particularly, as will be the case for this project, when large numbers of samples are required to be batch processed. Nevertheless, because they require physical samples to be removed, neither the gravimetric method nor the carbide meter is suitable for everyday moisture monitoring purposes. Instead, this requirement is to be fulfilled using a Protimeter electronic moisture meter, Protimeter electronic thermo-hygrometers, and Timber Probes Type 1 as described in the following sections.

4.7.3. *Protimeter electronic moisture meters*

Electronic moisture meters offer a method of measuring moisture change that is non-invasive and quick. Two commonly used instruments are the Protimeter MMS meter (Moisture Measurement System) and the Protimeter Surveymaster, both of which utilise two modes of operation for measuring moisture in building materials: measure-mode and search-mode. (GE Sensing, 2005).

For the Protimeter MMS meter, measure-mode readings are obtained using a Heavy Duty Probe attachment: the two-pins of the probe are pushed into the surface of the material to be sampled, as illustrated in Figure 40 below (GE Sensing, 2005, p. 7).

Figure 40: Protimeter MMS meter: measure-mode function using the Heavy Duty Probe.

The Heavy Duty Probe can be used with the Protimeter Surveymaster model, but this instrument is also fitted with two integral pins that can be pushed directly into the surface of the subject material hence replicating the probe's function, as shown in Figure 41 below (GE Sensing, 2009, p. 6).

Figure 41: Protimeter Surveymaster meter: measure-mode function using the integrated pins.

The measure-mode function enables the actual percentage moisture content of timber to be obtained within the range of 8%-29% (GE Sensing, 2005, p. 17; 2009, p. 6). Outside this range (i.e. >30-100%) measure-mode readings recorded on timber are not quantitative (GE Sensing, 2005, p. 17). The manufacturers of the Protimeter instruments claim that measure-mode readings obtained from materials other than timber are 'wood moisture equivalent' (WME) (GE Sensing, 2005, p. 7). However, because brick, stone, plaster, concrete, and other masonry materials are dissimilar, measure-mode readings recorded on them can only be considered relatively (Burkinshaw, 2002, p. 165; Burkinshaw & Parrett, 2003, p. 76).

As an alternative to the Heavy Duty Probe attachment, the measure-mode function can be used with Deep Wall Probes. These probes, shown in Figure 42 below, are 140 mm long and with the exception of their tips are insulated. By drilling small holes into a wall and

inserting the Deep Wall Probes, measure-mode readings can be obtained at depth. Interpretation of the readings obtained is identical to that of the standard two-pin probe.

Figure 42: Protimeter Surveymaster meter: Deep Wall Probes attached.

Protimeter search-mode readings are obtained using a capacitive-coupled sensor located in the back of the instrument, which is placed against the material under test, as illustrated in Figure 43 below. When used on solid, homogenous materials, search-mode can scan to depths of 15 mm or 19 mm using the MMS or Surveymaster models respectively (GE Sensing, 2005, p. 5; 2009, p. 3). Search-mode readings are provided as integers in the range of 0-1000 or 60-999[24] but these values are not quantitative and can only be compared relatively (GE Sensing, 2005, p. 5).

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[24] The Protimeter search-mode scale is 0-1000 for the MMS model and 60-999 for the Surveymaster model. The small numerical difference at each end of these two ranges is academic.

Figure 43: Protimeter Surveymaster meter: search-mode function.

Electronic meters offer a means of testing for moisture that is none invasive, quick, and easily repeatable. Despite these advantages, there are two reasons why caution is required. Firstly, Protimeter electronic moisture meters are calibrated for use on timber: readings obtained from masonry and plaster materials are not quantitative and can only be considered relatively (Burkinshaw, 2002, p. 165; Oliver, Douglas, & Stirling, 1997, p. 264). Secondly, the meters are technically measuring electrical resistance and will therefore respond to any form of moisture or any electrical conducting substance (Burkinshaw, 2002, p. 162; Oliver, Douglas, & Stirling, 1997, p. 264).

It is for this latter reason that the measure-mode and search-mode functions can return high values on certain materials that may not necessarily be damp or which are contaminated with hygroscopic salts (Burkinshaw, 2002, p. 171). Given that the walls of the project's house are, by design, expected to be affected by rising damp then

hygroscopic salts of chlorides or nitrates must be present and are expected to affect the values of any readings obtained using a Protimeter.

I am experienced in the use of electronic moisture meters and am fully aware of their inherent limitations and the potential for hygroscopic contamination or electrically conducting materials to result in anomalous readings. Consequently, such confounds will be accounted for where Protimeter functions are used to monitor moisture change. Nevertheless, it would be preferable if this project could make use of moisture monitoring equipment that avoids or at least mitigates the effect of hygroscopic contamination. To this end, the two final techniques presented below, electronic thermo-hygrometers and Timber Probes Type 1, measure moisture in ways that differ from the direct measurement of masonry utilised by the Protimeter. How effective these methods will prove to be in practice offers an interesting aspect to this moisture monitoring exercise.

4.7.4. *Protimeter Hygrostick and Lascar electronic thermo-hygrometers*

The Protimeter MMS meter can be used with several plug-in attachments: the Heavy Duty and Deep Wall Probes discussed above, a surface temperature thermometer, and a Hygrostick. It is the Hygrostick sensor that is of interest here because when attached it converts the Protimeter MMS meter into an electronic thermo-hygrometer, enabling it to measure the relative humidity and temperature of air.

A Hygrostick is not used to directly measure the moisture content of a masonry wall; instead, it is inserted into a hole drilled into the wall's surface. The logic behind this technique is that the relative humidity of the pocket of air within the drilled hole will equilibrate with the moisture content of the surrounding wall (Burkinshaw, 2009, p. 190). Thus, monitoring variations in the relative humidity measured by the Hygrostick enables changes in the moisture content of the wall to be tracked. Burkinshaw (2010, p. 9) found electronic thermo-hygrometers to offer a reliable method of measuring and monitoring the moisture change in masonry using the equilibrium relative humidity

(ERH) technique, and others have suggested that this method is suitable for this purpose (Bagg, 2006).

Hygrosticks are not embedded directly into a wall but require the installation of proprietary Humidity Sleeves. A process that involves drilling a 16 mm diameter hole, approximately 45 mm deep, into the surface, inserting the Humidity Sleeve, and sealing its outer end with a removable, plastic cap (Burkinshaw, 2009, p. 190; GE Sensing, 2005, p. 20). The Protimeter Hygrostick and Humidity Sleeve, with its end cap removed, are shown in Figure 44 below.

Figure 44: Protimeter Hygrostick, Humidity Sleeves and Humidity Sleeve's endcap.
The plastic body of the Humidity Sleeve is perforated by a series of slots. When its end cap is fitted, these slots enable moisture vapour evaporating from the surrounding masonry to equilibrate with the air inside the sleeve.

The Humidity Sleeve is designed to enable moisture present in the surrounding masonry wall to mix with the pocket of air it contains. To determine the relative humidity and

temperature of this pocket of air, the Humidity Sleeve's end cap is removed, and a Hygrostick attached to the Protimeter MMS meter with a proprietary extension lead is inserted into it, as illustrated in Figure 45 below. Hygrosticks require time to equilibrate with the air in the Humidity Sleeve and are therefore required to be inserted thirty to sixty minutes before readings can be taken (Burkinshaw, 2009, p. 191; GE Sensing, 2005, p. 19).

Figure 45: Protimeter MMS meter reading a Hygrostick inserted into a Humidity Sleeve embedded in a masonry wall.

Hygrosticks would appear to provide a mechanism for monitoring moisture change via variations to the ERH in the Humidity Sleeves; however, relative humidity is a function of temperature (BSI, 2011, p. 3; Burkinshaw, 2009, p. 190); consequently, there is a significant concern in using this method to extrapolate moisture contents, which is explained as follows.

If, for example, a series of Hygrostick readings revealed the relative humidity within the Humidity Sleeve to have a downward trend, by extension, the moisture content of the surrounding wall would be assumed to have fallen. But this is a flawed conclusion. Relative humidity is a function of temperature, so a fall of this property may simply be caused by an increase in temperature. Conversely, a drop in temperature will see a rise in relative humidity and this temperature effect will occur independently of any moisture changes in the wall. It is for this reason, that some have criticised the use of relative humidity as a mechanism for the measurement of moisture in walls (Remedial Technical Services, 2010).

Interestingly, Rirsch and Zhang (2010, p. 5) had planned to use ERH in their research on rising damp. Yet, they subsequently reported that although analyses of the temperature data from the electronic thermo-hygrometers yielded some useful findings, this was not the case for the relative humidity, which did not reveal any discernible pattern (Rirsch & Zhang, 2010, p. 5).

The criticism of the ERH method and the potential for erroneous relative humidity data to result simply from changes in temperature cannot be ignored. In essence, the inherent variability of relative humidity as a result of temperature change means that it is a potential confounding variable. There is, however, a simple technique to eliminate this effect.

This solution requires each pair of relative humidity and temperature readings to be converted into vapour pressures. BS 5250 (2011, p. 3) defines vapour pressure as "that part of atmospheric pressure which is due to the presence of water vapour." The temperature of air determines the maximum amount of water vapour that it may contain and thus its vapour pressure (BSI, 2011, p. 20): warmer air may have higher vapour pressure than cooler air (Mujumdar, 2015, pp. 5-6); however, vapour pressure is not a function of temperature.

The relationship of relative humidity, temperature, and vapour pressure is illustrated in the Psychrometric chart shown in Figure 46 below, which uses the example of air at a temperature of 20°C and relative humidity of 60% that equates to a vapour pressure of 1.40 kPa. Lowering the air temperature to 15°C has the effect of raising the relative humidity to 82%, but the vapour pressure remains unchanged at 1.40 kPa.

This model illustrates how a consideration of relative humidity alone, if monitoring moisture change in a masonry wall using the electronic thermo-hygrometer method, suggests a 22% increase had occurred when, as the vapour pressure value clearly indicates, the moisture content of the air is actually unchanged.

Thus, the conversion of temperature and relative humidity data pairs to vapour pressures provides a mechanism to monitor moisture change. It is a method that will be incorporated in this project, primarily to determine its effectiveness for this purpose, but it has the potential to add further interest to this study.
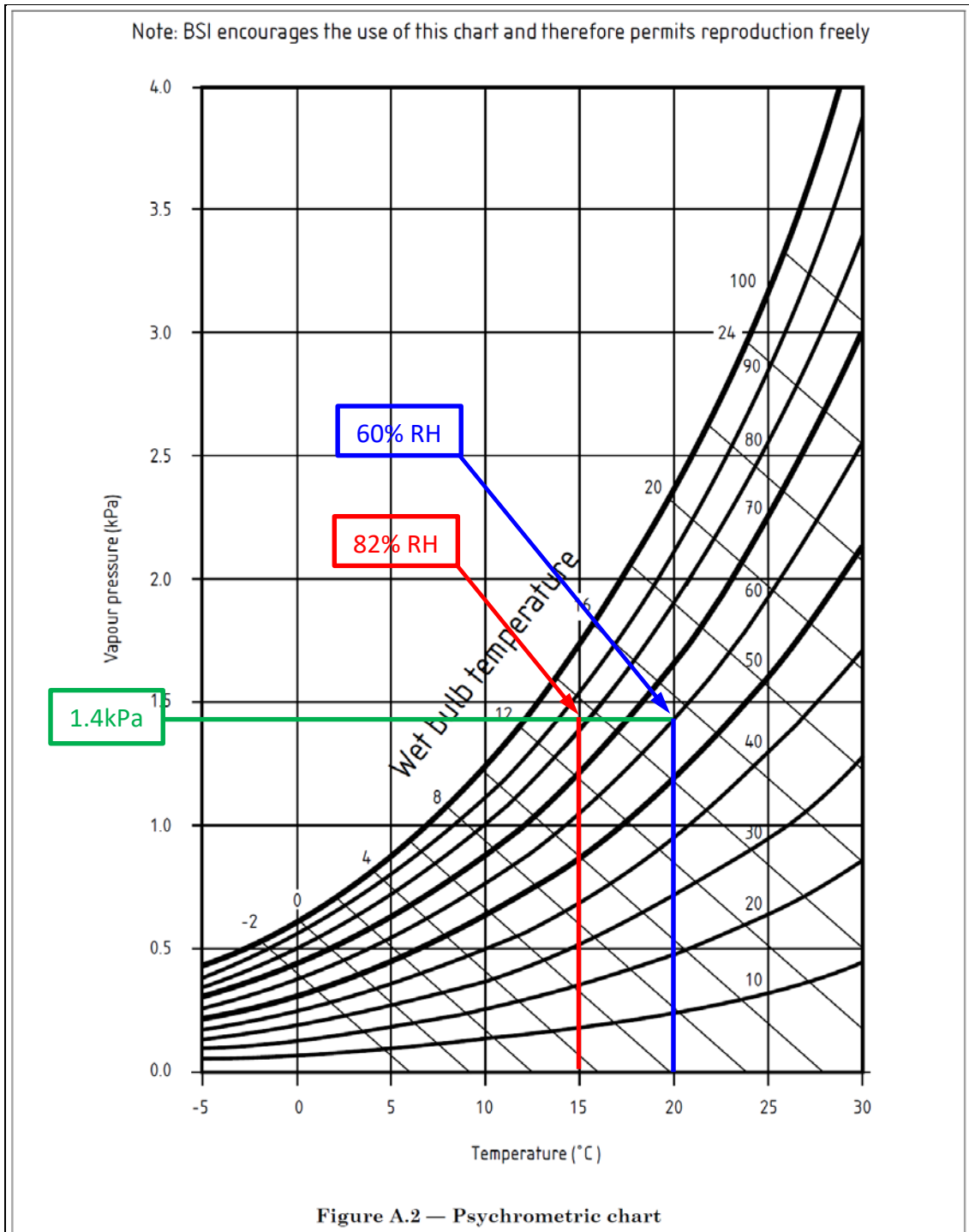
Figure 46: Psychrometric chart (Adapted from BSI, 2002, p. 69).

Vapour pressure is typically higher on the warmer side of a wall and therefore will be greater inside a heated dwelling (BSI, 2011, p. 14). And because vapour moves from high to low pressure areas, there is a tendency for moisture inside a dwelling to diffuse into external walls, potentially raising the moisture content through interstitial condensation

(Oliver, Douglas, & Stirling, 1997, pp. 153-154). Given this phenomenon, it would be useful, in addition, to measure and to compare the vapour pressures outside the house, inside the house, and in and at the boundary layer of the test panels.

The Hygrosticks are to be used to obtain data from within the test panel walls; the vapour pressures inside and outside the house and at the boundary layer of the panels will be calculated from data measured by Lascar ELB-USB-2+ data loggers, the device shown in Figure 47 below.
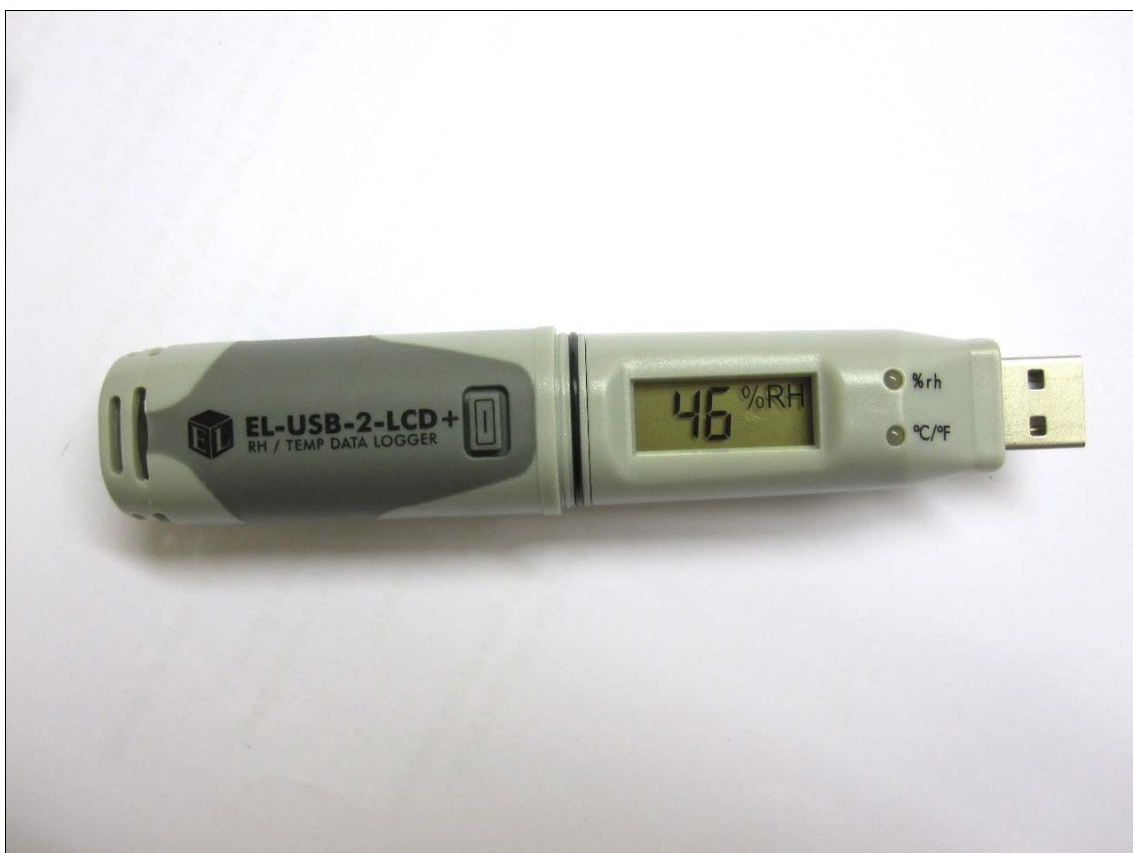
Figure 47: Lascar EL-USB-2+ humidity, temperature, and dew-point data logger.

Lascar data loggers, like Hygrosticks, are electronic thermo-hygrometers that measure air temperature and relative humidity. These data can be read from these standalone instruments as spot readings but the data loggers are programmable to enable automatic recording. On one end of the Lascar data logger is a USB attachment, which allows the instrument to be connected to a computer. Proprietary software, supplied by

the manufacturers, enables the data loggers to be programmed and, subsequently, for the data they record to be downloaded for analyses.

The Lascar data loggers were configured to measure air temperature and relative humidity automatically on each hour throughout the data collection phase, and these data were converted into vapour pressures during processing.

4.7.5.   Timber Probes Type 1

The precise moisture contents of the test panels will be determined using gravimetric analyses, which, as discussed earlier, although accurate, is not a practical method for monitoring purposes. Instead, monitoring is to be facilitated using the Protimeter measure-mode, search-mode, and Hygrostick functions; however, there are concerns.

The purpose of monitoring is to observe changes in the moisture content of the test panels. Provided that variations can be identified, a high degree of accuracy is not essential; nevertheless, it is clearly beneficial if moisture values are as accurate as possible and reflect the trend independently of the confounding influence of hygroscopic salt contamination.

As explained earlier, Protimeters are not specifically calibrated for masonry and values recorded using the measure-mode and search-mode functions are influenced by hygroscopic salts. In addition, extrapolating from the environmental properties of a pocket of air measured by the Hygrosticks to predict the moisture content of the surrounding masonry wall is, essentially, untested. Still, the speed, simplicity, and repeatability of the Protimeter does offer advantages with respect moisture monitoring. What is needed is a method that takes advantage of these strengths while mitigating the Protimeters' weaknesses.

The measure-mode function is able to provide quantitative moisture readings in timber within a range of 8-29% (GE Sensing, 2005, p. 17). Thus, a method that used timber to track the moisture content of a masonry wall could provide a solution.

Ridout (2000, p. 165) found that embedding timber dowels in damp walls offered a useful mechanism for monitoring rising damp. Following insertion, the moisture content of these dowels equilibrated with the masonry and their moisture content could be measured using the measure-mode mode function of the Protimeter. It is questionable that this method could provide precise measurement of moisture affecting the masonry, but it would reveal moisture changes in the timber dowels and, by extension, moisture variation in the test panels.

Prior to the start of this project, three types of timber probe, Type 1, Type 2, and Type 3, were designed and tested in a pilot study. All three types were constructed of 9 mm diameter softwood dowels with an arbitrary length of 50 mm, but their operation differed.

Timber Probes Type 2 and Type 3 were designed to be installed into an oversized hole drilled into the wall surface. The ends of their dowel bodies had been fitted with plastic spacers, as shown in Figure 48 and Figure 49 below, to ensure that they did not directly contact the surrounding masonry and therefore that they only absorbed moisture from the pocket of air within their accommodating hole
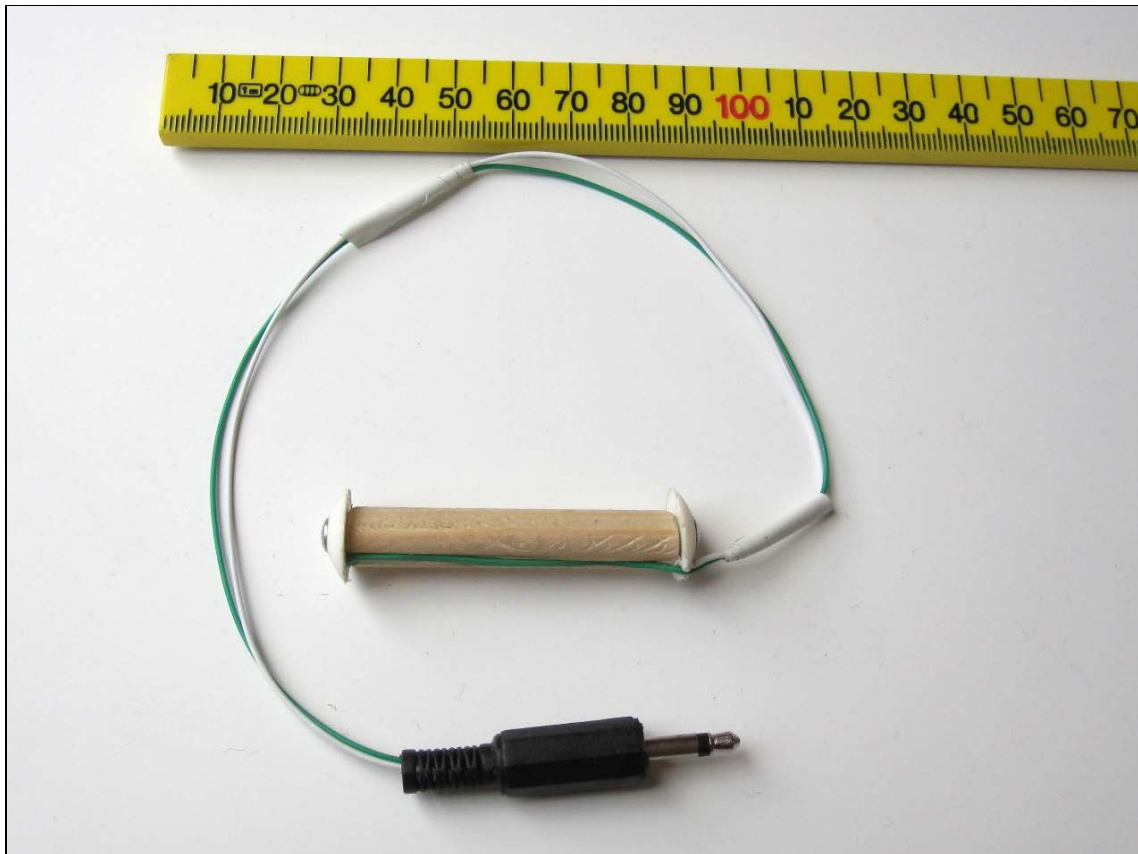
Figure 48: Timber Probe Type 2.

The plastic end spacers of the Type 3 probe ensure that its dowel body cannot directly contact the sides of the holes into which it is inserted. The 3.5 mm jack plug facilitates direct reading using the Protimeter's measure-mode function.

Figure 49: Timber Probe Type 3.

The plastic end spacers of the Type 3 probe ensure that its dowel body cannot directly contact the sides of the holes into which it is inserted. The attached wire is only to facilitate removal of the Type 3 probe from its accommodating hole for weighing.

Essentially, the Type 2 and Type 3 probe made use of the Hygrostick technique with the assumption that the moisture content of the pocket of air in the hole they were inserted would equilibrate with that of the surrounding masonry: changes to the former reflecting changes in the latter.

In contrast, the Type 1 probe, shown in Figure 50 below, was designed to be inserted into a smaller hole so that its dowel body was in contact with and would therefore absorb moisture directly from the surrounding masonry.
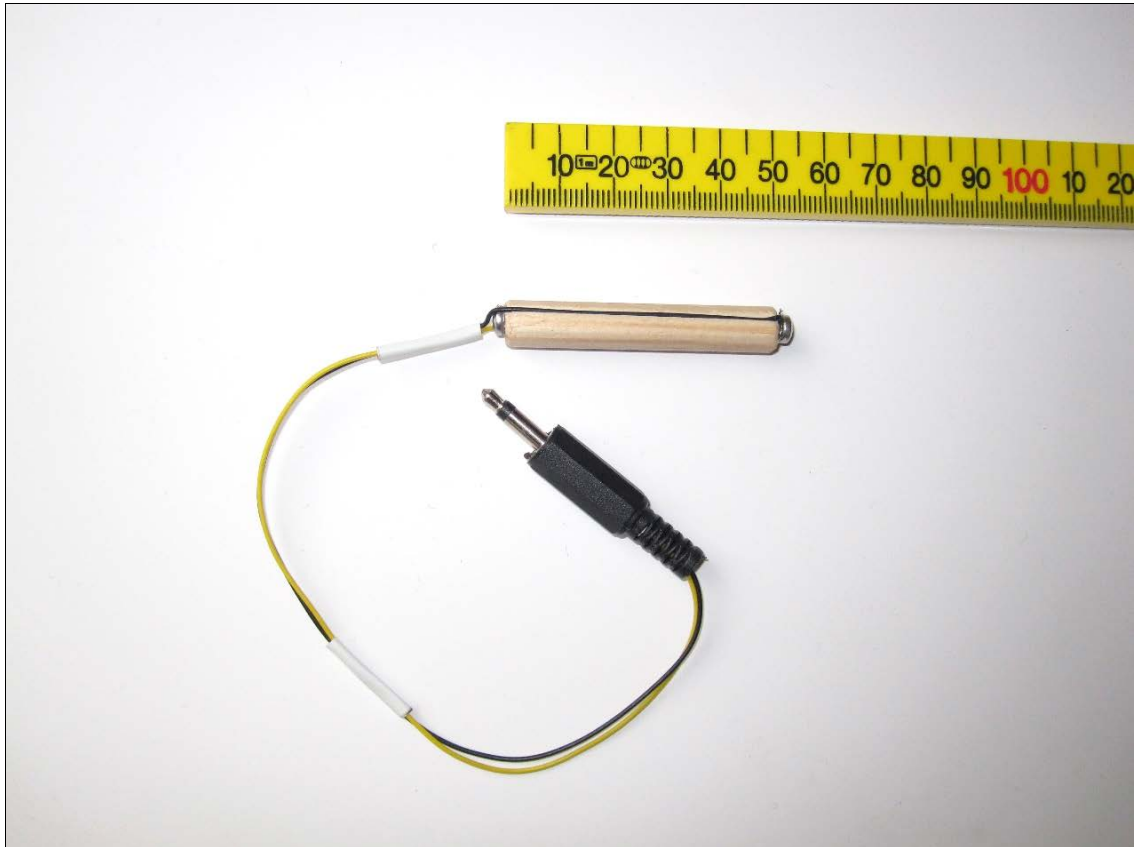
Figure 50: Timber Probe Type 1: prototype.

The plastic spacers are omitted from the Type 1 probe design to enable the dowel body to directly contact the sides of the holes into which it is inserted. The 3.5 mm jack plug facilitates direct reading using the Protimeter's measure-mode function.

The moisture content of the Type 1 and Type 2 probes is obtained using the measure-mode function of the Protimeter. This was made possible by attaching an insulated electrical wire with 13 mm long, stainless steel screws (to avoid corrosion in the damp environment) to each end of their dowel bodies. The configuration of the screws meant that the distance between their internal ends was 25 mm, precisely replicating the spacing between the needles of the Protimeter Heavy Duty Probe, as illustrated in Figure 51 below. The outer ends of each wire pair was terminated with a standard 3.5 mm jack plug that can be plugged directly into a Protimeter.

Figure 51: Timber Probes Type 1 & 2: screw configuration.

This unassembled probe illustrates that, once inserted, the internal ends of the two 13 mm long, stainless steel screws, which secure the connecting wires (not shown), essentially replicate the 25 mm spacing of the needles of the Protimeter Heavy Duty Probe.

The Type 3 probe was not read with the Protimeter; instead, it was oven dried and weighed before installation. To track moisture change, this probe was periodically removed from its accommodating hole and additional weighings made. These weights were converted into percentage moisture contents using Equation 4, Equation 5, and Equation 6, described earlier: the formulas from BRE Digest 245 (Trotman, 2007, p. 11).

The pilot study found Timber Probe Type 1 to provide the best results for monitoring moisture change. It is this probe that is used in this research project; however, the final version of the Type 1 probe did receive three minor modifications: the wires were lengthened to better facilitate attachment to a Protimeter; the wires were twisted to add strength; and the two screws securing the wires to the dowel body were

countersunk and covered with butyl rubber tape to ensure that they could not inadvertently make contact with the surrounding masonry. This final version of the Timber Probe Type 1 is shown in Figure 52 below.

Figure 52: Timber Probe Type 1: final design.

In this final design, the stainless steel screws securing the wires to the dowel body are recessed and sealed with butyl tape to prevent inadvertent short circuits. The wires have been lengthened and twisted together for convenience and added strength. In all other respects, the final design of Timber Probe Type 1 is identical to the prototype.

Two issues that were as yet undetermined with respect to embedding Timber Probes Type 1 into damp and hygroscopic salt contaminated masonry over an extended monitoring period were the potential for decay to affect the dowel body and for these salts to influence the values recorded using the Protimeter measure-mode function. Given that this is a real world study, testing for these concerns added interest to the

project; consequently, no precautions were to be taken to mitigate decay[25] and the study's findings would ultimately show if either of these concerns were valid.

4.8. Data types, validation, and presentation

The foregoing has described the techniques that are to be used to measure and monitor moisture change in the test panels. Chapter 5 explains how specific wall parts were allocated to each of the five test panels, and Chapter 6 describes the test panel setup, the configuration of the moisture monitoring apparatus, the treatment types and application, and the data collection protocol. Data also concerns the remainder of this chapter; specifically, the types to be collected, their validation measures, and how they are to be presented in the results.

The types of data that will be collected are summarised in the following list:

1. For each of the samples removed from the test panels:

    1.1. W_w: weight 'as found' (i.e. the weight of the sample when obtained);

    1.2. W_{75}: weight after processing at 75% relative humidity;

    1.3. W_d: weight after oven drying.

2. By spreadsheet calculation using the weights obtained in 1.1, 1.2, and 1.3 above:

    2.1. HMC: Hygroscopic moisture content;

    2.2. CMC: Capillary moisture content;

    2.3. TMC: Total moisture content.

3. Protimeter measure-mode readings obtained from the following materials:

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[25] The risk of decay can be mitigated by treating the timber dowel with a suitable fungicidal preservative prior to installation (Ridout, 2000, p. 165).

3.1. Surface of the panels;

3.2. Masonry at depth in the panels (using Protimeter Deep Wall Probes);

3.3. Dowel bodies of Timber Probes Type 1.

4. Protimeter search-mode readings from the surface of the panels;

5. From the Protimeter Hygrosticks using the Protimeter MMS moisture meter:

5.1. Relative humidity;

5.2. Temperature;

6. By spreadsheet calculation using the Hygrostick relative humidity and temperature pair sets obtained in 5.1 & 5.2 above:

6.1. Vapour pressure;

6.2. Vapour pressure delta (internal minus external vapour pressures);

7. From the Lascar data loggers at each data collection visit:

7.1. Relative humidity;

7.2. Temperature;

8. From the Lascar data loggers on each hour throughout the data collection phase[26]:

8.1. Time and date stamp;

8.2. Relative humidity;

8.3. Temperature;

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[26] Lascar data loggers can be programmed to record data automatically.

9. By spreadsheet calculation using the Lascar relative humidity and temperature pair sets obtained in 7.1 & 7.2 and 8.2 & 8.3 above:

    9.1. Vapour pressure;

    9.2. Vapour pressure delta (internal minus external vapour pressures).

In practice, these data types can be placed into five distinct groups:

1. Weights of samples determined during gravimetric analyses;

2. Protimeter values of measure-mode, search-mode, relative humidity, and temperature;

3. Lascar data logger values of relative humidity and temperature;

4. Calculation of hygroscopic, capillary, and total moisture contents derived from the sample weights;

5. Calculation of vapour pressures and vapour pressure deltas derived from the relative humidity and temperature pair sets.

All of the data in these five groups are numeric and quantitative. Their descriptions, the unit of measure, and an example of each type are shown in Table 1 below.

Instrument or process	Data type description	Unit	Example
Weigh samples	W_w: as found weight	mg	11.176 mg
	W_{75}: 75% RH weight	mg	11.019 mg
	W_d: dry weight	mg	10.990 mg
Protimeter values	Measure-mode	%	49.3%
	Search-mode	Integer	840
	Relative humidity	%	73.3%
	Temperature	^{O}C	16.6 ^{O}C
Lascar data logger values	Relative humidity	%	68.0%
	Temperature	^{O}C	19.2 ^{O}C
Calculation	Hygroscopic moisture content	%	1.6%
	Capillary moisture content	%	7.9%
	Total moisture content	%	9.5%
	Vapour pressure	kPa	2.23 kPa
	Vapour pressure delta	kPa	1.10 kPa

Table 1: Data types, units of measure, and examples.

Validation of the above data will be achieved, firstly by undertaking regular checks to verify the accuracy of the moisture measuring equipment and, secondly, by triangulating from multiple sources, a procedure that is more robust than reliance on any single data source (Yin, 2012, p. 13).

Apparatus checks are straightforward and are described below with respect to the equipment and techniques that will be used for gravimetric analyses, the Protimeter moisture meter functions, electronic thermo-hygrometer sensors (i.e. the Protimeter Hygrosticks and Lascar data loggers), and for transcribing and processing data.

4.8.1. Data validation: gravimetric analyses

To obtain the weights of samples for gravimetric analyses requires watch glasses or similar to hold each sample, an electronic milligram balance, a desiccator containing a saturated solution of sodium chloride (i.e. common salt), and a laboratory drying oven. This gravimetric process is documented in BRE Digest 245 (2007, p. 11) and was described earlier in this chapter.

The electronic balance is checked before each use with test weights and if necessary recalibrated before each stage of weighing.

The air within the desiccator (i.e. above the saturated salts solution) can be verified to be at 75% relative humidity by placing a Hygrostick or Lascar data logger inside this vessel and allowing the instrument to equilibrate for a few hours. A more robust technique, applying the principals of triangulation, is to place several sensors in the desiccator at the same time and thus to obtain device independent confirmation of the relative humidity.

The laboratory drying oven, a Heraeus Instruments model UT6P, is fitted with a digital thermostat, allowing the precise temperature to be selected. This temperature is easily verified by placing a thermometer in the oven. In practice, it is not the precise temperature that is important when drying samples, but only ensuring that excessively high temperatures are avoided and thus that water of crystallisation is not inadvertently lost.[27]

The gravimetric moisture analysis method requires the samples' weights to be taken at three separate stages of the process:

1. W_w: 'as found' weight (i.e. the weight of the sample when obtained);

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[27] The oven temperature is set to be no higher than 50°C to ensure controlled drying.

2. W_{75}: following processing at 75% relative humidity;

3. W_d: following oven drying.

The W_{75} and W_d values are not determined by single weighings; instead, check weights are recorded during 75% RH processing and oven drying. The final values are determined when two consecutive weighings confirm that the sample's weight has stabilised.

4.8.2. *Data validation: Protimeter measure-mode and search-mode functions*

Protimeters are supplied with a proprietary calibration check device, a Calcheck, which comprises a metal wire secured in a small plastic holder. To test the Protimeter's calibration, the built-in needles or those of a connected probe are placed in contact with the metal wire of the Calcheck tool. The Protimeter is correctly calibrated if the displayed reading is in the range of 18.2 ± 1.0, as illustrated in Figure 53 below (GE Sensing, 2009, p. 8). Thus, checking the accuracy of the Protimeter measure-mode function simply requires this test to be undertaken before each use.

Figure 53: Protimeter Surveymaster meter: calibration using Calcheck tool.

Checking the calibration of the Protimeter Surveymaster using the proprietary Calcheck tool. The display readout is 18.2 which falls within the acceptable range of 18.2 ± 1.0 stipulated by the meter's manufacturers. Calibration checks carried out on the Protimeter instruments used for the study were consistently in the range of 18.1-18.3.

The Protimeter search-mode function is checked against a reference wall: essentially, an area on a wall that is in a stable condition and does not contain pipes or wires (i.e. metallic items) (GE Sensing, 2005, p. 16; 2009, p. 8). The upper rows of each of the test panels will essentially serve as reference walls because, by design, this region of the panels will be unaffected by moisture or hygroscopic salts and will not contain hidden services. In practice, adding each set of values into an expanding database effectively creates a historical data set against which future readings can be compared and thus verified.

4.8.3. Data validation: relative humidity

Instruments that measure relative humidity, such as the Protimeter Hygrosticks and Lascar data loggers, can be checked for calibration by placing them in the desiccator containing the saturated solution of sodium chloride (GE Sensing, 2005, p. 16). This, technique works well with respect to the standalone Lascar data loggers but because Hygrosticks need to be connected to a Protimeter to obtain readings is not as efficient for these sensors. Instead, a simple test apparatus, constructed by drilling holes in the sides of a plastic container into which the Hygrosticks can be inserted above a saturated salts solution, as illustrated in Figure 54 and Figure 55 below, is both far more practical and enables batch testing (Burkinshaw, 2009, p. 194).

The stock of Hygrosticks were rotated to enable periodic testing and, by moving each from one panel location to another, ensuring that they are not permanently embedded in damp masonry.

Figure 54: Hygrostick batch testing apparatus shown without lid.

Figure 55: Hygrostick batch testing apparatus with Protimeter MMS meter attached.

This small plastic container was used for batch testing the Hygrosticks. In its base is a saturated solution of sodium chloride which provides the required 75.0% relative humidity environment when the container is sealed.

The Hygrosticks are pushed through 12 mm diameter holes drilled into the container's sides; the probe's tapered shape and rubberised surface provides an airtight seal.

The container accommodates eight Hygrosticks. In this example, only four are undergoing test. The unused holes on the rear and right-hand sides of the container are temporarily sealed with butyl tape.

The Hygrosticks are left in place for a few hours, typically overnight, and their relative humidity and temperature values subsequently read with a Protimeter MMS meter that is attached to each probe in turn using the proprietary extension lead as shown.

Hygrostick reference H33 is currently being read: its relative humidity, shown on the meter's display, is 73.7% which falls within the allowable tolerance of 75.0% ±2.0% for these sensors (GE Sensing, 2005, p. 17).

4.8.4. Data validation: triangulation

Triangulation is to be used to validate data and will essentially take two forms: 'methodological triangulation', whereby moisture measured through one method is verified against that measured by another, and 'triangulation by time', which is achieved by repeating the measurements over the duration of the data collection phase and, through patterns that will become established, enabling erroneous data to be identified (Alasuutari, Bickman, & Brannen, 2008, p. 222). In addition, as will be described in

Chapter 6, multiple rows of the moisture measuring apparatus will be installed in each test panel, and, therefore, values from one row can be verified with those from another.

4.8.5. *Data validation: transcribing and processing data values*

Technically, it would have been possible to create a spreadsheet and using a laptop computer to input values from the moisture measuring apparatus directly into it, during each data collection visit to the house. However, this strategy creates two issues: firstly, there is the potential to enter a value incorrectly and with no other record of these data, no means for later verification; and, secondly, there is no opportunity for reflection using a direct input method.

It is for these reasons that values recorded during the data collection phase are to be entered manually on paper forms created for this purpose. This protocol means that a permanent, handwritten record of every value will be retained and available for future reference. Of course, this does not avoid the potential for values to be entered on the form incorrectly. This issue will be managed by careful checking and by establishing a systematic protocol of data collection, whereby, the method used will be replicated at each site visit.

On completion of each data collection exercise, the handwritten values will be entered into a Microsoft Excel Workbook containing individual sheets set up to process these data. Again, there is the potential, for values to be entered in error. This will be managed through careful, systematic checks and, where necessary, through reference to the handwritten sheets.

The Excel workbook will have identically configured spreadsheets for each of the five test panels into which the values obtained from the moisture measuring apparatus will be entered, along with separate spreadsheets to facilitate gravimetric analyses.[28]

The primary use of the results workbook is to record and process the data values; therefore, algorithms are required to calculate the moisture contents derived through gravimetric analyses; to calculate vapour pressures and vapour pressures deltas from relative humidity and temperature data pair sets; and to undertake descriptive statistics.

The formulas to calculate the total, hygroscopic, and capillary moisture contents from the measured weights, which were described for Equation 4, Equation 5, and Equation 6 earlier in this chapter, are sourced from BRE Digest 245 (Trotman, 2007, p. 11).

The formulas to calculate the vapour pressures are sourced from BS 5250:2011 'Code of practice for control of condensation in buildings' (2011, p. 22) and are described in Equation 7 and Equation 8 below:

Equation 7

$$SVP = 0.6105exp\left(\frac{17.269T}{237.3+T}\right) \text{ (for T≥0°C)}$$

Where:

SVP = saturated vapour pressure.

T = dry bulb temperature in °C (i.e. air temperature).

(BSI, 2011, p. 22)

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[28] During data collection, some additional methods of moisture measurement were introduced and the spreadsheets updated to suit these changes. Ultimately, there were some minor differences in the configuration of the five test panels and thus their results spreadsheets, but these modifications were not significant and did not affect the formulas or the methods used for calculation.

Equation 8

$$\varphi = 100\,\frac{\rho}{SVP(Td)}$$

Where:

φ = % relative humidity.

ρ = vapour pressure.

$SVP(T_d)$ = saturated vapour pressure at dry bulb temperature in °C (i.e. the product of the SVP equation).

(BSI, 2011, pp. 22,23)

Equation 8 can be transposed, as shown in Equation 9 below, to provide the vapour pressure from the saturated vapour pressure and % relative humidity:

Equation 9

$$\rho = SVP(Td)\,\frac{\varphi}{100}$$

Where:

ρ = vapour pressure

To use Equation 9 to calculate vapour pressure in the Excel results workbook it was converted into the algorithm shown in Equation 10:

Equation 10

$$((0.6105*EXP((17.269*T)/(237.3+T)))*(\varphi/100))$$

Where:

T = recorded air temperature in °C.

φ = recorded % relative humidity.

Calculation of the vapour pressure delta is a simple subtraction of the external vapour pressure from the internal vapour pressures.

All algorithms and other formulas used in the spreadsheets were carefully entered and tested to verify their accuracy. Once this testing was complete, there was far less likelihood of an error when using a spreadsheet than there would be if each calculation or process was undertaken by hand.

Standard Excel functions were used for descriptive statistics and to produce tables and charts for the presentation of results.

4.9. Project programme

To conclude this chapter, this final section provides a summarised project programme in the form of a tabulated summary, shown in Table 2 below, which identifies the major milestones.

Project stage	Project activity
Stage 0	House selection and initial assessment for suitability.
Stage 1	Preliminary moisture analyses.
Stage 2	Full moisture profiling.
Stage 3 Step 1	Test panel setup: panel treatment initial phase.
Stage 3 Step 2	Test panel setup: install moisture measuring apparatus.
Stage 3 Step 3	Test panel setup: base line moisture analyses.
Stage 3 Step 4	Test panel setup: panel treatment final phase.
Stage 4	Data collection phase.
Stage 5	Conclusion of on-site work and final moisture analyses.
Stage 6	Data processing and results preparation.
Table 2: Project programme.	

Project Stages 1 and 2 are the topics of the next chapter.

Chapter 5

Determining the Existence of Rising Damp

5.1. Introduction

This chapter describes the process used to confirm those assumptions drawn from the initial, non-invasive survey; namely, that rising damp did indeed affect the ground floor walls of the house and, in doing so, to satisfy research objective 4.

Rising damp creates a moisture profile that has four distinct characteristics:

1. Capillary moisture in the wall base is higher than that in the masonry above;

2. The capillary moisture content falls abruptly directly above the highest point of damp rise (the vertical position on the wall referred to by Hall and Hoff (2012, pp. 256-257) as the Sharp Front);

3. Hygroscopic moisture content is highest towards the uppermost region of the damp rise in comparison to that in the base of the wall (Coleman, 1990, pp. 15-22; Kyte, 1987, p. 312; Trotman, 2007, pp. 5-6).

4. Hygroscopic soil salts become concentrated at the upper limits of the damp rise, a region referred to as the salt band (Alfano, Chiancarella, Cirillo, et al., 2006, pp. 1060-1061; Coleman, 1993, p. 6; Kyte, 1997, pp. 5-8; Safeguard Europe Ltd., 2007, p. 5).

This part of the project employed the gravimetric method of moisture analysis set out in the appendix to BRE Digest 245 (2007, pp. 11-12) and described in Chapter 4 and was undertaken in two stages. Stage 1 was to be preliminary analyses to broadly establish if excessive quantities of capillary moisture were present in the base of the ground floor walls and in the absence of other tangible reasons that rising damp was likely to be

occurring. Assuming Stage 1 yielded positive results, Stage 2 would involve far more comprehensive moisture profiling to determine if the distribution of capillary and hygroscopic moisture present in the walls was consistent with the rising damp model.

For the moisture analyses to provide meaningful results, plaster and masonry samples needed to be taken from ground floor wall parts that would ultimately be included as one of the five individual test panels. The remainder of this chapter describes the protocol used to allocate the test panels to specific ground floor wall parts and the procedure and results of the Stage 1 and Stage 2 moisture analyses. Comprehensive details with respect to the precise configuration of the test panels is subsequently provided in Chapter 6.

5.2. Allocation of test panels to ground floor wall parts

Ideally, the five test panels would be located on one continuous section of ground floor wall, thus providing panels of identical masonry construction and condition. However, each panel needed to have a minimum width that was not only sufficient to accommodate the moisture measuring apparatus but also ensured that the region where this equipment was located, its vertical centre line, could not be influenced by treatments applied to any adjacent panel. In addition, the potential for the panels' moisture content to be affected by such factors as rain water penetration, condensation, hygroscopic salts in excess of those associated with rising damp, or unknowable or unseen conditions meant that external walls, party walls, and walls that formed fireplaces were considered unsuitable.

These criteria effectively restricted the choice of test panel locations to three internal dividing walls: living room / kitchen (i.e. the living room rear wall); understairs cupboard / kitchen (i.e. the understairs cupboard right-hand side wall); and living room / front lobby.

All of these internal walls shared the same 110 mm, half-brick thick construction, but none were of sufficient length to accommodate all five test panels. The living room rear wall had a nominal length of 2.9 metres, but a redundant flue, located in the kitchen at its right-hand end, reduced its effective length to 2.4 metres. The understairs cupboard right-hand side wall had a nominal length of 2.1 metres and, like the living room rear wall, it formed a dividing wall with the kitchen. The remaining internal wall, which had a nominal length of 1.1 metres, formed a dividing wall between the living room and an unheated front lobby.

A logical compromise was to make use of the two longest internal walls, allocating three test panels, each 800 mm wide, to the living room rear wall and two test panels, each 1000 mm wide, to the understairs cupboard right-hand side wall. These two internal walls were in close proximity and because both formed dividing walls with the kitchen, would be subject to the same environmental conditions.

To aid identification, each of the five test panels was labelled alphabetically, thus providing the following arrangement, which is illustrated in Figure 56 below:

- Panel A: understairs cupboard; right-hand side wall; rear end.
- Panel B: understairs cupboard; right-hand side wall; front end.
- Panel C: living room; rear wall; left-hand end.
- Panel D: living room; rear wall; mid-section.
- Panel E: living room; rear wall; right-hand end (excluding the redundant flue).

The allocation of treatments to specific test panels is described in Chapter 6, but with their size, location, and reference having been defined, the preliminary, Stage 1 moisture analyses could commence.

OUTBUILDING

OUTBUILDING

UNDERSTAIRS CUPBOARD

PANEL A

PANEL B

KITCHEN

Redundant
flue

PANEL C PANEL D PANEL E

LIVING ROOM

ENT LOBBY
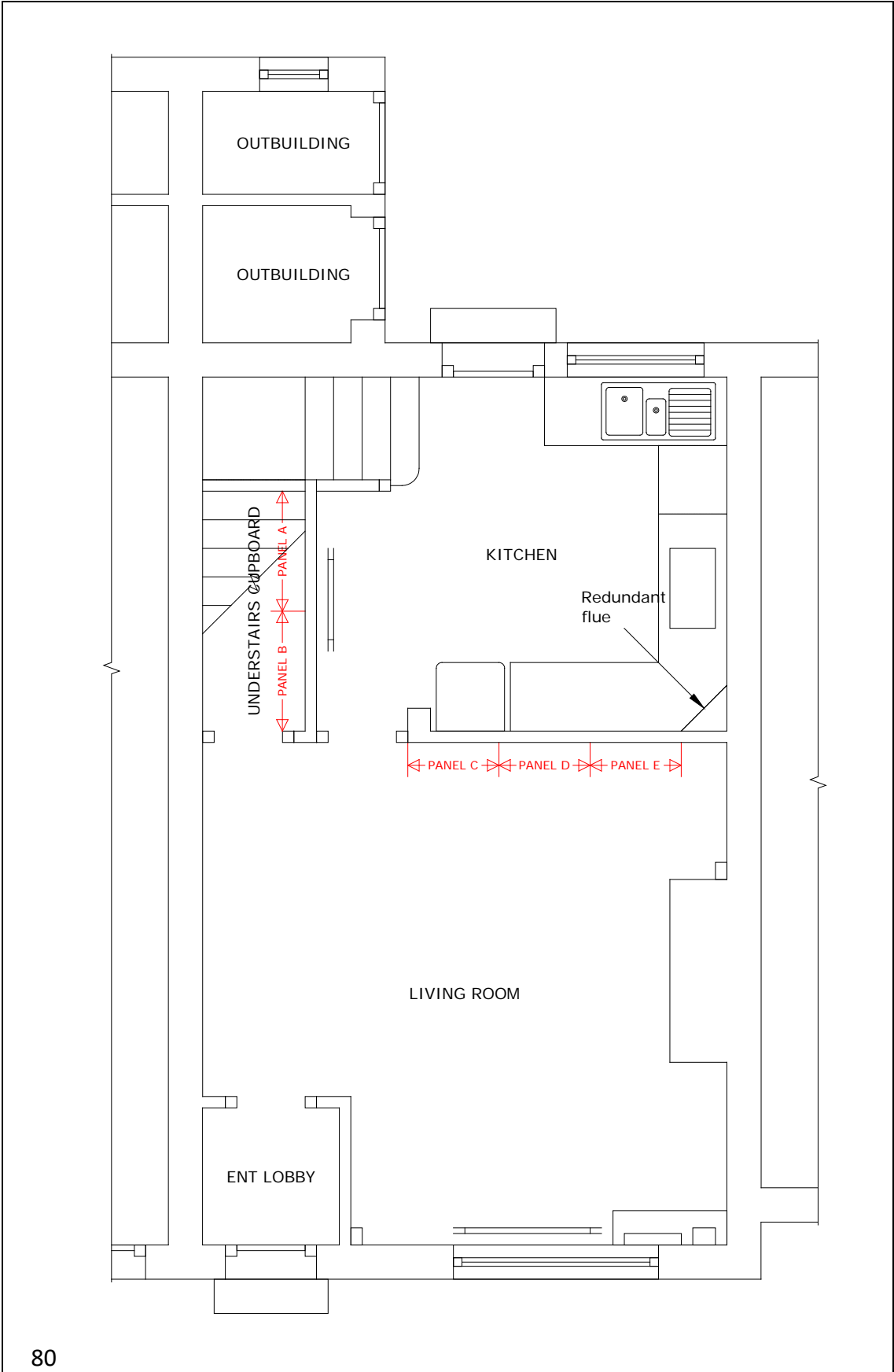
80

Figure 56: Case study house ground floor plan: location of the five test panels.

5.3. Stage 1 moisture analysis: procedure

The aim of Stage 1 moisture analyses was simply to establish if excessive capillary moisture was present in the base of the walls that comprised each of the five test panels. This exercise was to be facilitated through gravimetric moisture analysis of plaster and masonry samples removed from the damp region at the base of each panel.

Technically, moisture analysis may be carried out using samples of brick, mortar, or combinations of these materials, yet the sorptivity of mortar and brick differs because mortars, by design, are inherently weaker and therefore more porous than the masonry units that they bond (Hollis & Gibson, 2005, p. 237). Their higher sorptivity means that mortars will contain higher quantities of water (Coleman, 1990, p. 25; Rirsch & Zhang, 2010, p. 1820). It is for this reason that Trotman (2007, p. 11) recommends that samples used for gravimetric moisture analysis should be taken from the mortar joints.

Interestingly, Hall and Hoff (2012, p. 269) take the opposing view, arguing that in a wall affected by rising damp, the masonry units have the higher moisture content and therefore should be the material sampled. Burkinshaw and Parrett (2003, p. 86), although acknowledging the mortar versus masonry unit sampling debate, suggest that the homogeneity of bricks provide more consistent results, albeit that low levels of moisture in hard, dense masonry units do not necessarily represent that of the mortar joints.

The masonry units used in the construction of the house walls were relatively soft clamp bricks, typically found in buildings of this era in this area of Yorkshire. Consequently, it was excepted that moisture would be detectable in samples removed from the damp region of the walls, regardless of whether they were taken from the brick units or mortar joints. Nevertheless, like for like comparison provides consistency, and it was therefore useful if samples tested comprised the same material. This is a view advocated by Coleman (1990, p. 49), while recognising that pinpointing a particular material in a wall when the underlying masonry is not visible is difficult.

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On the living room rear wall the plasterwork obscured the masonry, so there was no option other than to drill for samples without knowing the precise location of the mortar joints. Rather than chance that this blind drilling might inadvertently provide a variety of sample types, the drill bit was positioned 100 mm above the base of the panels to increase the probability of penetrating the brick unit in the second course.

It was possible that the drill may penetrate a perpendicular mortar joint, but these joints are narrow in comparison with the stretcher face of a standard brick—around 5% of the brick length—and therefore an acceptable risk; in the worst case scenario, should a joint be struck, the sample hole could be re-drilled to one side of the first.

There were no such sampling issues with respect to the base of the understairs cupboard right-hand side wall because the plasterwork, which had previously been hidden by plasterboard dry lining, was discovered to have fallen away, thus exposing the bottom three courses of bricks. Thick deposits of efflorescent salts had accumulated on the face of the third course of these bricks, as shown on Figure 57 below. These efflorescent salts, which are not hygroscopic, essentially confirmed the wall to be damp affected: the salts crystallising on the surface from solution during the evaporation process (Property Care Association, 2007, p. 1).

The absence of plaster at the base of Panels A and B enabled precise positioning of the drill bit in the brick units. For consistency of moisture analyses, where this was possible, future samples would continue to be taken from the brick units rather than the mortar joints.

Figure 57: Understairs cupboard right-hand side wall (location of Panel A) illustrating the construction found behind the dry lining.

With the dry lining removed, the bottom three courses of brickwork were found to be without a plaster finish. Efflorescent salts had formed on the third brick course, suggesting evaporation of moisture and thus that this region of the wall was damp affected.

To penetrate the central portion of the walls, the drill bit was inserted to a nominal depth of 40 mm. For panel positions C, D, and E, located on the living room rear wall, the drillings from the plasterwork portion were kept separate from the drillings obtained from the underlying masonry wall. The colour and texture of these latter sample portions confirmed that, as intended, they had been obtained from brick units.

Unfortunately, the absence of plasterwork at their wall base meant that this sampling procedure was not possible for Panels A and B. Instead, because both the brick units and mortar joints were clearly visible, a sample of the brick and a separate sample of the mortar joint directly above were removed at nominal heights of 120 mm and 170 mm, respectively, above floor level. This method not only enabled the capillary moisture

content at the base of these two test panel bases to be determined but it facilitated a comparison of the moisture content of these two different material types.

Figure 58 and Figure 59 below illustrate the location of samples removed from Panels C, D, and E and Panels A and B, respectively. All drilled samples were placed in individual, screw topped, air tight containers, labelled, and taken off-site for processing.

Figure 58: Living room rear wall removal of samples from panel positions C, D, and E for Stage 1 moisture analysis.

Of the samples removed from the base of Panels C, D, and E, the plasterwork portion was separated from the underlying brick portion and each placed into individual, screw topped, airtight containers to be taken off-site for processing.

Figure 59: Understairs cupboard removal of samples from Panel A for Stage 1 moisture analysis.

For Panel A and the adjacent Panel B, samples were removed from the second brick course, 120 mm above floor level, and from the mortar joint between the second and third brick courses, 170 mm above the floor.

5.4. Stage 1 moisture analysis: results

Processing of the Stage 1 samples employed the gravimetric method of moisture analysis but with certain modifications to the number of check weights and drying temperatures, as described in Chapter 4. Table 3 below, provides details and individual weights for each of the Stage 1 samples tested and Table 4 their calculated percentage moisture contents.

Stage 1 moisture analysis									
						Weights			
Ref	Panel	Wall part	Height above floor	Drill depth	Type	W_o	W_w	W_{75}	W_d
$_{s1}$C1	Panel C	Living room, rear wall, LH end	100 mm	0-10 mm	Plaster	9.386	11.365	11.301	11.258
$_{s1}$C2	Panel C	Living room, rear wall, LH end	100 mm	10-40 mm	Brick	9.582	11.644	11.401	11.378
$_{s1}$D1	Panel D	Living room, rear wall, centre	100 mm	0-10 mm	Plaster	9.835	11.941	11.869	11.815
$_{s1}$D2	Panel D	Living room, rear wall, centre	100 mm	10-40 mm	Brick	9.424	11.583	11.309	11.297
$_{s1}$E1	Panel E	Living room, rear wall, RH end	100 mm	0-10 mm	Plaster	9.233	11.171	11.119	11.072
$_{s1}$E2	Panel E	Living room, rear wall, RH end	100 mm	10-40 mm	Brick	9.286	11.103	10.905	10.894
$_{s1}$B1	Panel B	Understairs cupboard, RH side wall, front end	170 mm	0-40 mm	Mortar	9.345	12.004	11.920	11.889
$_{s1}$B2	Panel B	Understairs cupboard, RH side wall, front end	120 mm	0-35mm	Brick	9.384	11.593	11.323	11.307
$_{s1}$A1	Panel A	Understairs cupboard, RH side wall, rear end	170 mm	0-40 mm	Mortar	9.874	12.264	12.199	12.171
$_{s1}$A2	Panel A	Understairs cupboard, RH side wall, rear end	120 mm	0-35mm	Brick	9.580	11.524	11.285	11.268

Table 3: Stage 1 moisture analysis: sample location, type, and weight.

For Panels C, D and E, located on the living room rear wall, the results from the plaster portion of the sample are paired with their corresponding brick portion. For Panels A and B, located on the understairs cupboard right-hand side wall where plaster was not present at the wall base, the results compare samples taken from the first mortar joint, reference $_{s1}$A1 and $_{s1}$B1, with those obtained from the second course of bricks directly below, reference $_{s1}$A2 and $_{s1}$B2.

						Moisture content		
						Stage 1 moisture analysis		
Ref	Panel	Wall part	Height above floor	Drill depth	Type	Total (TMC)	Hygroscopic (HMC)	Capillary (CMC)
$_{s1}$C1	Panel C	Living room, rear wall, LH end	100 mm	0-10 mm	Plaster	5.4%	2.2%	3.2%
$_{s1}$C2	Panel C	Living room, rear wall, LH end	100 mm	10-40 mm	Brick	12.9%	1.3%	11.6%
$_{s1}$D1	Panel D	Living room, rear wall, centre	100 mm	0-10 mm	Plaster	6.0%	2.7%	3.3%
$_{s1}$D2	Panel D	Living room, rear wall, centre	100 mm	10-40 mm	Brick	13.2%	0.6%	12.6%
$_{s1}$E1	Panel E	Living room, rear wall, RH end	100 mm	0-10 mm	Plaster	5.1%	2.5%	2.6%
$_{s1}$E2	Panel E	Living room, rear wall, RH end	100 mm	10-40 mm	Brick	11.5%	0.7%	10.8%
$_{s1}$B1	Panel B	Understairs cupboard, RH side wall, front end	170 mm	0-40 mm	Mortar	4.3%	1.2%	3.1%
$_{s1}$B2	Panel B	Understairs cupboard, RH side wall, front end	120 mm	0-35mm	Brick	12.9%	0.8%	12.1%
$_{s1}$A1	Panel A	Understairs cupboard, RH side wall, rear end	170 mm	0-40 mm	Mortar	3.9%	1.2%	2.7%
$_{s1}$A2	Panel A	Understairs cupboard, RH side wall, rear end	120 mm	0-35mm	Brick	13.2%	1.0%	12.2%

Table 4: Stage 1 moisture analysis: TMCs, HMCs, and CMCs.

In Table 4 above, the final three columns provide the total (TMC), hygroscopic (HMC), and capillary (CMC) moisture contents as a percentage of the wet weight W_w (i.e. the weight of the sample when it was removed from the wall). To further aid interpretation, each of these cells is filled with a colour: TMC blue, HMC green, and CMC red. The coloured fill is scaled proportionally, given the cells value, in the range of 0.0-13.2% (13.2% chosen because it was the highest TMC found in any of the samples); thus, the longer the coloured fill, the higher the moisture content.

The primary aim of Stage 1 moisture analyses was to identify if the parts of the ground floor walls to be used as test panels contained capillary moisture in excess of their hygroscopic moisture content (i.e. unwanted moisture that should not otherwise be present). The final column of Table 2, clearly illustrates this to be case as the CMC of all five brick units sampled is high, ranging from 10.8-12.6%.

The plaster portion of the samples obtained from Panels C, D, and E have lower CMCs, ranging from 2.6-3.3%. Clearly, these are lower values than those found in the brick units, but this is attributed to more ready evaporation from the plastered surface; in any case, some free water remains.

Trotman (2007, p. 6) suggests that moisture in excess of 5.0% at the base of a wall "can be taken as an approximate guide to the presence of rising damp", but that this assertion requires confirmation through further analysis to establish the moisture gradient: essentially the characteristic distribution of hygroscopic and capillary moisture present in the walls' base. The Building Research Establishment (1974, p. 1), although arguing that masonry in buildings can never be absolutely dry, states that brickwork, in the absence of active moisture sources, may be excepted to stabilise with a moisture content of around 1.0%.[29]

The Stage 1 CMC values are clearly well in excess of the 1% value that would be expected of dry brickwork. Despite Trotman's caveat that confirmation of rising damp should be achieved through moisture profiling (2007, p. 6), these results are compelling, confirming that excess capillary moisture is present in the base of the panels and suggesting in the absence of alternative reasons that rising damp is the cause.

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[29] The authors of Building Research Establishment Digest 163 are silent with respect to the precise nature of the moisture accounting for the 1% found in brickwork. Given that hygroscopic moisture is both an inherent property of a material but may also be independent of it—for example the hygroscopicity of brickwork can change significantly if it were contaminated with hygroscopic salts—the 1% figure quoted is assumed to refer to the capillary moisture content of the brickwork and therefore to be in excess of any inherent hygroscopic property.

For all ten results, the HMC value of the plaster or mortar component is higher than that found in the respective brick portion of the sample, but it is the plaster samples S_1C1, S_1D1, and S_1E1 at 2.2%, 2.7, & 2.5%, respectively, that have the higher HMCs. This anomaly is attributed to the effect of hygroscopic ground salts because they become more concentrated in the plaster. Hygroscopic salts present in solution are deposited at the boundary layer of the wall as water changes from liquid to gas during evaporation (Oliver, Douglas, & Stirling, 1997, p. 213). Hygroscopic moisture will be discussed more fully later in this chapter; at this stage, it is sufficient to highlight that this is a further characteristic of the rising damp model (Oliver, Douglas, & Stirling, 1997, p. 190; Trotman, 2007, p. 6).

Earlier, it was suggested that a comparison of the moisture content of the first course of bricks of Panels A and B with that in the horizontal mortar joint directly above would be an interesting exercise, given the contrasting opinions as to which of these materials would contain the greater CMCs. Reference to Table 4 reveals a significant difference in these values: for Panels A and B, the brick units contain 12.2% and 12.1% CMC but the mortar joints have far lower quantities of 2.7% and 3.1%, respectively. Clearly, from such a small sample size, it is not possible to draw generalizable conclusions. Nevertheless, this is an interesting find given that mortar would be expected to be more sorptive than brick and thus have a higher CMC, an expected outcome that was inconsistent with this result. Had samples only been taken from mortar joints, as is often recommended (Oliver, Douglas, & Stirling, 1997, p. 300; Trotman, 2007, p. 11), the conclusions drawn from Stage 1 moisture analyses would have differed and could potentially have resulted in this study being aborted at this early stage.

Project Stage 1 had provided a successful outcome by establishing that excess capillary moisture was present in the base of the ground floor walls allocated to the five test panels. Stage 2 analyses, to be undertaken to establish the vertical moisture profile, could now proceed.

5.5. Stage 2 moisture analysis: procedure

Rising damp manifests in a distinct and characteristic distribution of capillary moisture, hygroscopic moisture, and contaminating hygroscopic soil salts. Stage 2 moisture analyses was intended to establish if this profile applied to the damp affected ground floor wall parts used as the five test panels.

The location of the test panels had been determined to facilitate Stage 1 moisture analyses. For Stage 2 moisture analyses, samples would be obtained by drilling a column of seven, 10 mm diameter holes to a nominal depth of 40 mm in the central region of the five Panels A-E at heights of 50 mm, 150 mm, 225 mm, 300 mm, 450 mm, 600 mm, and 750 mm above internal floor level.

The maximum height of the damp rise found using the Protimeter was 400 mm, so extending the sampling to 750 mm provided a sufficient margin to ensure that all moisture affected masonry was included in the analyses. In addition, given the known position of the brick courses, the vertical spacing was expected, as far as possible, to cause the drill to penetrate brick units rather than horizontal mortar joints. To illustrate the sampling arrangement, Figure 60 and Figure 61 below show this drilling pattern for Panels D and A, respectively.
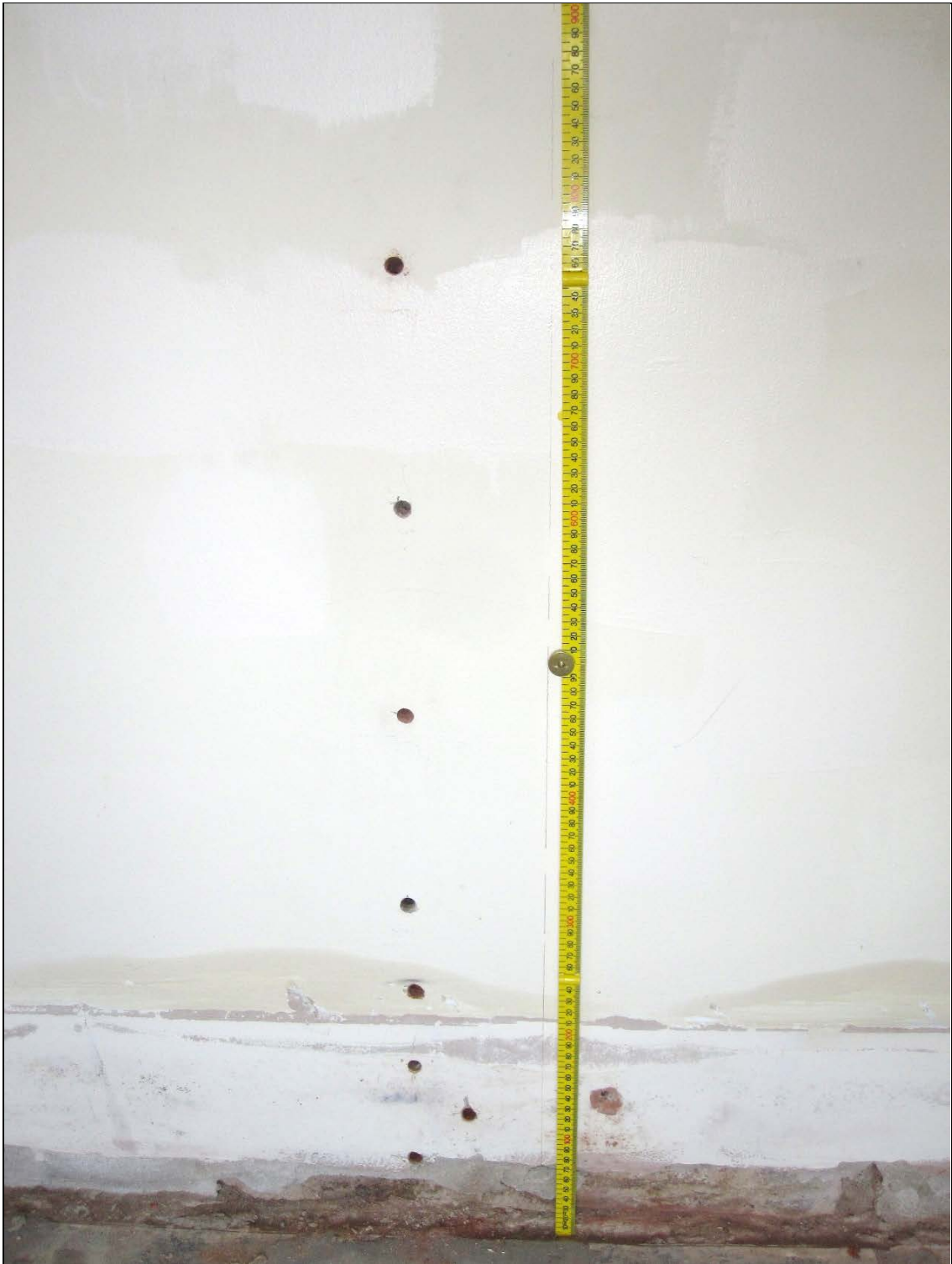
Figure 60: Panel D illustrating typical drilling pattern for Stage 2 moisture analyses.

A column comprising seven holes was drilled in each of the five test panels. The vertical position of the bottom four holes corresponding, respectively, with the first four brick courses and the top three holes with every other brick course. Damp staining is clearly visible on Panel D, terminating just above the third hole.

Figure 61: Panel A illustrating drilling pattern for samples required for Stage 2 moisture analysis.

The seven sampling points drilled in Panels A and B in the understairs cupboard were in essentially the same vertical positions as those drilled in Panels C, D, and E located in the living room. However, because of the absence of plaster at the wall base, the bottom three positions comprised a single sample of brick.

The intention was to split the drillings obtained from each hole into two parts, a plaster portion and a brick portion, therefore replicating the method used at Stage 1. However, because plaster was absent at the base of Panels A and Panel B, only brick was obtained from the three sampling positions in this region of those panels. Thus a total of thirty-five holes was drilled (seven per panel) to provide sixty-four separate samples: twenty-nine of plaster and thirty-five of material from the underlying masonry wall; thirty-three of these masonry samples yielded brick, thus achieving a 94% brick sampling success rate.

Later, during test panel setup when the existing plasterwork was stripped from Panels B and C the precise position of the sampling holes with respect to the bonding of the previously unseen brickwork was revealed. This exposure work confirmed that all but two samples had indeed been removed from brick units. Figure 62 below illustrates the Stage 2 analyses sampling pattern mapped against the typical brick bonding pattern of the underlying wall.
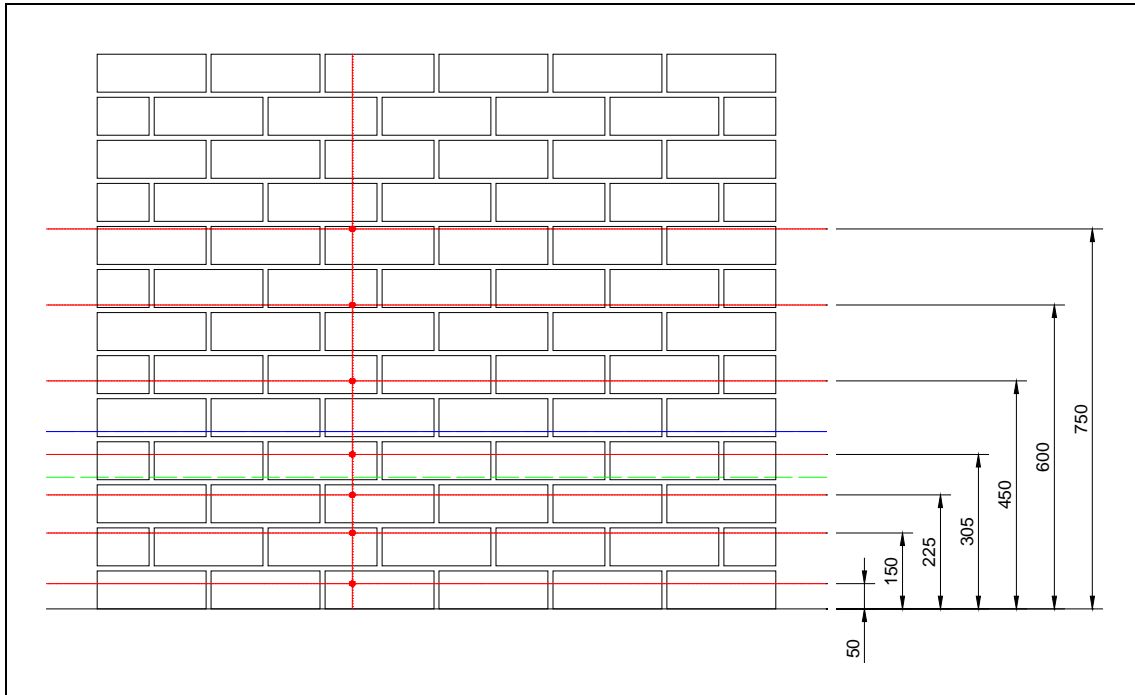
Figure 62: Typical elevation of wall test panel illustrating sampling points for Stage 2 moisture analysis.

This sketch provides a schematic elevation of a test panel. The blue and green horizontal lines illustrate the maximum height of dampness apparent on the understairs cupboard right-hand side wall and living room rear wall at 350 mm and 260 mm above floor level, respectively. The red horizontal lines indicate the height above floor level at which the seven sampling holes were drilled, and the red dots the precise sampling position. When these holes were drilled, the underlying masonry was not visible. Later, when plaster was stripped from Panels B and C, the relationship between each of the holes, the brick units, and the horizontal mortar joints could be seen. As intended, the drill had penetrated the bricks, albeit that in some places the holes were in close proximity to the mortar joints. The holes drilled in Panel A, position 4, at 450 mm above the floor, and in Panel E, position 2, at 150 mm above the floor, did coincide with mortar, but for the purposes of Stage 2 moisture analyses, this was not a concern.

Each Stage 2 sample was placed in an individual, screw topped, air tight container, labelled, inserted into a container configured to represent its respective panel position, as shown in Figure 63 below, and taken off-site for processing.

Figure 63: Samples obtained for the Stage 2 moisture analysis placed in individual air tight containers ready for processing.

For each of the seven sampling points of the individual test panels, the plaster portion, where available, was kept separate from the underlying masonry portion. Each of the samples was placed in individual, screw topped, air tight, containers, labelled, and taken off site to undergo gravimetric moisture analysis. In this photograph, the samples have been arranged in their respective positions: the first two columns representing Panel A, the second two columns Panel B, and so forth. For each pair of containers, the plaster portion is on the left and the masonry (predominantly brick) portion on the right. The bottom three containers of the left-hand columns of Panels A and B are missing because there was no plaster in these locations from which to obtain samples.

5.6. Stage 2 moisture analysis: results

The Stage 2 samples were processed using the same gravimetric method outlined earlier for Stage 1 and described in Chapter 4. At each step of processing, the samples' weights were recorded and entered into the results spreadsheet to calculate their total moisture content (TMC), hygroscopic moisture content (HMC), and capillary moisture content (CMC).

The results for Test Panels A, B, C, D, and E are provided, respectively, in Table 5, Table 6, Table 7, Table 8, and Table 9 in the following sections. For each of these tables the plaster and masonry[30] samples from equivalent locations appear in the same row and each of these rows represents the samples' vertical position: the lowest sampling point appearing at the bottom and the uppermost sampling point at the top of each table. The tables' first column provides the sampling point's numbered position and the second column the precise height, in millimetres, above the floor. Thus, each table is essentially a graphical representation of its corresponding panel.

The TMC, HMC, and CMC values are given as percentages of the wet weight W_w and to aid readability, applying the same method as that used for Stage 1 results, the cells of these columns are coloured blue for TMC, green for HMC, and red for CMC: the length of this coloured fill scaled within the range of 0% to 14.8%, the upper value representing the TMC of the masonry of Panel A at position 1, the highest quantity of moisture of any of the samples determined through Stage 2 analyses.

A quirk of the processing method is that some of the derived CMCs can be negative (i.e. have a moisture content indicated to be less than zero); however, this is easily explained. During processing, samples are conditioned at a constant relative humidity of 75% to provide their W_{75} weight, which is required in the calculation of their HMCs. If the on-site relative humidity was lower than 75% when the sample was removed, negative CMC values may result. In practice, negative CMCs can be considered zero and the relevant samples free of this form of moisture. This is reflected by the coloured highlighting, which is absent from any cells of a table that contain negative CMC values.

Each test panel's results have also been provided as a chart using a form typically adopted by other researchers and authors to illustrate the relationship between hygroscopic and

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[30] All but two of the thirty-five samples obtained from depth in the walls were brick, with only the samples removed from position 4 of Panel A and position 2 of test Panel E being mortar. To simplify the text, 'masonry' has been used as a general term to describe the construction material of the underlying wall; however, where appropriate the specific material under discussion will be made explicit.

capillary moisture. (Coleman, 1990, pp. 19,21; Kyte, 1997, p. 4; Oliver, Douglas, & Stirling, 1997, p. 191; Trotman, 2007, p. 6).

5.6.1. Stage 2 moisture analysis: results Panel A

The first sets of gravimetric moisture analysis results, shown in Table 5 below, are for Panel A, located at the rear end of the understairs cupboard right-hand side wall. Because there was no plaster at the base of Panel A, the results do not include moisture content values for plaster in the bottom three positions, and these cells of the table are empty.

Stage 2 Moisture Analysis: Test Panel A							
Vertical	Vertical	Plaster			Masonry		
Position	Height (mm)	TMC	HMC	CMC	TMC	HMC	CMC
7	750	3.8%	3.8%	0.0%	0.1%	0.2%	-0.1%
6	600	4.8%	5.1%	-0.3%	0.1%	0.1%	0.0%
5	450	2.8%	2.7%	0.1%	0.9%	1.0%	-0.1%
4	300	6.3%	5.6%	0.7%	6.3%	5.6%	0.7%
3	225				7.5%	5.2%	2.3%
2	150				12.9%	1.5%	11.4%
1	50				14.8%	1.0%	13.8%

Table 5: Stage 2 moisture analysis results: Panel A.

In the absence of results for the plaster component at the base of the wall, the last three columns of this table, those which provide data for the masonry portion of the wall, are the most useful. Column 8 shows the CMC value for the masonry wall to be highest at position 1, the first brick course (13.8%), slightly lower at position 2, the second brick course (11.4%), and to reduce significantly at position 3, the third brick course (2.3%). Significantly, there is clearly defined, sharp fall in capillary moisture at this third brick course, with neither the masonry nor the plaster components of the wall parts above containing any free water.

In contrast, the HMC values for the masonry component, shown in column 7, are relatively low in the bottom two brick courses (1.0% and 1.5%), but increase significantly at positions 3 and 4 (5.2% and 5.6%). Above this height, the values reduce abruptly with no significant quantities of hygroscopic moisture found in the masonry from position 5 upwards. However, the elevated HMC trend does continue in the plaster portion of the upper wall parts, as shown in column 4, with values ranging from 2.7% to 5.6% in positions 4-7.

This table of results is entirely consistent with the moisture profile for rising damp and is perhaps clearer to see in Figure 64 and Figure 65 below, which employ a distinctive chart form often used to illustrate the characteristic distribution of capillary and hygroscopic moisture: high for the former at the wall base; high for the latter in the wall parts directly above (Coleman, 1990, pp. 15-22; Kyte, 1987, p. 312; Trotman, 2007, pp. 5-6).
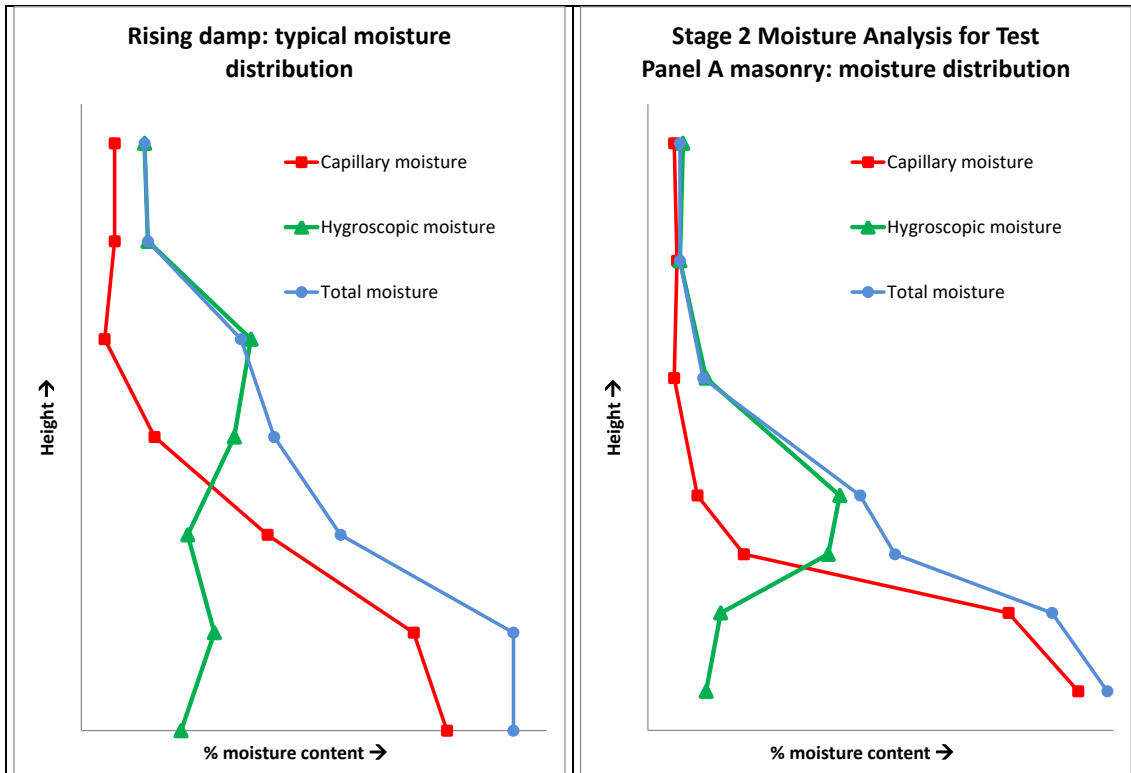
Figure 64: Rising damp profile illustrating HMC v CMC v TMC distribution. (Adapted from Coleman, 1990, pp. 19,21; Kyte, 1997, p. 4; Oliver, Douglas, & Stirling, 1997, p. 191; Trotman, 2007, p. 6).

This chart illustrates the relationship and distribution of hygroscopic v capillary v total moisture in a ground floor wall affected by rising damp. A characteristic moisture profile is created: hygroscopic moisture is higher towards the uppermost region of the damp rise in comparison to that in the base of the wall; capillary moisture is higher in the wall base than in the masonry above; and the capillary moisture values fall abruptly at the horizontal boundary between the damp masonry and the unaffected parts above.

Figure 65: Panel A, Stage 2 moisture analysis results for masonry illustrating HMC v CMC v TMC distribution.

This chart illustrates the Stage 2 moisture analysis results for the masonry portion of Panel A configured to match Figure 64, adjacent. The HMC, CMC, and TMC values may differ from the text book version, but the intrinsic relationship, profile, and distribution of these forms of moisture clearly matches.

5.6.2.   Stage 2 moisture analysis: results: Panel B

The second set of gravimetric moisture analysis results, shown in Table 6 below, are for Panel B, located at the front end of the understairs cupboard right-hand side wall. As was the case with Panel A, because there was no plaster at the base of Panel B, the results do not include moisture content values for plaster in the bottom three positions.

Stage 2 Moisture Analysis: Test Panel B							
Vertical Position	Vertical Height (mm)	Plaster			Masonry		
		TMC	HMC	CMC	TMC	HMC	CMC
7	750	2.5%	3.0%	-0.5%	0.1%	0.2%	-0.1%
6	600	2.9%	3.3%	-0.4%	0.1%	0.3%	-0.2%
5	450	3.7%	3.9%	-0.2%	0.3%	0.3%	0.0%
4	300	4.8%	4.8%	0.0%	4.6%	4.8%	-0.2%
3	225				0.8%	1.2%	-0.4%
2	150				9.8%	3.3%	6.5%
1	50				10.8%	0.1%	10.7%

Table 6: Stage 2 moisture analysis results: Panel B.

Essentially, these results are the same as those found for Panel A, albeit with differing values: elevated CMCs of 10.7% and 6.5% found in the masonry portion removed from positions 1 and 2, the bottom two brick courses; a sharp cut-off followed by a complete absence of capillary moisture in positions 3-7, the masonry wall above the third brick course; HMC values elevated in the region of the wall between positions 2-4 (3.3%, 1.2%, and 4.8%, respectively); and, as shown in column 4, elevated HMC values in the plaster portion of the upper wall parts, positions 4-7 (values ranging from 3.0-4.8%). Again, this is a distribution of hygroscopic and capillary moisture entirely consistent of rising damp.

Displaying these results in chart form helps to make this clearer. The absence of results for the plaster component of the wall in the bottom three positions of Panel B means that this chart, shown in Figure 66 below, is not particularly useful, but this is not the

case for the masonry component of Panel B, as shown in Figure 67 below. Comparing this latter chart with Figure 64 above, which describes rising damp, reveals a similar distribution and relationship of capillary and hygroscopic moisture.
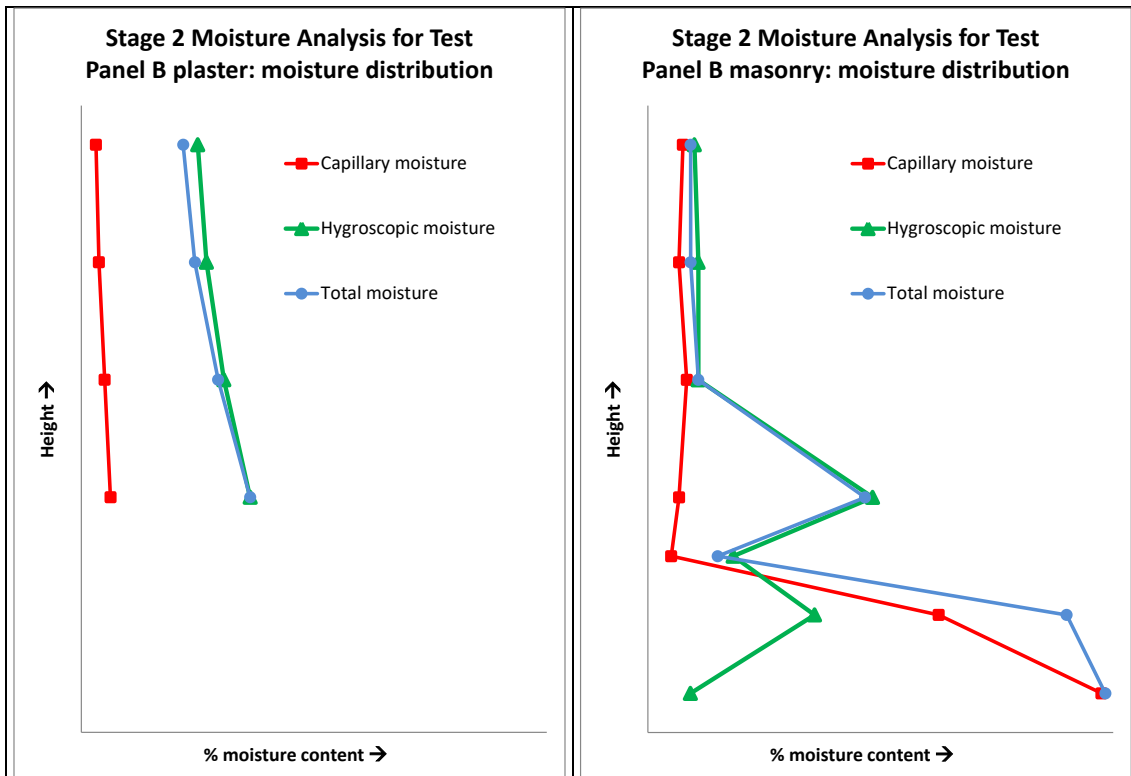
Figure 66: Panel B, Stage 2 moisture analysis results for plaster illustrating HMC v CMC v TMC distribution.	**Figure 67: Panel B, Stage 2 moisture analysis results for masonry illustrating HMC v CMC v TMC distribution.**
This chart illustrates the Stage 2 moisture analysis results for the <u>plaster</u> portion of Panel B configured to match the convention used for Figure 64. Given that the moisture contents of the plaster portion in the bottom three positions could not be obtained, these results are not particularly useful; however, they do illustrate that the TMC is comprised wholly of hygroscopic moisture and that the HMC is elevated in the upper parts of this panel.	This chart illustrates the Stage 2 moisture analysis results for the <u>masonry</u> portion of Panel B configured to match the convention used for Figure 64. The HMC, CMC, and TMC values may differ but the intrinsic relationship, profile, and distribution of these forms of moisture clearly matches that of rising damp.

5.6.3.   Stage 2 moisture analysis: results: Panel C

The third sets of gravimetric moisture analysis results, shown in Table 7 below, are for Panel C, located at the left-hand end of the living room rear wall. These samples include moisture content values for both plaster and masonry in all seven row positions.

Stage 2 Moisture Analysis: Test Panel C							
Vertical	**Vertical**	**Plaster**			**Masonry**		
Position	**Height (mm)**	**TMC**	**HMC**	**CMC**	**TMC**	**HMC**	**CMC**
7	750	0.6%	0.7%	-0.1%	0.0%	0.0%	0.0%
6	600	0.8%	1.3%	-0.5%	0.4%	0.6%	-0.2%
5	450	0.6%	0.7%	-0.1%	0.0%	0.1%	-0.1%
4	300	2.0%	2.3%	-0.3%	4.8%	4.5%	0.3%
3	225	3.8%	3.6%	0.2%	10.6%	6.0%	4.6%
2	150	3.8%	2.9%	0.9%	11.8%	2.7%	9.1%
1	50	2.8%	1.6%	1.2%	11.3%	0.5%	10.8%

Table 7: Stage 2 moisture analysis results: Panel C.

Similar to the results of Panels A and B, it is the last three columns of this table, the portion of the samples obtained from the masonry wall, that are perhaps the most compelling with respect to the characteristic profile of rising damp: the total moisture content (column 6) is high in the bottom four courses but cuts off abruptly from the fifth course upwards; hygroscopic moisture (column 7) is highest in brick courses 2-4 and particularly in courses 3 and 4, at the peak of the damp rise; conversely, capillary moisture (column 8) is highest in the bottom three brick courses, falling, progressively, relative to the height above the floor, through positions 1-4.

Columns 3-5 show the results for the plaster portion of the samples, which, unlike Panels A and B, include the bottom three positions on the wall. The distribution of total, hygroscopic, and capillary moisture is similar to that of the masonry set, although the quantity of capillary moisture is far lower, having a maximum value of just 1.2% in the

bottom brick course. Nevertheless, the characteristic shape produced when these two sets of results are graphed, as shown in Figure 68 and Figure 69 below, essentially matches that of the text book chart illustrated in Figure 64 above.
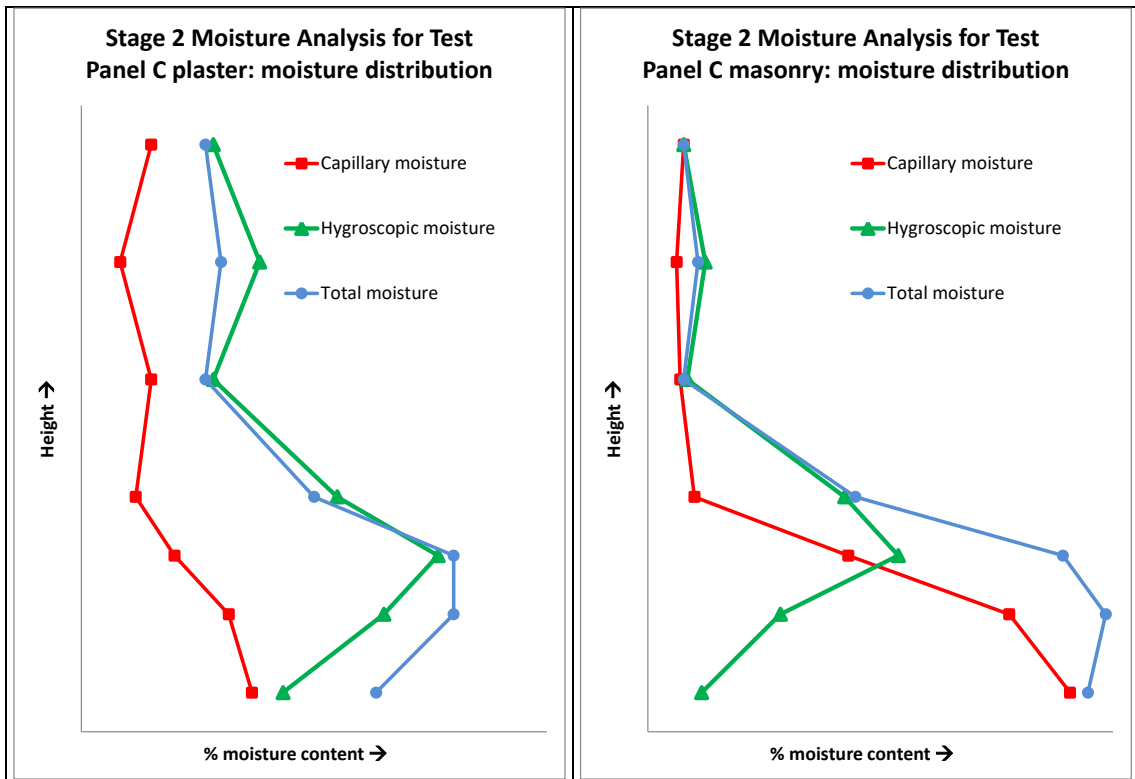
Figure 68: Panel C, Stage 2 moisture analysis results for plaster illustrating HMC v CMC v TMC distribution.

This chart illustrates the Stage 2 moisture analysis results for the <u>plaster</u> portion of Panel C configured to match the convention used for Figure 64. Here the CMC values are generally low; nevertheless, they are highest at the wall base. In contrast, the HMC values are higher and, importantly, peak in course 2-4, the highest point of the damp rise.

Figure 69: Panel C, Stage 2 moisture analysis results for masonry illustrating HMC v CMC v TMC distribution.

This chart illustrates the Stage 2 moisture analysis results for the <u>masonry</u> portion of Panel C configured to match the convention used for Figure 64. The intrinsic relationship, profile, and distribution of the total, hygroscopic, and capillary moisture is a clear match.

5.6.4. Stage 2 moisture analysis: results: Panel D

The fourth set of gravimetric moisture analysis results, shown in Table 8 below, are from Panel D, located at the mid-point of the living room rear wall. These samples include moisture content values for both plaster and masonry in all seven row positions.

Stage 2 Moisture Analysis: Test Panel D							
Vertical Position	Vertical Height (mm)	Plaster			Masonry		
		TMC	HMC	CMC	TMC	HMC	CMC
7	750	0.5%	0.9%	-0.4%	0.0%	0.0%	0.0%
6	600	0.7%	1.1%	-0.4%	0.5%	0.7%	-0.2%
5	450	0.9%	1.2%	-0.3%	0.0%	0.1%	-0.1%
4	300	2.4%	2.3%	0.1%	3.5%	2.3%	1.2%
3	225	2.1%	1.9%	0.2%	4.6%	2.6%	2.0%
2	150	3.5%	2.6%	0.9%	11.8%	2.7%	4.6%
1	50	4.6%	2.4%	2.2%	11.7%	0.9%	10.8%

Table 8: Stage 2 moisture analysis results: Panel D.

Although the values vary, this set of results if very similar to those obtained from Panel C, which is located to the left of and directly adjacent to Panel D. What is important is that the distribution of capillary and hygroscopic moisture in the masonry wall again fits the rising damp model.

The moisture distribution is more evident in the graphed version of these results shown in Figure 70 and Figure 71 below, which relate to the plaster and masonry result sets respectively. Again, the characteristics displayed in Figure 71, for the masonry portion of the wall, compare favourably with Figure 64 above. However, the result for the plaster portion is less compelling, because despite the hygroscopic moisture content being elevated, it is more evenly distributed rather than concentrated in the region of the maximum height of the damp rise. One reason for this latter result is the remedial damp proof course works that are known to have been undertaken at the house, as described

in Chapter 4. This work included the removal of the original plaster, and therefore plasterwork contaminated with hygroscopic salts; this plasterwork subsequently being reinstated with cement render that is intended to resist contamination from hygroscopic salts. In contrast, the underlying masonry is original and therefore the moisture distribution found in this part of the wall is more meaningful. That said, there has to be some reason why the plaster at the wall base had elevated hygroscopicity, and as will be demonstrated later in this chapter, additional tests identified contamination from nitrate salts.
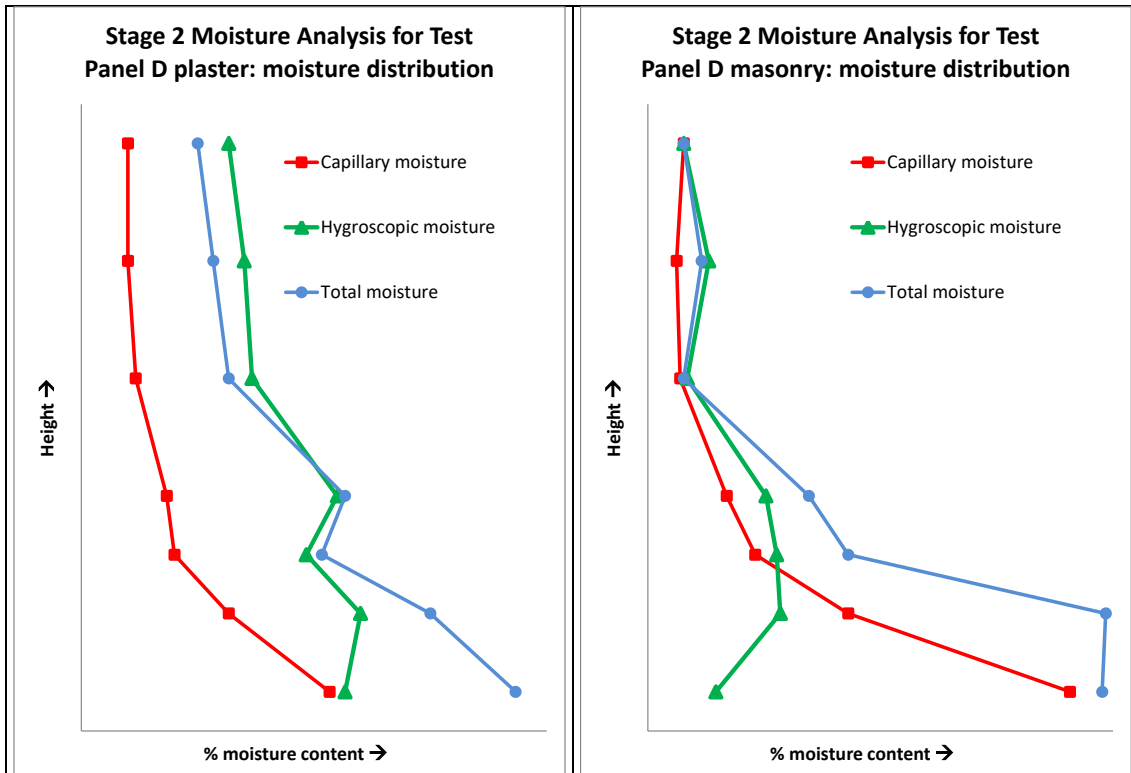
Figure 70: Panel D, Stage 2 moisture analysis results for plaster illustrating HMC v CMC v TMC distribution.

This chart illustrates the Stage 2 moisture analysis results for the <u>plaster</u> portion of Panel D configured to match the convention used for Figure 64. Here the CMC values are generally low, although still highest at the wall base. The HMC values relatively consistent at the wall base rather than peaking at the highest point of the damp rise.

Figure 71: Panel D, Stage 2 moisture analysis results for masonry illustrating HMC v CMC v TMC distribution.

This chart illustrates the Stage 2 moisture analysis results for the <u>masonry</u> portion of Panel D configured to match the convention used for Figure 64. Again, the intrinsic relationship, profile, and distribution of the total, hygroscopic, and capillary moisture is a clear match.

5.6.5. Stage 2 moisture analysis: results: Panel E

The fifth and final set of gravimetric moisture analysis results, shown in Table 9 below, are from Panel E, located at the right-hand end of the living room rear wall. These samples include moisture content values for both plaster and masonry in all seven row positions.

Stage 2 Moisture Analysis: Test Panel E							
Vertical	Vertical	Plaster			Masonry		
Position	Height (mm)	TMC	HMC	CMC	TMC	HMC	CMC
7	750	0.8%	1.0%	-0.2%	0.1%	0.4%	-0.3%
6	600	0.9%	1.0%	-0.1%	0.1%	0.2%	-0.1%
5	450	0.8%	1.0%	-0.2%	0.1%	0.1%	0.0%
4	300	2.6%	2.4%	0.2%	9.7%	6.3%	3.4%
3	225	3.7%	4.0%	-0.3%	8.6%	6.3%	2.3%
2	150	3.1%	3.0%	0.1%	3.4%	2.0%	1.4%
1	50	4.2%	3.9%	0.3%	4.4%	2.0%	2.4%

Table 9: Stage 2 moisture analysis results: Panel E.

This set of results is similar to those obtained from Panel D, which is located to the left of and directly adjacent to Panel E. The distribution of hygroscopic and capillary moisture in the masonry (columns 7 and 8) aligns with the rising damp model, albeit that the free moisture quantities are relatively low. As with the results obtained from Panel D, capillary moisture is essentially absent from the plaster and although hygroscopic moisture (column 4) is clearly elevated, it is distributed relatively evenly in the base of the wall.

Displaying these results in chart form, as shown in Figure 72 and Figure 73 below, illustrates a good match to Figure 64 with respect to hygroscopic moisture but less so with respect to capillary moisture.
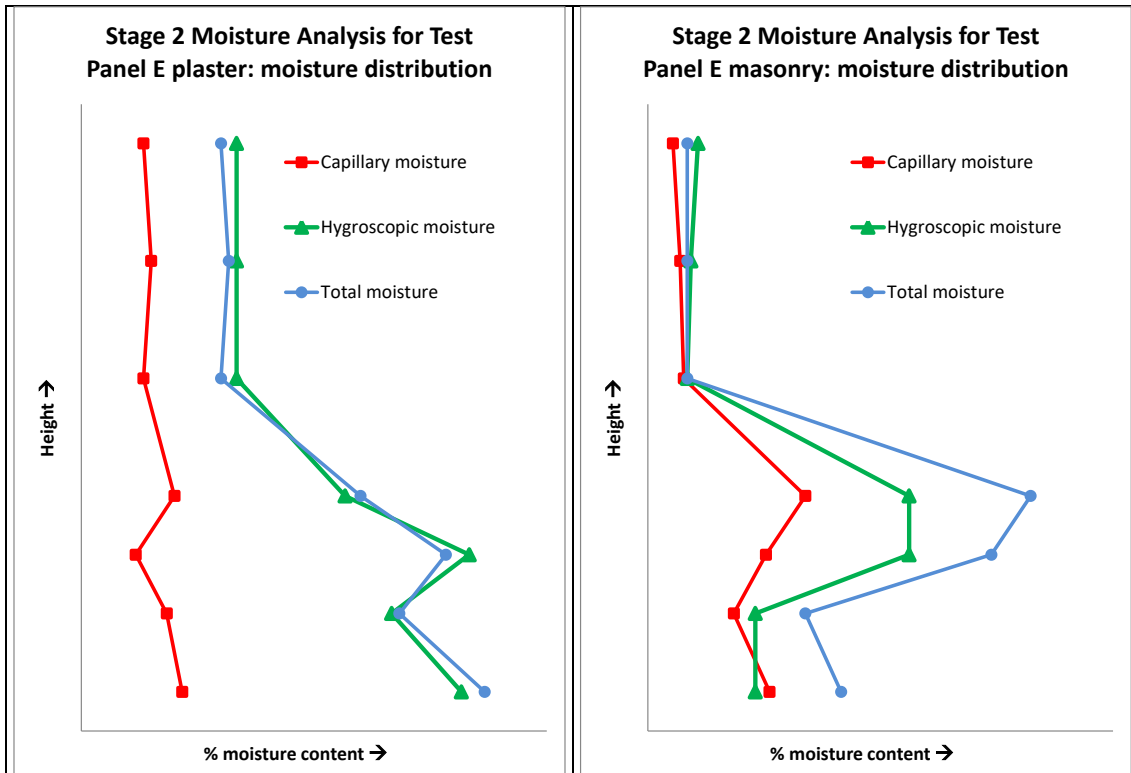
Figure 72: Panel E, Stage 2 moisture analysis results for plaster illustrating HMC v CMC v TMC distribution.	Figure 73: Panel E, Stage 2 moisture analysis results for masonry illustrating HMC v CMC v TMC distribution.
This chart illustrates the Stage 2 moisture analysis results for the <u>plaster</u> portion of Panel E configured to match the convention used for Figure 64. Here the CMC values are low. The HMC values tend to be higher at the wall base than peaking at the highest point of the damp rise.	This chart illustrates the Stage 2 moisture analysis results for the <u>masonry</u> portion of Panel E configured to match the convention used for Figure 64. Capillary moisture is relatively low, but the hygroscopic moisture aligns with the profile and distribution of rising damp.

Comparing the Stage 2 gravimetric moisture analyses results to the characteristics of the theoretical model for rising damp reveals some differences in the sample sets, particularly with respect to the moisture profiles derived from the plaster component of the walls. However, the replacement of original plaster with cement render is likely to be a confound because evidence of long term rising damp in the form of hygroscopic contamination will inevitably have been removed when this work was undertaken.

Despite these anomalies, there are consistent and clearly identifiable trends across the sample sets:

1. Capillary moisture is present and concentrated at the base of the masonry walls;

2. Capillary moisture found in the base of the masonry walls stops abruptly and forms a distinct boundary between the damp and dry regions of the wall;

3. Hygroscopic moisture is present in the masonry walls and is concentrated in the boundary between the regions of capillary and non-capillary moisture;

4. Capillary moisture in the plaster component is generally low but where present is concentrated at the wall base;

5. Hygroscopic moisture is present in the plaster component, but the concentration is less distinct than that found in the underlying masonry wall.

Rising damp as the moisture source would explain the moisture distribution in the masonry walls and support the other evidence found. Clearly, hygroscopic moisture was present in significant quantities in both the masonry and plaster components of the walls. Its distribution in the masonry wall was consistent both with long term rising damp and the deposition of hygroscopic soil salts such as nitrates in the parts of the wall corresponding with the uppermost region of the damp rise.

To confirm if nitrate salts were indeed present, Stage 2 gravimetric analyses was supplemented with selected salts tests, using the protocol described in the following section.

5.7. Testing for hygroscopic salts: nitrates

As described earlier in this chapter, rising damp produces a characteristic moisture profile in walls. In addition, hygroscopic salts of nitrates or chlorides present in the ground would be expected to affect walls that have been subject to long term rising

damp (Oliver, Douglas, & Stirling, 1997, p. 189). In fact, in the absence of evidence to the contrary, it would seem logical to expect that these salts would account for the elevated hygroscopicity of the affected plaster and masonry parts.

Oliver et al (1997, p. 189) suggest that nitrates and to a lesser extent chlorides are not normally present in construction materials. Therefore, a positive test for these salts, and particularly nitrates, while not necessarily confirming rising damp in isolation, would add support to the results of gravimetric moisture analyses. For this reason, it was advantageous to undertake tests to determine if nitrate salts were present.

Unlike gravimetric analysis, which is aimed at determining the precise quantitative moisture contents of samples, salts tests are typically qualitative and their objective is simply to establish if a particular contaminant, in this case nitrates, is present. Proprietary testing kits are available for this purpose: a reagent, in the form of a tablet, changes the colour of a solution made from the sample and distilled water if it contains the subject salt (Burkinshaw & Parrett, 2003, p. 90).

Proprietary salts kits are expensive. At the time of writing, in January 2017, the Protimeter Salts Analysis Kit, which is supplied with materials to carry out ten nitrate and ten chloride tests, retails at £90.00 or £4.50 per individual test (Survey Express Services, 2017). Unlike the gravimetric analysis method, where a number of samples can be processed simultaneously, salt tests have to be undertaken per sample, so testing multiple samples is time consuming. Burkinshaw and Parrett state that few surveyors make use of proprietary salt testing kits (2003, p. 89). Perhaps this is unsurprising, given these issues; however, there are alternatives.

Quantofix is a manufacturer of tests strips that are used in the water industry to detect a variety of substances including nitrate and chloride salts (Machery-Nagel, 2015b, 2015c). Unlike the proprietary salts testing kits, these test strips are not expensive; for example, a container of nitrates strips sufficient to carry out one hundred tests can be purchased for £31.20 (£26.00 + VAT), which equates to £0.31 per test (Charlton Scientific

Ltd, 2017). Quantofix test strips are also simple to use and, although a separate test is required for each sample, the process is relatively quick.

An unused nitrate test strip has an end tab that is white, as shown in Figure 74 below. In the presence of nitrates, this end tab becomes pink, as shown in Figure 75 below; the deeper this pink coloration, the more concentrated the nitrates. When used for testing, the strip is dipped into water for one second, removed, and after one minute compared to a seven-part, coloured scale provided on the test strip's container that is shown in Figure 74 and Figure 75. This scale provides the concentration of nitrates in values of 0, 10, 25, 50, 100, 250, and 500 milligrams per litre of water.

Figure 74: Quantofix nitrate test strip: unexposed strip.	**Figure 75: Quantofix nitrate test strip: positive result.**
This Quantofix test strip can be used to detect both nitrates and nitrites. The strip, which in this photograph has not yet been used, has two white tabs at its tip: the end tab is used for nitrate identification purposes. In use, the strip is dipped into water and the end tab changes colour in the presence of nitrates. By comparing the tab to a coloured scale printed on the side of the container, the nitrate concentration can be determined.	This Quantofix test strip has been dipped into a solution made up from 500 mg of sample mixed with distilled water. This particular strip was used to test the brick sample obtained from Panel B, position 4 at 300 mm above the floor. For nitrate detection, the end tab of the strip is compared to the colour of the scale printed on the left-hand side of the container. In this photograph, the test is strongly positive for nitrates with a match to the colour provided for a concentration of 500 mg/l.

Quantofix test strips are easily adopted for the purposes of testing construction materials. For example, Veiga et al (2009), although silent with respect to the precise method employed, made use of test strips to inform their research into the cause of defects to plaster and renders at the Inglesinhos Convent in Lisbon.

I am required to undertake tests for the presence of nitrates in construction materials while investigating dampness for my professional work. Given their relatively low cost and simplicity of use, I developed the following protocol to enable Quantofix test strips to be used for this purpose:

1. A solution is prepared from 500 mg of sample and 10 ml of distilled water;

2. The nitrate test strip is dipped into this solution for one second, removed, and excess fluid shaken off;

3. After one minute the end tab of the strip is compared to the coloured scale for nitrate concentration provided on the strip container;

4. The concentration in mg/l relevant to the colour shown by the end tab of the strip is recorded.

For water industry purposes, the coloured scale is used to determine the concentration of nitrates in the water supply under test and thereby to provide a semi-quantitative result (Machery-Nagel, 2015c). Typically, this degree of accuracy is not required for salt tests of construction materials where the primary aim is only to determine if the relevant contaminating salt is present. However, it is possible to obtain a quantitative result using the following amended method:

1. Mix 500 mg of sample with 10 ml of distilled water, insert test strip, remove, wait one minute, and obtain the result in mg/l;

2. If the result is a nitrate concentration of 250 mg/l or lower (i.e. at or below the penultimate value provided on the Quantofix scale) divide the result by 500 mg (the weight of the sample) and record the number;

3. Multiply the number obtained in step 2 by 10/1000 to account for 10 ml rather than one litre of water being used to make up the test solution and record the number;

4. Multiply the number obtained in step 3 by 100 to provide the percentage concentration of nitrates.

This is an example using the above steps and assuming a nitrate test strip value of 250 mg/l or less:

1. Using a value of 250 mg/l;

2. 250 mg/l / 500 mg/l = 0.5;

3. 0.5 x 10/1000 = 0.005;

4. 0.005 x 100 = 0.5% concentration.

If an initial test indicated the maximum concentration of 500 mg/l, the test requires repeating with progressively weaker solutions until the penultimate value of 250 mg/l or less is obtained. The quantity of distilled water needed to create the successful dilute is then substituted in step 3 of the calculation. For example, if an initial 500 mg/l test required two further tests, the first using 20 ml and the second using 30 ml of water before providing a result of 250 mg/l, the formula at step 3 requires modifying as follows:

1. Using the value of 250 mg/l obtained from a 30 ml solution;

2. 250 mg/l / 500 mg/l = 0.5;

3. 0.5 x 30/1000 = 0.015 (30 ml of water used);

4. 0.015 x 100 = 1.5% concentration.

Essentially, any quantity of water may be used for the test with the calculations adjusted to suit. Thus a more generic formula is provided in Equation 11:

Equation 11

For S_r = ≤ 250 mg/l

Then (S_r/S_w) x $(S_q/1000)$ x 100 = % concentration.

Where:

S_r = test strip result in mg/l.

S_w = weight of sample in mg.

S_q = quantity of distilled water in ml.

Rather than to risk having to undertake multiple tests, should the first yield a concentration of 500 mg/l dilution, an alternative approach is to use a larger quantity of distilled water for the initial test: say 30 ml rather than 10 ml. The potential downside to this strategy is that low concentrations of nitrates are less detectable in weaker solutions and an otherwise positive result may be missed. Using 10 ml of water to create the initial test solution avoids erroneous results where low concentrations of nitrates may be present but will require repeated tests for nominal quantification of solutions with higher concentrations.

So, the percentage nitrate concentration could, technically, be calculated using the method described above. Concentrations of hygroscopic salts found in a wall affected by long term rising damp are typically in the range of 1.0-3.0% (Kyte, 1987, p. 312). As

the above worked examples suggest, positive results would be expected to fall within this range, which implies reasonable precision.

In practice, the accuracy of such results is questionable: the absolute weight of samples will vary depending on their initial moisture content and minor errors during dilution and in the subjective judgement required in precisely matching the test strip to the coloured scale are inevitable. For these reasons, percentage nitrate concentrations derived using this method can only be claimed, at best, to be semi-quantitative.

However, the aim is simply to determine if nitrates are present in the subject materials, and the qualitative test strip method fulfils this requirement. By using, approximately, the same quantity of sample and distilled water to prepare the solution in each case, there is consistency of testing, and an estimate of the severity of nitrate contamination, based on the depth of pink of the test strip, entirely feasible.

It is worth noting that Quantofix suggest a similar qualitative use of test strips to test for the presence of nitrates in potatoes, vegetable, and fruits (Machery-Nagel, 2015a). In this application, the food item to be tested is cut in half, the test strip tab placed in contact with the cut face for a few seconds, then, after 60 seconds, nitrates are present if the colour of the tab changes to pink.

Ultimately, the nitrate test strip method is a viable alternative to proprietary salt testing kits and, importantly, serves the purposes of this study.

For Stage 2 moisture analyses, it was not necessary to test all samples for salts but only those straddling the boundary between the wet (lower) and dry (upper) parts of the panels. If rising damp was responsible for the dampness, nitrate concentrations should be elevated in the masonry at the top of the damp rise but low or absent in the unaffected dry parts above. Therefore, only the samples from row 3 and 4, corresponding to heights of 300 mm and 450 mm, respectively, above floor level, were tested.

The results of these salts test, shown in Table 10 below, confirmed that nitrates were highly concentrated in the region of the masonry wall corresponding with brick course 4, the maximum vertical height of dampness, but absent from brick course 5, directly above.

Stage 2 Nitrate Salts Test: Masonry						
Vertical Position	Vertical Height (mm)	Wall Test Panel				
		A	B	C	D	E
7	750					
6	600					
5	450	0	25	0	0	0
4	300	500	500	500	500	500
3	225					
2	150					
1	50					
Table 10: Stage 2 nitrate salts test results from masonry.						

Technically, the Quantofix test strips did detect trace nitrates in position 5 of Panel B, but the concentration was so low, 25 mg/l in contrast to 500 mg/l found in the course below, that it was not considered significant or to alter the conclusion that nitrate contamination tended to cease abruptly at the fourth brick course: the maximum height to which damp had risen up the walls.

5.8. Stage 2 moisture analysis: closing remarks

In Chapter 4, it was suggested that no sources of moisture other than rising damp could reasonably be responsible for dampness affecting the base of the ground floor walls of the house. The Stage 2 moisture analyses found a moisture and salt distribution consistent with the rising damp model (Coleman, 1990, pp. 15-22; Kyte, 1987, p. 312; Trotman, 2007, pp. 5-6).

Undeniably, there were some anomalies in the test results obtained from the plaster samples but these can be accounted for by changes brought about through replacement

of the original plasterwork. This was not the case with respect to the underlying, original masonry walls from which the results consistently aligned with the rising damp model.

Significantly, this was a real world test and some deviation from ideal results is inevitable. Ultimately, there was far more evidence in support of rising damp than against, and given this outcome and the supporting facts, four conclusions are postulated:

1. Rising damp is a real phenomenon;

2. Rising damp can be identified through a systematic process of analysis;

3. Rising damp affects the ground floor walls of the subject house and, importantly, those wall parts that have been allocated as test panels for the purposes of this study;

4. Research objective 4 has been satisfied.

With Stage 2 complete and positive results obtained, Stage 3, setting up of the test panels, installation of the moisture measuring apparatus, and the third phase of moisture profiling, could commence. It was anticipated that this latter action, the third phase of moisture profiling, would add support and essentially confirm the above conclusions. Stage 3 is the topic of the next chapter.

Chapter 6
Evaluating the Damp Proofing Treatments Part 1: Process

6.1. Introduction

In Chapter 5 the protocol to allocate the five test panels, A-E, to specific ground floor wall parts and the method used to confirm that rising damp affected these wall parts was explained. This Stage 3 phase of the project is concerned with the quasi-experimental work; specifically, how the test panels will be configured to determine the effect that contemporary remedial damp proof course treatment has on the moisture in a wall affected by rising damp.

6.2. Stage 3: test panel set up

All five test panels were nominally 1000 mm in height. Panels C, D, and E had a width of 800 mm and Panels A and B a width of 1000 mm. Configuration of each panel required the application of a specific treatment and the installation of moisture measuring equipment in the form of similarly arranged apparatus. One panel would serve as a control, its treatment was technically 'no treatment', and the remaining four panels receive a component part of the process that together comprise the contemporary method for the remedial treatment of rising damp.

This method of remedial damp proofing typically involves the removal of plaster from the bottom one metre of the walls (i.e. corresponding to the test panel's height); the drilling of 12 mm diameter holes at the intersection of each perpendicular mortar joint and the lowest horizontal mortar bed joint (i.e. at 100-120 mm centres) to a depth of 100 mm in a 115 mm thick, half-brick wall; insertion of a silane/siloxane damp proofing cream into the pre-drilled holes; and reinstatement of the plasterwork removed using a low-permeability cement render and plaster finish coat (Safeguard Europe Ltd., 2015,

pp. 1-4; Triton Chemical Manufacturing Co. Ltd., 2011, pp. 3-4; Wykamol Group, 2009, pp. 1-2).

The aim of this on-site work was to provide answers to two questions: firstly, what components of the remedial method provides a damp proofing effect? And, secondly, how would rising damp respond if low-permeability cement render was applied in the absence of any attempt to actively control capillary moisture? These two questions can be reframed as the following four statements:

1. Moisture in the ground is said to rise up the mortar joints by capillary action (Coleman, 1990, p. 26; Safeguard Europe Ltd., 2007, p. 5). Would drilling holes at the intersection of each perpendicular joint and the horizontal mortar bed joint disrupt this mechanism and thereby depress rising damp?

2. Following installation in the base of a wall, the damp proofing cream is intended to reduce capillary moisture by depressing the vertical rise of water from the ground. If the associated plastering work is not undertaken and hygroscopic moisture is therefore not controlled does the installation of the damp proofing cream in isolation offer any benefit?

3. Stripping the plaster and reinstating with low-permeability cement render is required to control hygroscopic ground salts that remain present in the masonry walls. Such renders are highly water resistant (Trotman, Sanders, & Harrison, 2004, p. 162). Is it the render rather than the cream that provides the damp proofing effect?

4. Given that low-permeability cement render is water resistant, if this render is applied to a wall affected by rising damp without any other intervention (i.e. in the absence of any attempt to prevent capillary moisture rise) does the height attained by capillary moisture increase?

Thus, including the 'no treatment' of the control panel, these effects were to be tested, respectively, by allocating to them one of the following five treatments:

1. No treatment;

2. Drill holes into the lowest horizontal mortar bed joint in the configuration typically required for the installation of silane/siloxane damp proofing cream (i.e. 12 mm diameter holes drilled to a nominal depth of 100 mm at the intersection with each perpendicular mortar joint);

3. Drill holes into the lowest horizontal mortar bed joint in the configuration typically required for the installation of silane/siloxane damp proofing cream and install the damp proofing cream;

4. Remove plaster and reinstate with the specification typically used following the installation of a remedial damp proof course (i.e. low-permeability cement render containing a proprietary salt inhibiting additive, finished with a coat of gypsum plaster);

5. Remove plaster, reinstate with the specification typically used following the installation of a remedial damp proof course, drill holes into the lowest horizontal mortar bed joint in the configuration typically required for the installation of silane/siloxane damp proofing cream, and install the damp proofing cream.

Construction works involved in the foregoing were to be carried out under supervision by operatives employed by my business. Before these activities could commence, each panel needed to be allocated a specific treatment. To which panel a particular treatment should apply was partly governed by site conditions—for example, the control could be neither Panel A nor Panel B because plaster was absent from their base—and partly through the desire to avoid any one treatment adversely interfering with another. Thus,

treatment 2 (drilling only) would be applied to the panel adjacent to the control and treatments 4 and 5, which involved the application of low-permeability cement render, would not be allocated to adjacent panels.

Table 11 below illustrates the mapping of treatments to individual test panels: treatments 1, 2, 3, 4, and 5 assigned to Panels E, D, A, B, and C respectively.

Treatment ref.	Treatment type	Panel	Location
1	No treatment (control panel).	E	Living room; rear wall; right-hand end.
2	Drill holes into the lowest horizontal mortar bed joint in the configuration typically required for the installation of silane/siloxane damp proofing cream (i.e. 12 mm diameter holes drilled to a nominal depth of 100 mm at the intersection with each perpendicular mortar joint).	D	Living room; rear wall; mid-section.
3	Drill holes into the lowest horizontal mortar bed joint in the configuration typically required for the installation of silane/siloxane damp proofing cream and install the damp proofing cream.	A	Understairs cupboard; right-hand side wall; rear end.
4	Remove plaster and reinstate with the specification typically used following the installation of a remedial damp proof course (i.e. low-permeability cement render containing a proprietary salt inhibiting additive, finished with a coat of gypsum plaster).	B	Understairs cupboard; right-hand side wall; front end.
5	Remove plaster, reinstate with the specification typically used following the installation of a remedial damp proof course, drill holes into the lowest horizontal mortar bed joint in the configuration typically required for the installation of silane/siloxane damp proofing cream, and install the damp proofing cream.	C	Living room; rear wall; left-hand end.
Table 11: Mapping of treatments to individual test panels.			

The individual components and methods used to measure moisture were discussed in Chapter 4. The precise arrangement of these apparatus with respect to the panels is described in detail later in this chapter; however, installation of the equipment required a series of holes to be drilled. The dust produced by these drillings was retained and processed using the gravimetric analysis method to determine the baseline moisture

content of each panel at commencement of the monitoring phase. Thus, this Stage 3 phase of the project would be undertaken in four distinct steps, as set out in Table 12 below:

Stage 3	**Step 1**	(Panels B and C) undertake plastering works associated with treatments 4 and 5.
	Step 2	(Panels A-E) drill panel face to install moisture monitoring apparatus and collect drillings for Stage 3 moisture analyses.
	Step 3	(Panels A-E) undertake Stage 3 baseline moisture analyses using drillings obtained at Step 2.
	Step 4	(Panels A, C, and D) drill mortar bed joint and install damp proofing cream where applicable (i.e. in Panels A and C) to complete treatments 2, 3, and 5.
Table 12: The four steps of project Stage 3.		

With specific treatments identified and mapped to individual test panels, the practical work in setting up each panel could proceed.

6.3. Stage 3 Step 1: (Panels B and C) plastering works associated with treatments 4 and 5

The existing plasterwork was stripped from both sides of Panels B and C. The plasters' appearance suggested that rather than an original lime-based type, characteristic of the age and construction of a house of this era, it comprised cement render overlaid with a finish coat of plaster. This was entirely consistent with the assumption made at survey stage that remedial damp proof course work had previously been undertaken at the house.

The existing plaster on the face of Panel B was relatively thin, being just 3-5 mm thick, and varied from 8-20 mm on the face of Panel C and on the reverse side of both panels, as shown in Figure 76 and Figure 77 below.

Figure 76: Panel B with existing plaster stripped.

Removal of the existing plaster from Panel B revealed it to be a slender coating just 3-5 mm thick. The underlying masonry wall was painted with white emulsion, which had deteriorated in the damp region at the base of the wall base, exposing the underlying brickwork.

Figure 77: Panel C with existing plaster stripped.

Removal of the existing plaster from Panel C revealed it to vary in thickness from 8-20 mm. The existing plaster on the reverse sides of both Panel C and Panel B was of similar thickness.

Manufacturers of damp proofing systems typically require the render used in reinstatement to have a total thickness of 20-24 mm (Safeguard Europe Ltd., 2005, p. 2; Wykamol Group, 2013, p. 2). Given that the prime function of the render is to prevent hygroscopic salts present in the underlying masonry wall from migrating into the plaster finish coat, it was perhaps unsurprising that Panel B's thin coating of plasterwork had exhibited significant dampness.

This project is designed to have a real world setting and therefore locations where plaster reinstatement would be limited to 8-20 mm were not a concern. Indeed, although contrary to manufacturer's specification, this thickness may well represent the norm in properties of this type and therefore be worthy of testing. However, this was not the case with respect to Panel B where the application of low-permeability cement

render was intended to evaluate the effect of restricting evaporation from the panel's surface and thus to determine how this may influence capillary moisture within the depth of the wall. Therefore, rather than attempt reinstatement within the available 3-5 mm thickness, 20 mm deep timber battens were fixed to the side and top edges of Panel B, as shown in Figure 78 below, to serve as guides and enable the manufacturer's specified thickness of render to be applied.

Figure 78: Panel B: low-permeability cement render applied.

20 mm thick battens were temporarily fitted at the top and side edges of Panel B to serve as guides and enable two accurately controlled 10 mm thick coats of cement render to be applied.

Mixing and application of the low-permeability cement render was undertaken in accordance with Safeguard Europe's specification for such work and their Renderguard

Gold additive was used in the batching water (Safeguard Europe Ltd., 2005).[31] Although not essential for the purposes of the study, a finish coat of Thistle Board Finish plaster was applied to the render. The completed plasterwork of Panel C's front face is shown in Figure 79 below with the reverse side of this panel and of Panel B shown in Figure 80 overleaf.

Figure 79: Panel C on completion of plasterwork reinstatement.

Panel C four days after the plaster finish coat had been applied to the low-permeability cement render backing coat.

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[31] Technically, any damp proofing manufacturers' products could have been used for this project. Safeguard Europe's products were chosen because they are well known within the construction industry, are familiar to the operatives who carried out the treatment works, and have been used in studies by other researchers (Burkinshaw, 2010; Rirsch & Zhang, 2010).

Figure 80: Panels B and C reverse side on completion of plasterwork reinstatement.

Reverse side of Panel B (right side of door opening) and Panel C (left side of door opening) after the plaster finish coat had been applied to the low-permeability cement render backing coat.

The existing plasterwork that was not to be removed from Panels D and E extended down to meet the solid floor. The mechanism by which plasterwork detailed in this manner can bridge a damp proof course was described in Chapter 4. In contrast, the plasterwork was missing from the bottom three courses of Panel A. Given that Panel A was to receive no intervention other than the installation of the damp proofing cream, the bricks at its base would remain exposed. Thus, for consistency with Panel A, to facilitate drilling and the installation of the damp proofing cream into Panels C and D, and to ensure that this damp proof course could not be bridged, the bottom edges of the plasterwork of Panels C, D, and E were trimmed above the height of the lowest horizontal mortar joint.

However, because Panel B was intended to test the effect of applying a low-permeability render to damp masonry, to avoid inadvertent moisture loss, its render coat was purposely extended down to meet the solid floor and its bottom edge not trimmed.

6.4. Stage 3 Step 2: (Panels A-E) moisture monitoring apparatus preliminary set up

A pilot study had determined that the following methods would be used in this project as the mechanism to dynamically monitor moisture change in the test panels:

1. Protimeter measure-mode values recorded directly from the panels;

2. Protimeter search-mode values recorded directly from the panels;

3. Vapour pressure values extrapolated from relative humidity and temperature data measured by embedded Protimeter Hygrosticks;

4. Protimeter measure-mode values recorded from the embedded Timber Probes Type 1.

Each component of these apparatus, as well as the gravimetric method of analyses used to determine the baseline and final moisture contents of each test panel at the start and end of the monitoring phase, was described in detail in Chapter 4. This chapter is concerned with how this equipment was configured.

For each test panel, the constituent parts of the apparatus were arranged about its vertical centre line in seven, essentially, identical rows. Each of these rows aligned with the approximate horizontal centre line of the seven lowest brick courses. Stage 2 moisture analyses had found significant moisture to only affect the four lowest brick courses of each test panel. By installing moisture measuring apparatus in these four brick courses and additionally in the three courses of bricks directly above, it would be possible to monitor moisture changes not only in the specific parts known to be damp

but also in dry masonry. For this reason, although Stage 2 moisture analyses had made use of masonry samples removed up to a maximum height of 750 mm above floor level, the quasi-experimental work would only be concerned with moisture in the base of the walls extending to the horizontal centre line of the seventh brick course, a nominal height of 545 mm above internal floor level.

To install Humidity Sleeves, Timber Probes Type 1, and to facilitate insertion of the Protimeter Deep Wall Probes required the drilling of single 16 mm, single 9 mm, and pairs of 5 mm diameter holes, respectively, in each row. The single 16 mm and 9 mm diameter holes were drilled at a distance of 50 mm to each side of the panel's vertical centre line and to depths of 45 mm and 60 mm, respectively. The two 5 mm diameter holes of each pair were drilled to a depth of 50 mm and spaced 12.5 mm each side of the vertical centre line so that when inserted the Deep Wall Probes would replicate the 25 mm needle spacing of the Protimeter Heavy Duty Probe. Thus, the holes for the apparatus spanned a width of 100 mm.

This drilling pattern was repeated for each of the seven rows on all five panels, as illustrated in Figure 81 below. For reference purposes, individual lines of apparatus are identified by their respective panel letter and row number: for example, A1 is the lowest row of Panel A and E7 the uppermost row of Panel E. The dust produced by drilling the 9 mm and 16 mm diameter holes was retained for gravimetric moisture analyses, as described later in this chapter.
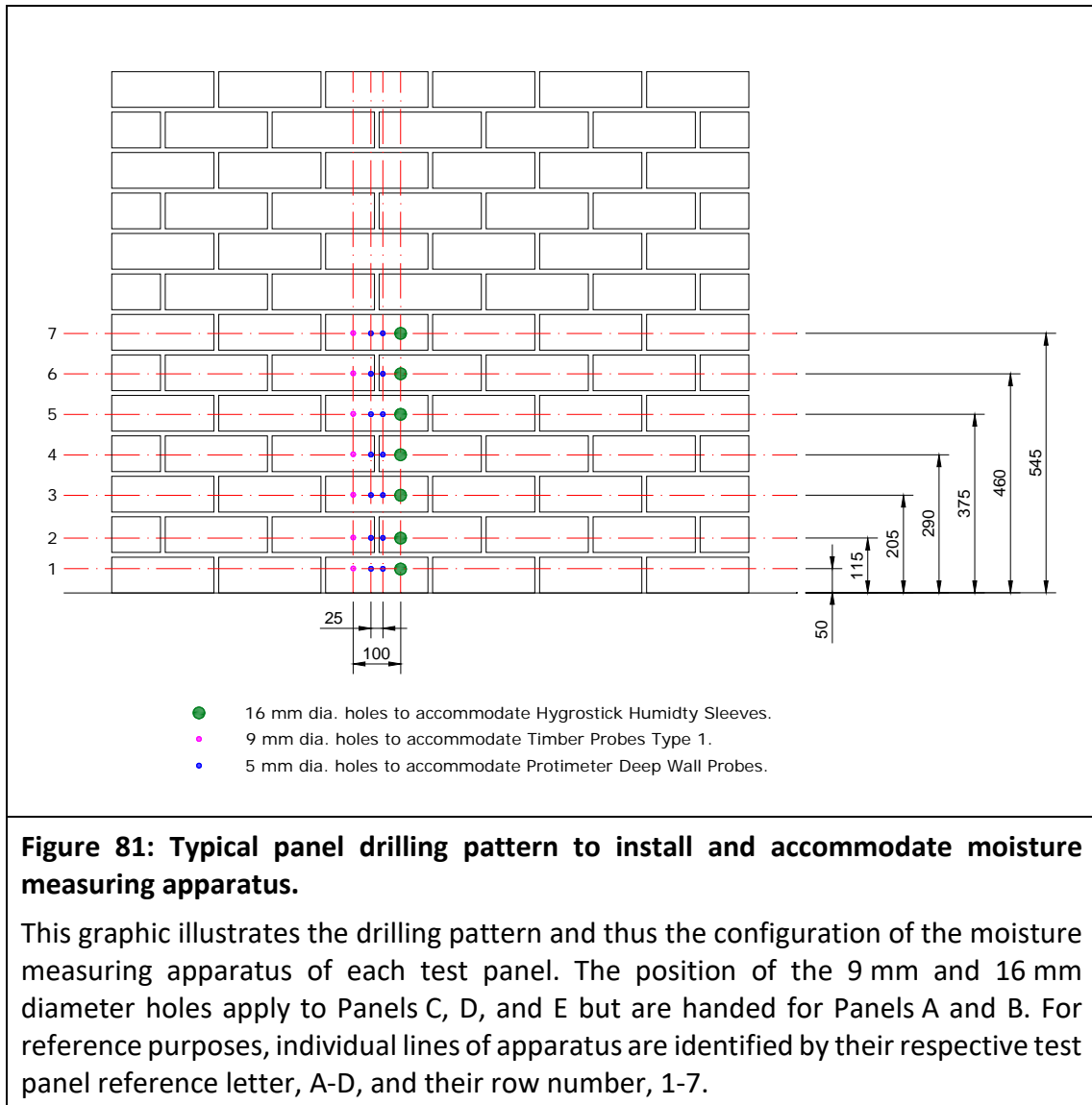
Figure 81: Typical panel drilling pattern to install and accommodate moisture measuring apparatus.

This graphic illustrates the drilling pattern and thus the configuration of the moisture measuring apparatus of each test panel. The position of the 9 mm and 16 mm diameter holes apply to Panels C, D, and E but are handed for Panels A and B. For reference purposes, individual lines of apparatus are identified by their respective test panel reference letter, A-D, and their row number, 1-7.

A proprietary Humidity Sleeve was inserted into each of the 16 mm diameter holes; a Timber Probe Type 1 inserted into each of the 9 mm diameter holes and sealed with a butyl rubber plug to prevent moisture loss; and, finally, a pre-programmed Lascar ELB-USB-2+ data logger was mounted on the face of each panel between rows 2 and 3 using a proprietary bracket screw fixed in position. A Lascar data logger was similarly attached at mid-height to the living room's rear wall, directly above Panel D, and placed outside the house. Figure 82 below shows Panel C after the holes to accommodate the moisture measuring apparatus had been drilled and the Timber Probes Type 1, Humidity Sleeves, and Lascar data logger installed.
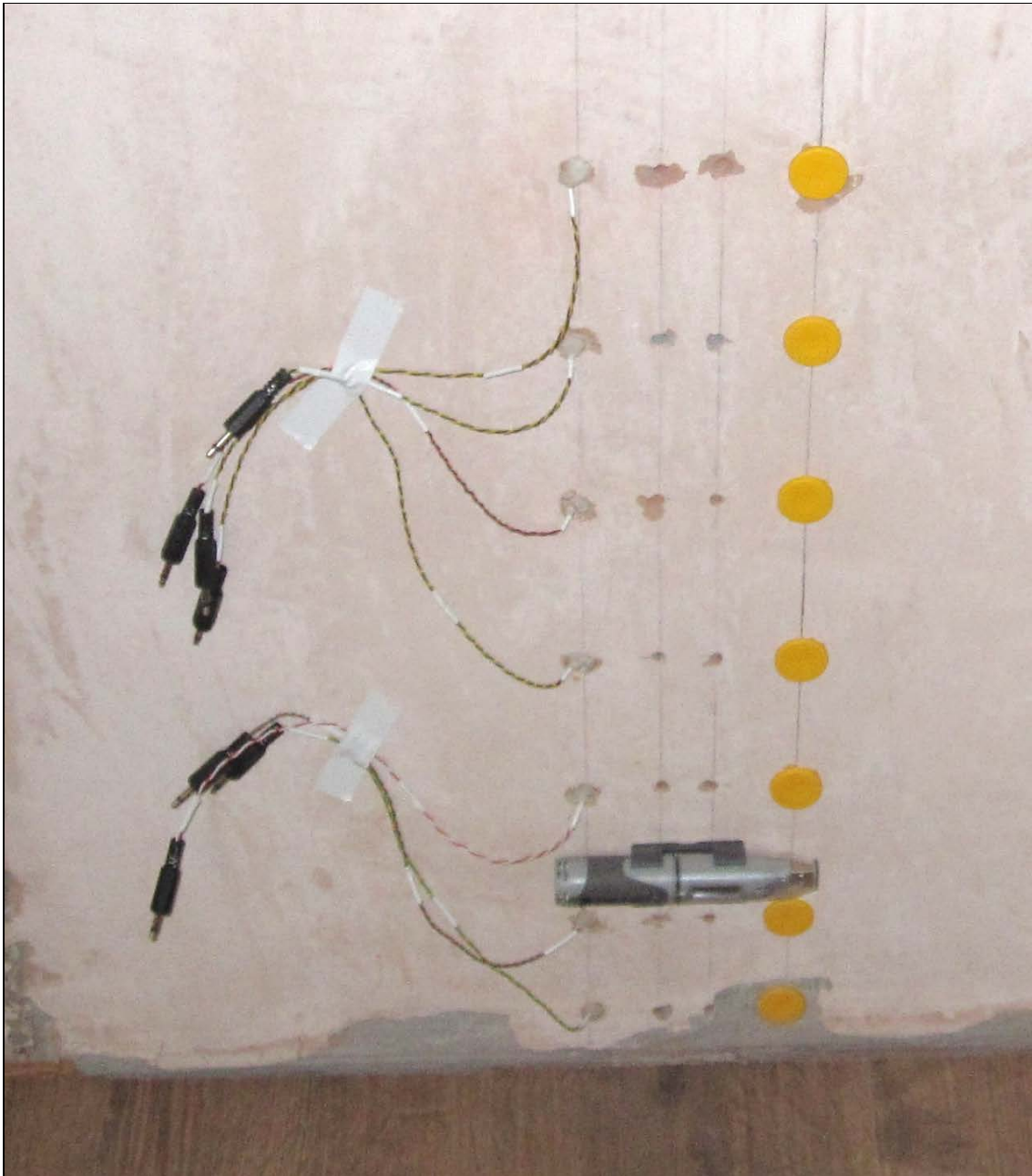
Figure 82: Panel C typical moisture measuring apparatus configuration.

Typical configuration of test panel following installation of moisture measuring apparatus. Each of the seven rows comprises a Timber Probe Type 1, a pair of 5 mm diameter holes to accommodate the Protimeter Deep Wall Probes, and a Humidity Sleeve with its end cap fitted. A Lascar data logger is mounted on the wall surface between rows 2 and 3. At this stage of panel setup, the bottom edge of the plasterwork has not been trimmed.

Figure 83 below shows the same panel with Hygrosticks inserted into each of the Humidity Sleeves.

Figure 83: Panel C typical moisture measuring apparatus configuration with Hygrosticks in place.

Typical configuration of test panels following installation of the Hygrosticks into the Humidity Sleeves.

This panel configuration was the basic arrangement of the moisture measuring apparatus at the start of the study. Certain issues and experience gained during the initial phase of data collection necessitated some changes that are described later in this chapter.

6.5. Stage 3 Step 3: (Panels A-E) baseline moisture analyses

This section describes Stage 3 Step 3, the gravimetric analyses to determine the baseline moisture content of the panels; a process that was intended to serve two purposes.

Firstly, it would provide the baseline moisture content of the test panels in each row position at the start of the study, with these values subsequently compared to those derived from a similar set of samples removed from the test panels at Stage 5, the last phase of the study.

Secondly, given the results of Stage 2 analyses, the distribution of the hygroscopic and capillary moisture determined at Stage 3 should add support to the claim that rising damp affected the base of the ground floor walls.

The drillings from the two outermost holes of each panel row were to be used for these analyses. Where plasterwork was present, this portion of the drillings was separated from the underlying masonry portion, thus providing 138 separate samples: twenty-eight from each of Panels B, C, D, and E and twenty-two from Panel A. In the majority of cases, and as intended, the portion of the samples taken from the underlying masonry walls contained only brick; however, two samples comprised mortar and four a mixture of brick and mortar, presumably because the drill had inadvertently struck horizontal or, more probably, perpendicular joints. The precise locations of these mortar or mixed brick and mortar samples are shown in Table 13 below.

Panel ref.	Row	Height (mm)	Hole dia. (mm)	Material
E	7	545	9	Mortar
A	6	460	16	Brick & mortar
D	2	115	9	Brick & mortar
D	2	115	16	Brick & mortar
E	1	50	9	Mortar
E	1	50	16	Brick & mortar
Table 13: Stage 3 moisture analysis location of masonry of material other than brick.				

The six samples referenced in Table 13 comprised just 4% of the total sample set of the underlying masonry walls: a small percentage that is arguable not statistically significant (Everitt, 2006, p. 364; Leedy & Ormrod, 2005, p. 279; Saunders, Lewis, & Thornhill, 2009, p. 450). In any case, Stage 3 analyses found the moisture contents of samples containing mortar to be consistent with that of the pure brick samples obtained from adjacent rows. Therefore, any concerns with respect to present or future samples that may inadvertently comprise mortar would seem unfounded.

Stage 3 moisture analyses found the distribution of capillary and hygroscopic moisture in the masonry wall of all five test panels to be generally consistent and to align with the findings of the Stage 2 analyses with two notable exceptions: the brick samples removed from the 9 mm diameter hole of Panel A's row 2 and the 16 mm diameter hole of Panel B's row 3.

In the case of the 9 mm diameter brick sample A2, its capillary moisture content, at 0.7%, was far lower than the 13.8% and 4% found in the 9 mm diameter samples obtained from A1 and A3 (i.e. the rows directly above and below), as illustrated in Table 14 below.

Vertical	Masonry: 9 mm dia.			Vertical	Masonry: 16 mm dia.			Vertical	Masonry		
Position	TMC	HMC	CMC	Position	TMC	HMC	CMC	Position	TMC	HMC	CMC
7	0.1%	0.2%	-0.1%	7	0.3%	0.3%	0.0%	7	0.1%	0.2%	-0.1%
6	0.3%	0.4%	-0.1%	6	0.6%	0.7%	-0.1%	6	0.1%	0.1%	0.0%
5	2.4%	1.9%	0.5%	5	1.3%	1.5%	-0.2%	5	0.9%	1.0%	-0.1%
4	8.5%	7.2%	1.3%	4	5.9%	5.0%	0.9%	4	6.3%	5.6%	0.7%
3	8.1%	4.1%	4.0%	3	8.2%	3.5%	4.7%	3	7.5%	5.2%	2.3%
2	1.8%	1.1%	0.7%	2	13.5%	0.9%	12.6%	2	12.9%	1.5%	11.4%
1	14.7%	0.9%	13.8%	1	15.2%	1.1%	14.1%	1	14.8%	1.0%	13.8%
Panel A Stage 3 moisture analysis: masonry of 9 mm diameter drill holes.				**Panel A Stage 3 moisture analysis: masonry of 16 mm diameter drill holes.**				**Panel A Stage 2 moisture analysis: masonry of single samples.**			

In the above three charts, the results from Panel A's row 2 are highlighted in yellow.

The left-hand chart shows the CMC value of the sample removed from the 9 mm dia. hole A2 at Stage 3 to be low (0.7%) when compared to the CMC values of A1 and A3 directly below and above.

The middle chart, which uses the other sample of this pair set obtained from the 16 mm dia. hole, shows the CMC value of A2 to be 12.6%. This is close to and logically slightly lower than the value of 14.1% obtained from A1, directly beneath.

The right-hand chart, which shows the results of the Stage 2 analysis, indicates the CMC value of row 2 to be 11.4%. This value and the overall CMC distribution of A1-A4 aligns well with the middle chart.

Considered together, these three charts suggest that the result obtained from the masonry sample of the 9 mm dia. hole of Panel A's row 2 is inconsistent with the adjacent 16 mm dia. hole and the result derived from Stage 2 analyses.

Table 14: Panel A: Stage 2 and Stage 3 masonry moisture analysis compared.

In the case of the 16 mm diameter brick sample removed from B3, its capillary moisture content, at 1.1%, was far lower than the 7.9% and 8.6% found in the 16 mm diameter sample obtained from B2 and B4, the rows directly above and below, as illustrated in Table 15 below.

Vertical Position	Masonry: 16 mm dia.			Vertical Position	Masonry: 9 mm dia.			Vertical Position	Masonry		
	TMC	HMC	CMC		TMC	HMC	CMC		TMC	HMC	CMC
7	5.2%	0.6%	4.6%	7	3.7%	0.4%	3.3%	7	0.1%	0.2%	-0.1%
6	2.3%	0.3%	2.0%	6	1.8%	0.5%	1.3%	6	0.1%	0.3%	-0.2%
5	1.9%	0.4%	1.5%	5	5.6%	1.7%	3.9%	5	0.3%	0.3%	0.0%
4	9.5%	1.6%	7.9%	4	8.1%	3.4%	4.7%	4	4.6%	4.8%	-0.2%
3	2.0%	0.9%	1.1%	3	8.6%	4.4%	4.2%	3	0.8%	1.2%	-0.4%
2	9.7%	1.1%	8.6%	2	11.4%	1.9%	9.5%	2	9.8%	3.3%	6.5%
1	9.6%	1.9%	7.7%	1	12.2%	0.5%	11.7%	1	10.8%	0.1%	10.7%

Panel B Stage 3 moisture analysis: masonry of 16 mm diameter drill holes.	Panel B Stage 3 moisture analysis: masonry of 9 mm diameter drill holes.	Panel B Stage 2 moisture analysis: masonry of single samples.

In the above three charts, the results from Panel B's row 3 are highlighted in yellow.

The left-hand chart shows the CMC values of the sample removed from the 16 mm dia. hole B3 at Stage 3 to be low (1.1%) when compared to the CMC values of B2 and B4 directly below and above.

The middle chart, which uses the other sample of this pair set obtained from the 9 mm dia. hole, shows the CMC values of B3 to be 4.2%, which looks to better fit the moisture distribution of the wall profile.

The right-hand chart, which shows the results of the Stage 2 analysis, indicates the CMC value of B3 to be -0.4% (i.e. zero) and in consideration of B1-B3 of this chart, suggests a similar profile to that of the left-hand chart.

Considered together, these three charts suggest a potential inconsistency with respect the results for the samples removed from the 16 mm dia. holes at Stage 3.

Table 15: Panel B: Stage 2 and Stage 3 masonry moisture analysis compared.

Given the two anomalous results, 9 mm A2 and 16 mm B3, two additional samples were removed from row 2 of Panels A and B, approximately 100 mm to the side of the original sampling points, and processed to determine their moisture contents.

For the additional brick sample removed from A2, its capillary moisture content, at 9.7%, corresponded well with the earlier results and, as shown in the modified charts of Table 16, below demonstrates are far more logical moisture profile at the wall base.

Vertical Position	Masonry: 9 mm dia.			Vertical Position	Masonry: 16 mm dia.			Vertical Position	Masonry		
	TMC	HMC	CMC		TMC	HMC	CMC		TMC	HMC	CMC
7	0.1%	0.2%	-0.1%	7	0.3%	0.3%	0.0%	7	0.1%	0.2%	-0.1%
6	0.3%	0.4%	-0.1%	6	0.6%	0.7%	-0.1%	6	0.1%	0.1%	0.0%
5	2.4%	1.9%	0.5%	5	1.3%	1.5%	-0.2%	5	0.9%	1.0%	-0.1%
4	8.5%	7.2%	1.3%	4	5.9%	5.0%	0.9%	4	6.3%	5.6%	0.7%
3	8.1%	4.1%	4.0%	3	8.2%	3.5%	4.7%	3	7.5%	5.2%	2.3%
2	12.0%	2.3%	9.7%	2	13.5%	0.9%	12.6%	2	12.9%	1.5%	11.4%
1	14.7%	0.9%	13.8%	1	15.2%	1.1%	14.1%	1	14.8%	1.0%	13.8%
Panel A Stage 3 moisture analysis: masonry of 9 mm diameter drill holes using the additional sample from row 2.				**Panel A Stage 3 moisture analysis: masonry of 16 mm diameter drill holes.**				**Panel A Stage 2 moisture analysis: masonry of single samples.**			

In this modified version of Table 14, the CMC value of 9.7%, obtained from the additional sampling hole, has been inserted in the left-hand chart at position A2, replacing the original result of the sample removed from the 9 mm dia. hole. This modification creates a smooth and logical moisture gradient over A1-A4 and aligns with the earlier results of samples removed from the 16 mm dia. holes, shown in the middle chart, and those from the Stage 2 analysis, shown in the right-hand chart.
Table 16: Panel A: Stage 2 and modified Stage 3 masonry moisture analysis compared.

For Panel B, the analysis of the additional sample removed from row 3 revealed it to have a capillary moisture content of -0.1%. This is lower than the original sample and essentially identical to -0.4% found at Stage 2 analyses, as shown in the modified charts in Table 17 below.

Vertical Position	Masonry: 16 mm dia.			Vertical Position	Masonry: 9 mm dia.			Vertical Position	Masonry		
	TMC	HMC	CMC		TMC	HMC	CMC		TMC	HMC	CMC
7	5.2%	0.6%	4.6%	7	3.7%	0.4%	3.3%	7	0.1%	0.2%	-0.1%
6	2.3%	0.3%	2.0%	6	1.8%	0.5%	1.3%	6	0.1%	0.3%	-0.2%
5	1.9%	0.4%	1.5%	5	5.6%	1.7%	3.9%	5	0.3%	0.3%	0.0%
4	9.5%	1.6%	7.9%	4	8.1%	3.4%	4.7%	4	4.6%	4.8%	-0.2%
3	0.5%	0.6%	-0.1%	3	8.6%	4.4%	4.2%	3	0.8%	1.2%	-0.4%
2	9.7%	1.1%	8.6%	2	11.4%	1.9%	9.5%	2	9.8%	3.3%	6.5%
1	9.6%	1.9%	7.7%	1	12.2%	0.5%	11.7%	1	10.8%	0.1%	10.7%

Panel B Stage 3 moisture analysis: masonry of 16 mm diameter drill holes using the additional sample from row 3.	Panel B Stage 3 moisture analysis: masonry of 9 mm diameter drill holes.	Panel B Stage 2 moisture analysis: masonry of single samples.

In this modified version of Table 15, the CMC value of -0.1%, obtained from the additional sampling hole, has been inserted in the left-hand chart at position B3, replacing the original result of the sample removed from the 16 mm dia. hole. This modification better aligns the left-hand chart with the right-hand chart (the results from Stage 2 analysis) and suggests that the CMC of B3 in this region of the panel is accurate.

Table 17: Panel B: Stage 2 and Stage 3 modified masonry moisture analysis compared.

The variation in the moisture content of Panel B is attributed to construction moisture present in the render applied to its face. This is illustrated by comparing the TMC and CMC values derived at Stage 3, shown in Table 15 and Table 17 above, with those from Panel A, shown in Table 14 and Table 16 above. Moisture present in the upper rows of Panel B is completely absent from these same locations in Panel A. Similarly, such moisture was also absent from Panels C, D, and E and indeed from Panel B when Stage 2 analyses were undertaken.

If necessary, the Stage 3 results from Panel B could be modified to regularise the data through reference to the Stage 2 results. In practice, precise quantification is of less importance than measuring how the moisture content of the panels may change over the duration of this study. Ample data is available for this purpose.

The results of Stage 3 moisture analyses were found to align closely with those derived at Stage 2; namely, that the distribution of hygroscopic and capillary moisture was consistent with the rising damp model (Coleman, 1990, pp. 15-22; Hall & Hoff, 2012, pp. 256-257; Kyte, 1987, p. 312; Trotman, 2007, pp. 5-6). Yet, the primary purpose of this exercise was to provide the baseline moisture content of the test panels at the start of the study and for these data to be used in conjunction with the results of Stage 5 moisture analyses, the final moisture contents of the panels and thus the moisture changes over the duration of the study. A discussion of these results is provided later in this chapter.

The necessity to take two additional masonry samples from A2 and B3 for Stage 3 moisture analyses had required the drilling of two further holes. Into these two extra holes were placed, respectively, an additional Timber Probe Type 1 and a Humidity Sleeve, as shown in Figure 84 and Figure 85 below, to complete the basic apparatus configuration of these two panels.

Figure 84: Panel A with additional Timber Probe Type 1 installed in row 2.

Panel A with moisture monitoring equipment in place. The additional Timber Probe Type 1 was installed in row 2 (arrowed) 100 mm to the left of the column of Humidity Sleeves.

Figure 85: Panel B with additional Humidity Sleeve installed in row 3.

Panel B with moisture monitoring equipment in place. The additional Humidity Sleeve was installed in row 3 (arrowed) 100 mm to the left of the original column of Humidity Sleeves. In this photograph, Hygrosticks are installed in the Humidity Sleeves of rows 1-5.

Stage 3 Step 2, preliminary panel set-up, had concluded. The intention was to allow ten days to enable the moisture content of the dowel body of the Timber Probes Type 1 and the pocket of air within each of the Humidity Sleeves to equilibrate before recording the first set of readings from each piece of equipment and then to proceed with Stage 3 Step 4, the damp proofing treatments of Panels A, C, and D.

6.6. Stage 3 Step 4: Panels A, C, and D damp proofing works associated with treatments 2, 3, and 5

Panel A was to receive the damp proofing cream but its plaster was not to be replaced. This damp proofing cream was installed in the lowest horizontal mortar bed joint using the procedure described earlier in this chapter and illustrated in Figure 86 and Figure 87 below.

Installation was undertaken by trained operatives employed by my business. The intention was for the method of work to match a real world application, albeit that the spacing and depth of each hole and the quantity of damp proofing cream inserted was carefully monitored to confirm that it complied with the manufacturer's specification for this work (Safeguard Europe Ltd., 2007, p. 12; Triton Chemical Manufacturing Co. Ltd., 2011, p. 2; Wykamol Group, 2009, p. 2).
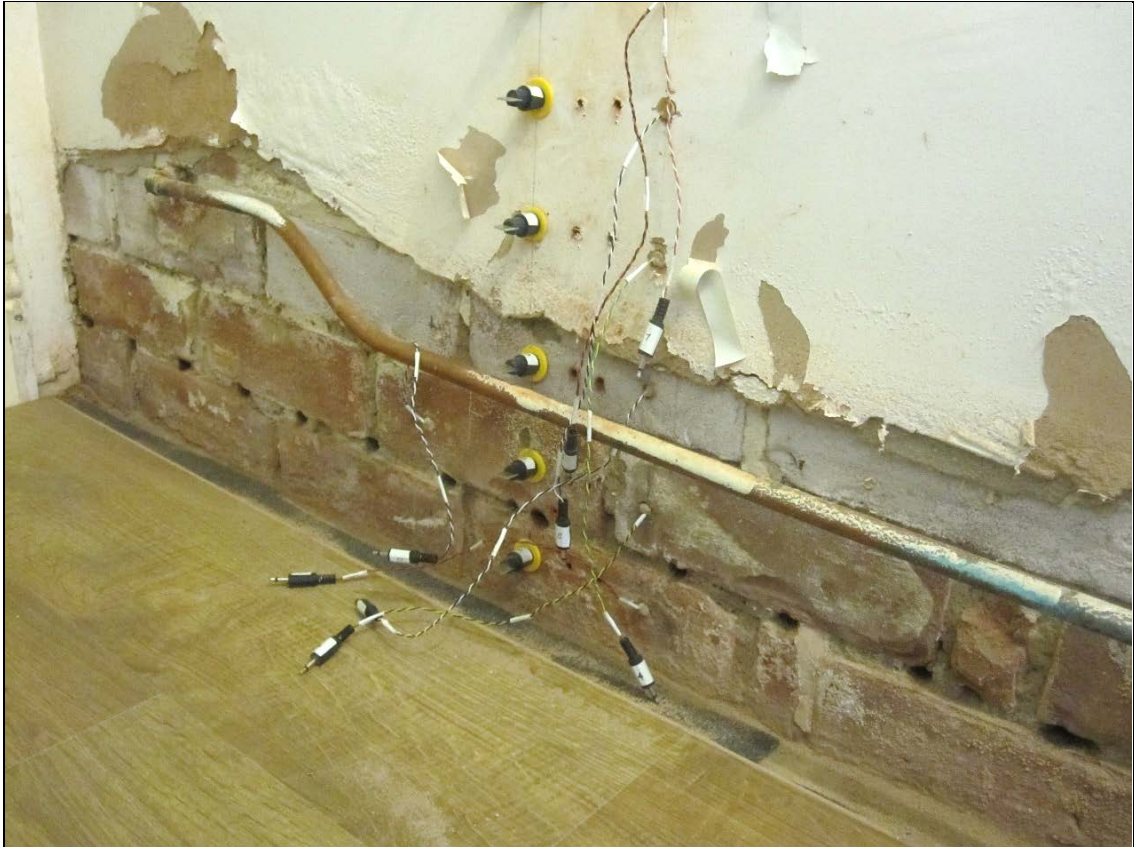
Figure 86: Panel A drilling pattern for the damp proofing cream.

In accordance with manufacturers' typical specification, 12 mm diameter holes, spaced at nominal 120 mm centres, were drilled to a depth of 100 mm into the lowest, horizontal mortar bed joint of Panel A. The missing plaster at the base of this panel meant that this joint was conveniently exposed.

Figure 87: Panel A inserting damp proofing cream into pre-drilled holes.

Inserting the damp proofing cream into the pre-drilled 12 mm diameter holes of Panel A using the proprietary applicator.

For Panel C, low-permeability cement render had been applied at Stage 3 Step 1. To facilitate installation of the damp proofing cream the bottom edge of this render was trimmed to expose the lowest horizontal mortar bed joint; in all other respects, the method of installation was identical to that used on Panel A, as shown in Figure 88 below.

Figure 88: Panel C inserting damp proofing cream into pre-drilled holes.

Inserting the damp proofing cream into the pre-drilled 12 mm diameter holes of Panel C using the proprietary applicator. To accommodate this treatment, the bottom edge of the render has been trimmed to expose the horizontal mortar bed joint.

For Panel D, the bottom edge of the existing plaster was trimmed to expose the lowest horizontal mortar bed joint. Holes were drilled into this joint of the same spacing and depth as those formed in Panels A and C, but the damp proofing cream was not inserted.

Finally, for consistency the bottom edge of the plasterwork of Panel E (the control) was trimmed above the lowest horizontal mortar bed joint. The arrangement of the three panels, C, D, and E, is shown in Figure 89 below.

Figure 89: Panels C, D, and E: initial test panel set-up complete.

Panels C, D, and E with initial set up complete:

- Moisture measuring apparatus installed;

- Panel C's low-permeability render applied;

- Bottom edge of plasterwork trimmed above the lowest horizontal mortar bed joint;

- Holes drilled in the lowest mortar bed joint of Panels C and D to accommodate the damp proofing cream;

- Damp proofing cream inserted into the pre-drilled holes of Panel C.

Thus, treatments 2, 3, and 5 were complete and with treatment 4, the low-permeability cement render of Panel B also applied, the configuration of the test panels concluded. Some changes were to be made during Stage 4, the data collection phase, and these and the data collection process are described in the next section.

6.7. Stage 4: data collection

At each visit to the houses the following data were recorded on a paper form and subsequently entered into an Excel Workbook for processing:

1. Date, time, and duration of visit;

2. Protimeter reference number and Calcheck (calibration) reading;

3. From each of the five test panels:

   3.1. Location of each Protimeter reading;

   3.2. Location and reference number of each Hygrostick;

   3.3. Location and reference number of each Lascar data logger;

   3.4. Relative humidity and temperature value from each Hygrostick;

   3.5. Relative humidity and temperature value from each Lascar data logger;

   3.6. Protimeter measure-mode reading of the wall surface using the Heavy Duty Probe;

   3.7. Protimeter measure-mode reading of the wall at depth using the Deep Wall Probes;

   3.8. Protimeter measure-mode reading of the timber Probes Type 1 using the connected 3.5 mm jack plugs;

   3.9. Protimeter search-mode readings;

4. Relative humidity and temperature value from Lascar data logger 6, mounted at the mid-point of the living room's rear wall;

5. Relative humidity and temperature value from Lascar data logger 7, located externally.

The paper data collection form was arranged with six tables: five configured to represent the apparatus of Panels A-E and the sixth to record data from the non-panel mounted Lascar data loggers 6 and 7. Version 1 of the data collection form is provided in Appendix 1.

The Lascar data loggers had been programmed to record environmental data continuously at one hour intervals throughout the monitoring period. So, in addition to spot readings taken from these instruments at each site visit, the recorded data was downloaded to a computer midway through and at the end of the data collection phase.

Apparatus installation and the first phase of treatment had concluded on the 14 September 2012. Following a ten-day period to allow the Timber Probes Type 1 and pocket of air in the Humidity Sleeves to equilibrate with the surrounding masonry, an initial set of readings was taken from the moisture measuring apparatus on the 24 September 2012. This day essentially marked the start of the monitoring period.

Treatments 2, 3, and 5, the remedial damp proof course work associated with Panels D, A, and C, respectively, (described earlier in Stage 3 Step 4) were completed fifteen days later, on the 9 October 2012, when the second set of readings was recorded. Subsequent data sets were logged on an approximate ten to eleven-day cycle with some variation to accommodate holidays, etc.

The data collection phase, which spanned a fifteen-month monitoring period and provided forty-four individual data sets, concluded on the 31 December 2013. At the outset, a single data set comprised 266 individual items and required around ninety minutes of on-site work to complete. There were, however, five issues that became apparent during data collection that necessitated changes to its protocol and to the moisture measuring apparatus:

1. The Protimeter MMS meter in measure-mode was slow to respond, particularly when taking readings from Timber Probes Type 1 located in the wetter wall parts;

2. Hygrosticks when moved from one Humidity Sleeve to another provided inconsistent readings, raising concern over their accuracy and reliability;

3. A fault in the central heating system resulted in high internal temperatures for several weeks;

4. Some of the Timber Probes Type 1 provided persistently high measure-mode readings, raising concerns that they had wiring faults;

5. The owner vacated the house towards the end of the data collection period.

These matters and the actions taken to alleviate or mitigate these concerns are described in the following sub-sections.

6.7.1. Issue 1: Protimeter MMS meter measure-mode function

Prior to the start of data collection, a Protimeter MMS meter intended to be used in this project had been serviced and checked for calibration by GE Sensing, the manufacturers. Although this essentially verified the instrument's accuracy, the response of its measure-mode function was subsequently found to be slow, taking several seconds for this value to stabilise when used on masonry materials and up to one minute when used with the Timber Probes Type 1, particularly where these probes were embedded in wetter regions of the panels. Given the number of separate readings that were required to be taken at each site visit, a problem that incurred unnecessary additional time was a concern.

Following consultation, GE Sensing attributed the slow instrument response to the updated version of the MMS meter's firmware (M. Fitzpatrick, personal communication, 4 April 2010). In the absence of a software fix, the matter was resolved by purchasing a different model, a Protimeter Surveymaster, which was brought in to service on the 1 November 2012 and used for the remainder of the project to record the measure-mode and search-mode readings. However, because the Surveymaster cannot read

Hygrosticks, this function, which was not affected by the firmware bug, was fulfilled by the original MMS meter.

Interestingly, while the maximum measure-mode reading displayed on the MMS meter had been a logical 100%, the maximum value for the Surveymaster never exceeded 98.2%, Still, this upper value is well within the acceptable operating parameters for this meter: in excess of 80% (M. Fitzpatrick, personal communication, 9 July 2013).

6.7.2. Issue 2: Hygrostick equilibration time and calibration drift

Each of the five test panels contained a column of seven Humidity Sleeves into which a Protimeter Hygrostick was to be inserted to record the relative humidity and temperature of the pocket of air that they contained. GE Sensing recommend Hygrosticks are inserted into Humidity Sleeves sixty minutes before measurements are taken to allow for equilibration (GE Sensing, 2005, p. 19).

The Humidity Sleeves had been installed in the panels seven days prior to recording the first data set and would be left in place until termination of this phase of the project. To install a Hygrostick into each sleeve required a stock of at least thirty-five.[32] However, Hygrosticks are relatively expensive, retailing at £44.00 each at the start of this study, and requiring a total expenditure of £1,540.00 to purchase thirty-five. As a compromise, balancing cost against practicality, the project was started with an initial stock of twenty Hygrosticks. Each Hygrostick was placed in one Humidity Sleeve and after its data had been recorded was moved to a second Humidity Sleeve and given sixty minutes to equilibrate before these second readings were recorded.

After collecting the first few data sets, anomalous values were apparent: relative humidities recorded from Hygrosticks that had been relocated and allowed sixty

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[32] As explained earlier in this chapter, an additional Humidity Sleeve was installed in Panel B's row 3, where the check sample for Stage 3 moisture analysis was removed, so, technically, Panel B could accommodate eight Hygrosticks, increasing the total to thirty-six.

minutes to equilibrate were inconsistent with readings taken from the same location where equilibration was equivalent to the period between data collection visits. In addition, some relative humidity readings differed sufficiently, from values recorded earlier in the same location and from adjacent Hygrosticks, to suggest that these sensors may be faulty.

It is a simple process to test Hygrosticks for calibration either by comparing them to reference probes or by using a standard salts solution (GE Sensing, 2005, p. 16). As described in Chapter 4, a testing apparatus using this latter method had been constructed specifically for this purpose.

For tracking purposes, each Hygrostick had been referenced with the letter 'H' and a number based on its chronology: hence, H1-H20 were used as the references for the initial stock of twenty Hygrosticks. Hygrostick, H14, was the first suspected to be faulty. It was taken off site, tested, and with a relative humidity value of 68.2% at 19.8°C against a nominal tolerance of 75.0% ± 2.0% at the same temperature, confirmed to be faulty. H14 had only been in use for four weeks, so this raised concerns over the integrity of the values from the nineteen Hygrosticks that remained in service.

The issues of slow equilibration and rapid calibration drift were referred to GE Sensing who suggested that a solution to mitigate both of these concerns was an increase in stock to enable all of the Humidity Sleeves to have a Hygrostick and to provide a surplus to enable systematic testing. By way of assistance, GE Sensing kindly offered a 40% discount against the Hygrostick's purchase price (P.Leach, personal communication, 24 October 2012).

An additional twenty-five Hygrosticks were purchased, increasing the stock to forty-five. This enabled thirty-six to be in use at any one time, one for each Humidity Sleeve, along with nine spares. The additional Hygrosticks were received on the 9 November 2012, labelled H21-H45, using the convention previously described, and installed into the empty Humidity Sleeves. Four days later the sixth data set was recorded. With one

Hygrostick in each of the thirty-six Humidity Sleeves data collection was notably easier and as envisaged effectively alleviated concerns with respect to slow equilibration.

To maintain their accuracy, GE Sensing recommend that Hygrosticks should not be permanently placed in saturated environments and in circumstances where this is not possible frequently checked for calibration and replaced as necessary (GE Sensing, 2005, p. 16). Gravimetric analyses had determined the upper regions of the test panels to be dry and for significant moisture only to be present in the bottom four brick courses. Technically, excessive capillary moisture (i.e. potential saturation) only affected the bottom two brick courses.

This situation presented something of a dilemma: leaving the Hygrosticks in place avoided equilibration issues but it could potentially increase saturated environment related failure rates. On balance, enabling the Hygrosticks to properly equilibrate to their environment and therefore to provide consistent readings was considered a priority. Nevertheless, to mitigate concerns with respect to the effect of saturation and of calibration drift more generally, an operating protocol was implemented: Hygrosticks installed in wet regions of the panels were relocated to drier parts following each data collection visit and the entire stock was rotated to enable continuous testing.

This rotation method is illustrated in Table 18, Table 19, and Table 20 below, which demonstrates how the Hygrosticks were repositioned to mitigate the effects of saturated masonry and to facilitate systematic testing.

		PANEL				
		A	**B**	**C**	**D**	**E**
ROW	**7**	H1	H8	H16	H23	H30
	6	H2	H9	H17	H24	H31
	5	H3	H10	H18	H25	H32
	4	H4	H11	H19	H26	H33
	3	H5	H12 & H13	H20	H27	H34
	2	H6	H14	H21	H28	H35
	1	H7	H15	H22	H29	H36

Table 18: Hygrostick rotation method step 1.

In this example, Hygrosticks H1-H36 are installed in the Humidity Sleeves in numerical order: A7-A1, B7-B1, C7-C1, D7-D1, and E7-E1. Each row of this table is colour filled to aid tracking of the later positions of each Hygrostick in Table 19 and Table 20 below. Note that an additional Humidity Sleeve had been installed in Panel B's row 3, hence the reason for two Hygrosticks to be referenced in table cell B3 and for a total of thirty-six to be in use at any one time.

		PANEL				
		A	**B**	**C**	**D**	**E**
ROW	**7**	H28	H35	H43	H14	H21
	6	H29	H36	H44	H15	H22
	5	H30	H37	H9	H16	H23
	4	H31	H38	H10	H17	H24
	3	H32	H39 & H40	H11	H18	H25
	2	H33	H41	H12	H19	H26
	1	H34	H42	H13	H20	H27

Table 19: Hygrostick rotation method step 2.

Configuration of Hygrosticks after first re-position: H1-H8 removed for testing; Hygrosticks H9-H36 moved forwards nine places; Hygrosticks H37-H44 (introduced from the stock) inserted into the empty Humidity Sleeves at locations B5, B4, B3 (two), B2, B1, C7 and C6. Hygrosticks formerly in the lower, wetter, rows of the panels are thus re-located into the upper, drier rows and vice versa.

		PANEL				
		A	**B**	**C**	**D**	**E**
ROW	**7**	H18	H25	H33	H40	H3
	6	H19	H26	H34	H41	H4
	5	H20	H27	H35	H42	H5
	4	H21	H28	H36	H43	H6
	3	H22	H29	H37	H44	H7
	2	H23	H30 & H31	H38	H1	H8
	1	H24	H32	H39	H2	H17

Table 20: Hygrostick rotation method step 3.

Configuration of Hygrosticks after second re-position: H9-H16 removed for testing; Hygrosticks H17-H36 moved forwards ten places; Hygrosticks H1-H8 (following successful calibration testing) reintroduced into the empty Humidity Sleeves at locations D2, D1, E7, E6, E5, E4, E3, and E2. Hygrosticks formerly in the lower, wetter, rows of the panels are re-located into the upper, drier rows and vice versa.

In practice, despite employing a method that enabled the Hygrosticks to be periodically tested for calibration drift, left in place for sufficient time to equilibrate, and mitigate the potential effects of saturated masonry, rotation was not straightforward because throughout the data collection phase ongoing failures depleted the available stock, necessitating ad hoc shuffling and redistribution of Hygrosticks in use until new replacements were supplied.

To monitor Hygrostick use, their unique serial number, date when first used, date and result of each calibration test, and, if applicable, the date of failure and withdrawal from service was logged in a spreadsheet of the Excel workbook. Overtime, this log proved to be extremely useful as a mechanism to relay data to GE Sensing as they endeavoured to establish why these failures had occurred.

At the start of the project, in September 2012, twenty Hygrosticks were available for use, by mid November 2012 the stock had increased to forty-five, but over the following thirteen months, thirty-nine of the original Hygrosticks had been replaced because of

calibration drift. When the project concluded at the end of December 2013 a total of eighty-four separate Hygrosticks had been used. Final testing, undertaken on the 14 January 2014, revealed just eleven of the eighty-four to remain within acceptable calibration, as shown in Figure 90 and Figure 91 below.
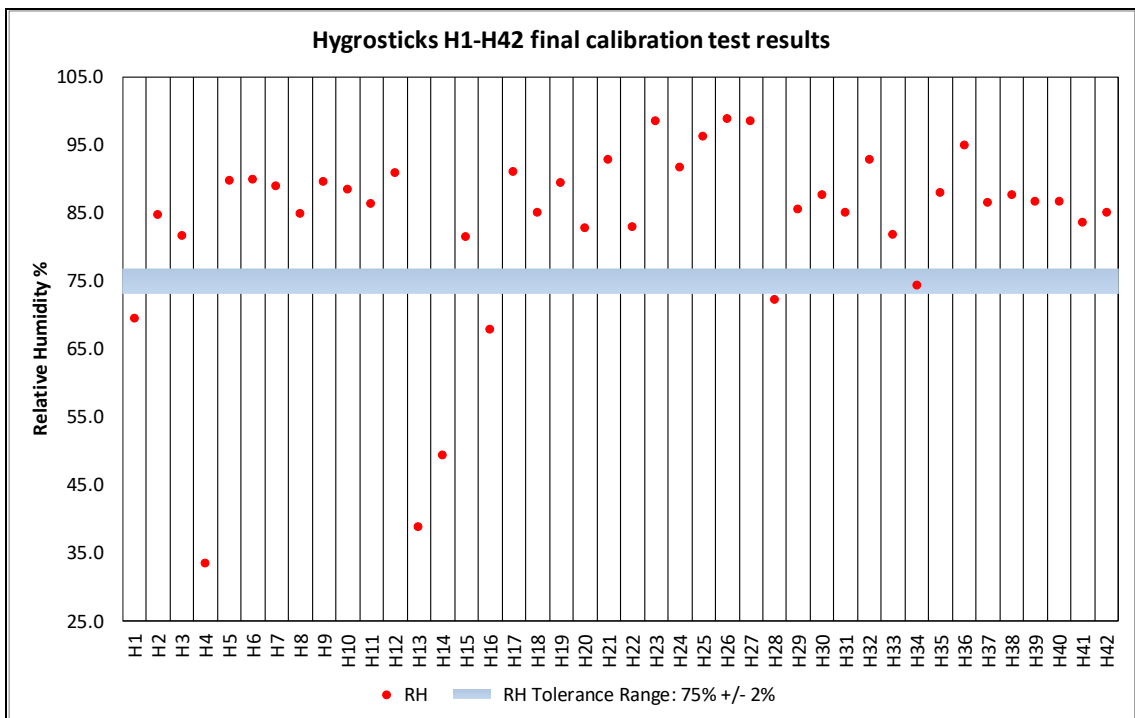
Figure 90: Hygrosticks H1-H42 calibration test results.

The horizontal line illustrates the range of acceptable tolerance: 75.0% ± 2.0%. For Hygrosticks H1-H42, only one remained within calibration tolerance at the end of the data collection phase: H34.
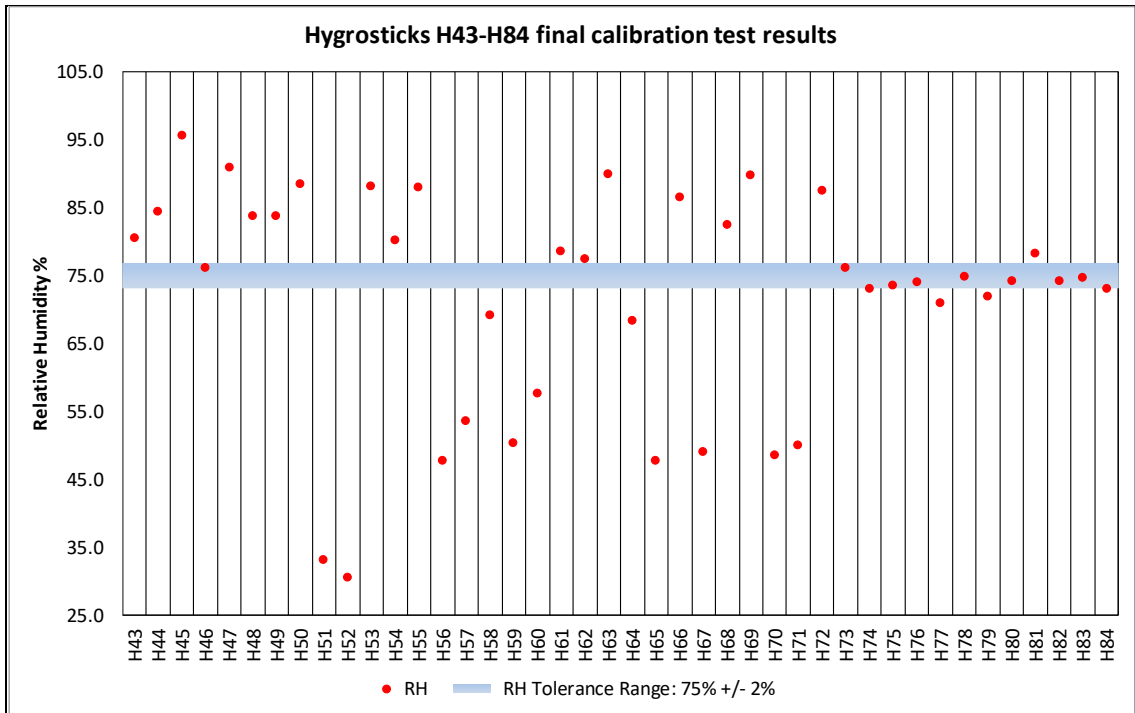
Figure 91: Hygrosticks H43-H84 calibration test results.

For Hygrosticks H43-H84, ten remained within calibration tolerance at the end of the data collection phase, the bulk of these being the most recent additions to the stock: H46, H73, H74, H75, H76, H78, H80, H82, H83, and H84.

Perhaps unsurprisingly, the calibration tests revealed that the Hygrosticks remaining in tolerance at the end of the study to essentially be those introduced in the latter months of the project: reference H73 and above. Of the eighty-four Hygrosticks used, fifty-three failed with relative humidities in excess of 77.0% and twenty-two failed with relative humidities below 73.0%. However, there was a significant difference with respect to longevity: some Hygrosticks installed early in the project remained in tolerance for many months (for example H3, H9, and H11) and contrasted with those introduced later such as H71 and H72 which failed testing after just thirty days' service. H50 was the worst performer, failing calibration testing before ever being used in the project. The dates of first use, last use, and length of service for each Hygrostick is shown in Figure 92 and Figure 93 below.
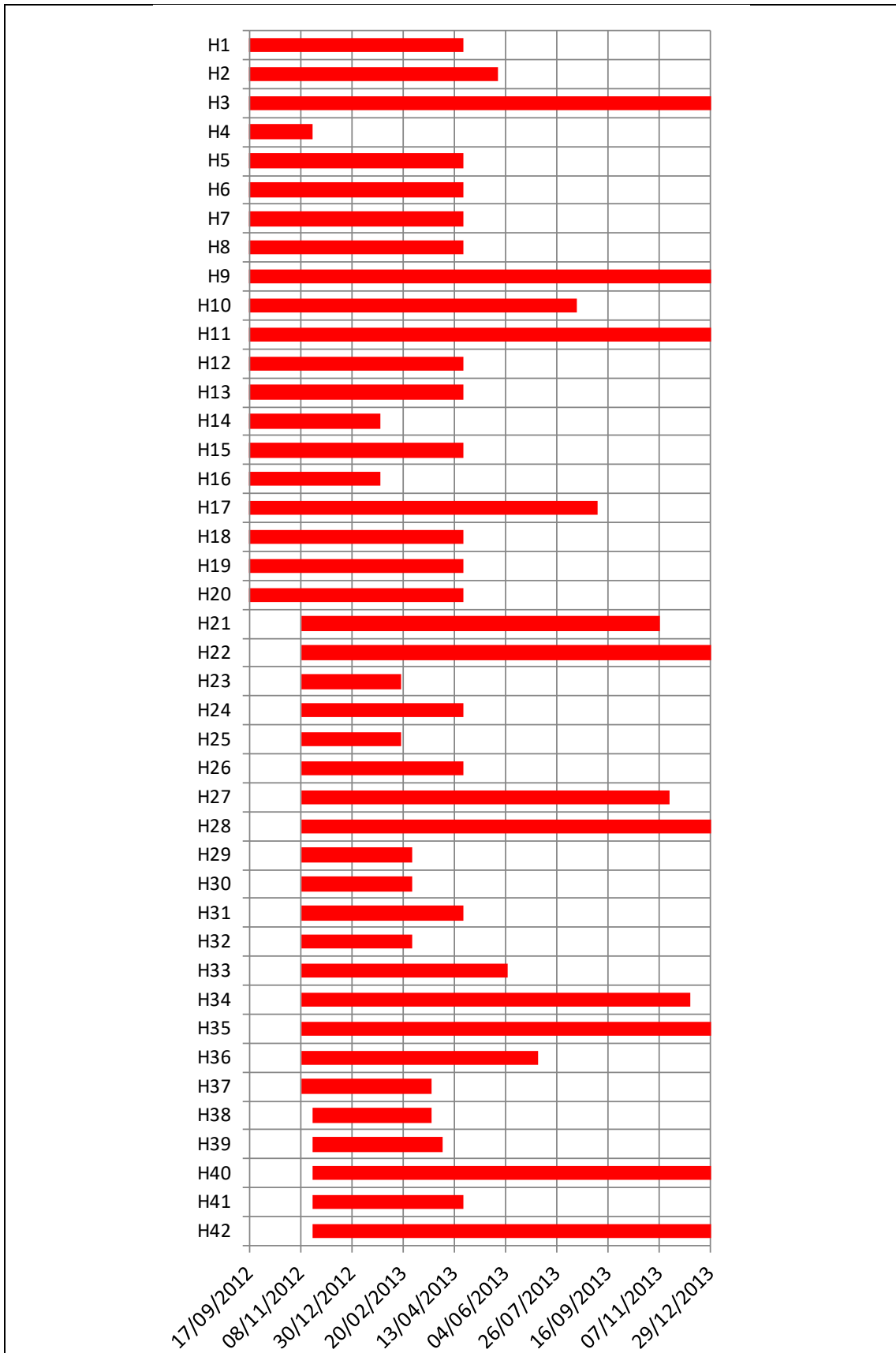
Figure 92: Hygrosticks H1-H42: dates of installation, withdrawal, and total service.
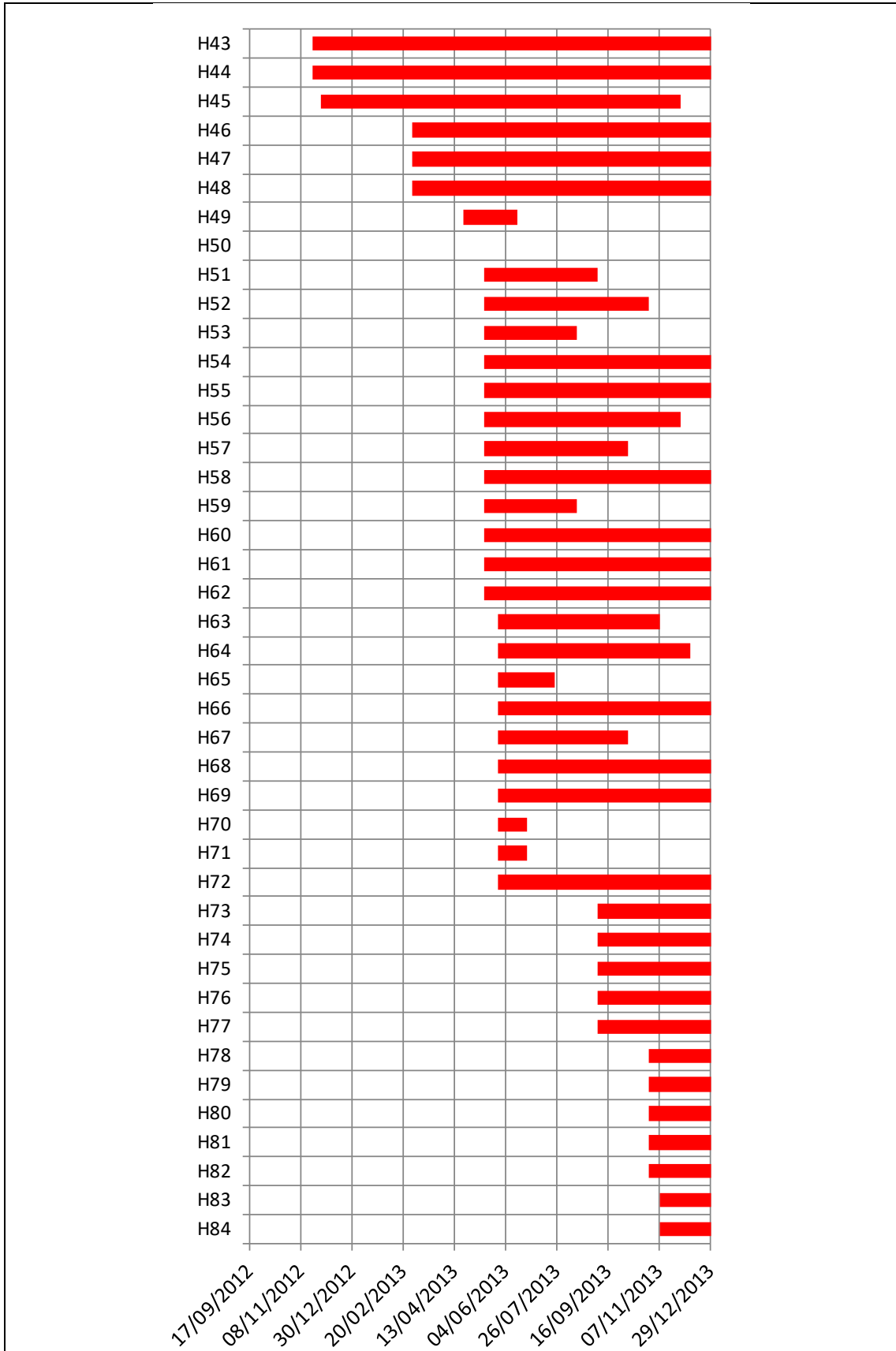
Figure 93: Hygrosticks H43-H84: dates of installation, withdrawal, and total service.

GE Sensing were extremely helpful in mitigating the potential consequence of the many Hygrostick failures by systematically replacing those found to be faulty. They arranged for returned Hygrosticks to be checked using their own laboratory equipment, a Thunder Scientific 2500 Humidity Generator with an accuracy of 1.0% (C.Ranwell, personal communication, 28 June 2013; Thunder Scientific Corporation, 2015). The manufacturer's tests concurred with the results identifying calibration drift that I had found using the saturated salts solution method (P.Leach, personal communication by email, 2 August 2013).

GE Sensing were provided with full details of the Hygrosticks' use but were unable to identify precisely why failures had occurred. They speculated that it may be related to installation for extended periods in bricks that were saturated or contaminated with salts or through exposure to volatiles in the damp proofing cream (P.Leach, personal communication, 2 August 2013).

During the first two months of the project, Hygrosticks had essentially remained in the same position, so, although those at the base of the test panels, where the walls were the dampest, may have been affected by long term exposure to moisture, some of these Hygrosticks continued to provide reliable data for relatively long periods. This situation contrasted with Hygrosticks used later in the project that failed calibration relatively quickly. Furthermore, as time progressed, the position of the Hygrosticks, both in terms of their height above the floor and location in any one individual test panel, became more varied.

The possibility that the sensors may have been affected by volatiles contained in the damp proofing cream was also inconclusive. Only Panels A and C had received this treatment, and on the 5 August 2013, a careful examination of the drill holes into which the cream had been inserted revealed no evidence that it remained, and it was assumed that the carrier, and thus the volatiles, had long since dissipated. In addition, although Panels B and C had received the low-permeability cement render and plaster treatment, it was never established if the materials used could adversely affect the Hygrosticks. All

that could be known with certainty was that the render and plaster had cured many months before.

Hygrostick H49 is worthy of mention because it had been installed in Panel E, the control panel, which did not receive treatment of any type. H49 failed calibration on 16 May 2013 after just six weeks' service. This Hygrostick had initially been placed in row 1, the lowest course; however, on subsequent visits to the house, it had been moved to row 6, row 7, and finally row 4, all of which were relatively dry.

The operating protocol ensured that Hygrosticks which drifted from calibration were quickly identified and replaced. As the results set expanded over the monitoring period, it was easy to identify anomalous Hygrostick data by comparing current values with those recorded previously and with those from adjacent rows. It is for these reasons that although Hygrostick use was far less straightforward than envisaged, the data they provided is both reliable and useful for the purposes of this project.

6.7.3.   Issue 3: heating system malfunction

On visiting the house on 12 November 2012, to record the sixth data set, the internal environment felt noticeably warmer. The owner reported that a fault affecting the living room thermostat had caused the central heating system, a gas fired boiler serving wet radiators, to operate continuously at high temperatures.

Previously, the average temperature recorded by the Lascar data loggers mounted on Panels A-E and the mid-point of the living room rear wall had been in the range of 17.8-19.2^{o}C and 19.0-20.5^{o}C. However, during this thermostat malfunction, these temperatures had risen to 20.3^{o}C and 21.5^{o}C, respectively.

The temperature values returned from the Hygrosticks had displayed the same trend across all five panels: 18.0-19.0^{o}C in row 1 rising to 19.0-20.0^{o}C in row 7; however, at this sixth visit, although a modest temperature increase of around 1.0^{o}C was apparent

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on Panels C, D, and E, a far more significant rise affected Panels A and B: 20.3-28.7°C for Hygrosticks A1-A7 and 20.7-24.5°C for B1-B7. These anomalous values was attributed to heat from a radiator that was mounted on the kitchen side of Panel A and, as pictured in Figure 84 and Figure 85 above, from uninsulated central heating pipes that extended across the bases of Panels A and B.

Data subsequently downloaded from the Lascar data loggers indicated that the high temperatures resulting from this fault persisted for approximately seven days, spanning the period 6 to 13 November 2012. The initial concern was for elevated temperatures to influence drying of the test panels and affect the moisture measuring equipment; yet, the relative humidity of the pocket of air in the Humidity Sleeves, measured by the Hygrosticks during the excessive temperature period, remained high. Given that relative humidity is a function of temperature (BSI, 2011, pp. 20-21; Garratt & Nowak, 1991, p. 5) it should have demonstrated a fall. Furthermore, the values returned and trend apparent from other apparatus used in this study to measure moisture change, including the Timber Probes Type 1, revealed no effect from the rise in temperature.

This is a practice-based research project and, significantly, endeavours to place the study firmly in the rear world. Many dwellings in the UK are likely to be under or over-heated at times. In this respect, a brief period of high temperatures is not a significant deviation from the norm. Indeed, a review of the temperature data recorded by the living room sited Lascar data logger reveals various temperature fluctuations over the fifteen-month data collection phase. This trend is shown in Figure 94 below, which not only illustrates the upward spike in temperature during the period 6 to 13 November 2012 but reveals a further and more prolonged rise in July 2013, presumably as a consequence of warmer, summer weather. In addition, temperatures fluctuations are apparent at other times: a substantial fall from mid-December 2012 to early January 2013, when the property was vacant over the Christmas period; a fall of shorter duration in March 2013; and a temperature fall followed by a rise in December 2013.
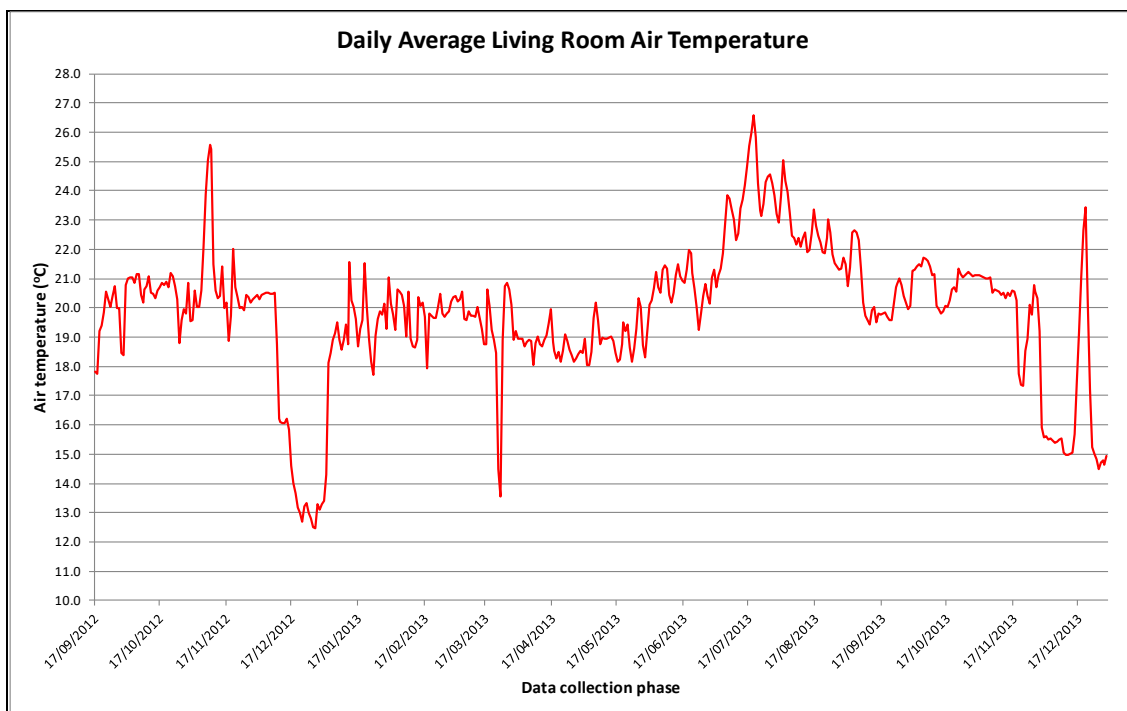
Figure 94: Daily average living room temperature.

Ultimately, when the results were processed, variations in internal air temperature were not found to be detrimental to the outcome of this study.

6.7.4. Issue 4: Timber Probes Type 1 and plain dowels

At the beginning of November 2012, when the fifth data set was recorded, it was apparent that Protimeter measure-mode values obtained from some Timber Probes Type 1 may be erroneous. The general trend across the five test panels was for these values to be higher from Type 1 probes located in lower rows, where moisture levels were highest, and lower from probes located in upper rows, thus producing a gradually receding gradient of moisture versus row height. However, six Type 1 probes, identified in Table 21 below, persisted in returning maximum measure-mode values of 100%[33] independently of their location and of the trend of probes in adjacent rows.

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[33] Technically, the maximum measure-mode reading of a Protimeter is 100%, but the highest reading obtainable from the Protimeter Surveymaster used in this project from the 1 November 2012 onwards was 98.2%. In practice, the 1.8% discrepancy is academic and has been rounded up to 100% for convenience.

Panel	Row	Room location
A	3	Understairs cupboard
B	4	Understairs cupboard
B	5	Understairs cupboard
C	2	Living room
D	3	Living room
E	2	Living room

Table 21: Location of six Timber Probes Type 1 from which maximum measure-mode values persisted.

It was possible that these maximum measure-mode values were an accurate representation of the moisture content of the surrounding masonry, but this seemed unlikely with respect to probes located in the upper rows where moisture was not otherwise apparent. The alternative was that the probes were faulty, and the most probable fault to produce 100% readings was a wiring short.

The Type 1 probes had been installed in tight-fitting holes to ensure maximum contact with the surrounding masonry. Contact with moisture caused their dowel bodies to expand and this meant they could not easily be removed from their accommodating holes. Despite this difficulty, it was possible to test the continuity of the external wiring and the 3.5 mm jack plugs that connected the probes to the Protimeter. These tests were carried out using a multi-meter and a test lead, shown in Figure 95 below, that had been constructed for this purpose.

Figure 95: Timber Probe Type 1 test lead.

The test lead comprised a standard, 2-pole, 3.5 mm jack plug with each of its attached wires terminated with an insulated crocodile clip. Following removal of their original jack plugs, this test lead enabled the remaining parts of the Timber Probe Type 1 undergoing test to be connected to the Protimeter.

Unfortunately, the tests were inclusive, suggesting that a fault, if present, must affect concealed parts of the probes. Type 1 probes B4, B5, C2, D3, and E2, continued to display maximum measure-mode readings and although A3's reading would eventually fall to 55%, it required several minutes to stabilise.

As it transpired, some of the anomalous measure-mode values did show a fall through December 2012: B5 to 43%, E2 to 61%, and A3 to 40% (albeit still requiring several minutes to stabilise), but C2 and D3, remained high at 90%, and B4 was unchanged at 100%.

Ultimately, gravimetric analyses would determine if Protimeter measure-mode values obtained from these, and indeed from the other Type 1 probes, accurately reflected the

moisture content of the surrounding masonry. Nevertheless, it was regrettable that data from Type 1 probes B4, C2, and D3 may be flawed and, for this reason, several changes were made to the timber probe method.

The dowel bodies of the Timber Probes Type 1 were intended to absorb moisture from the surrounding masonry wall and, through Protimeter measure-mode values obtained from these probes over time, to register changes in the moisture content of the test panels. The potential fault affecting the Type 1 probes was suspected to relate to their wiring; therefore, the ability to take the Protimeter measure-mode readings directly from their dowel bodies would effectively alleviate this concern. Thus, an obvious solution was presented: construct and use as a supplementary monitoring method: a timber probe comprising a plain timber dowel that could be removed from the wall to enable Protimeter measure-mode readings to be taken directly from it.

Initially, three of these plain softwood dowels were installed, one each at positions B4, C2, and D3, comprising a 75 mm long piece of the 9 mm diameter softwood dowel used in the construction of the Type 1 probes.

To insert these dowels, one of the pair of 5 mm diameter holes that had been drilled to accommodate the Deep Wall Probes was enlarged to 9 mm. This size hole enabled the plain dowels to make good contact with the masonry while allowing sufficient width for expansion of the timber and, importantly, easy removal. Before insertion, the pins of the Protimeter Heavy Duty Probe were pushed into the dowels' surface to create two small holes that marked where future measure-mode values would be taken, as shown in Figure 96 and Figure 97 below.

Figure 96: 9 mm diameter plain softwood dowel.

The plain softwood dowels were made from 75 mm lengths of the same 9 mm dia. timber used for the bodies of the Timber Probes Type 1. The holes where the needles of the Protimeter Heavy Duty Probe are inserted are circled.

Figure 97: 9 mm diameter plain softwood dowel undergoing reading using the Protimeter measure-mode function.

Protimeter measure-mode values are obtained from the 9 mm dia. plain softwood dowels by removing them from their accommodating hole and pushing the needles of the Heavy Duty Probe directly into the timber surface. In this photograph, the Protimeter display shows 11.5%.

The three plain softwood dowels were installed on the 16 December 2012 and allowed eight days to equilibrate to the moisture content of the surrounding masonry. Initial measure-mode values were taken from them on the 24 December 2012, in conjunction with the recording of the tenth data set. Values continued to be collected for the remainder of the data collection phase.

Interestingly, the initial measure-mode values obtained from the 9 mm plain softwood dowels B4, C2, and D3 were far lower than those of the respective Timber Probes Type 1. However, the Type 1 probes had been installed at commencement of the study, before any treatments were carried out. The application of the render and plaster materials initially caused a rise in the moisture content of Panels B and C, and values obtained

from the Type 1 probes could potentially be influenced by hysteresis, a phenomenon where wetting of porous materials may not necessarily see them returning to their pre-wetting moisture contents (Phillipson, 1996, p. 15). Furthermore, although undetermined at this stage, the capillary moisture content of Panels A, C, and D may well have fallen as a result of damp proof course treatments. Installation of the 9 mm plain softwood dowels three-months after applying these treatments would see them inserted into masonry with lower capillary moisture content from the outset.

Manufacture, installation, and reading of the 9 mm plain softwood dowels was simple and quick and removed any doubt with respect to the validity of the measure-mode values obtained. Thus, they offered a useful method of measuring moisture change in the test panels; yet, they had not provided a definitive answer with respect to the integrity of Type 1 probes B4, C2, and D3 or of the slow response of A3; consequently, two further changes were made to the panel's set up.

Firstly, on the 1 January 2013 four additional Timber Probes Type 1, which had been carefully constructed and tested, were installed 25 mm to the side of each of the existing Type 1 probes A3, B4, C2, and D3. Clearly, it was unrealistic to anticipate exact replication of measure-mode values because of the effect of hysteresis and moisture changes in the panels, as discussed above, but they would, nevertheless, provide supplementary data.

Secondly, given the positive outcome of the 9 mm plain softwood dowels, this method would be extended across all five panels and used as an additional method of monitoring moisture change. To avoid unnecessary disturbance of the test panels, 5 mm hardwood dowel was sourced from a local timber merchant, cut into 75 mm lengths, as illustrated in Figure 98, and installed by enlarging one of the pair of existing 5 mm diameter holes in each of the seven rows of the five panels to 6 mm.

Figure 98: 5 mm diameter plain hardwood dowel.

5 mm dia. hardwood dowel was cut into 75 mm lengths and inserted into the test panels following enlargement to 6 mm of one of the pair of 5 mm dia. holes previously drilled to accommodate the Deep Wall Probes of the Protimeter.

The method used to obtain Protimeter measure-mode values from these 5 mm plain hardwood dowels was, as shown Figure 99 below, precisely the same as that described previously for the 9 mm plain softwood dowels.

Figure 99: 5 mm diameter plain hardwood dowel undergoing reading using the Protimeter measure-mode function.

Protimeter measure-mode values are obtained from the 5 mm plain hardwood dowels by removing them from their accommodating hole and pushing the needles of the Heavy Duty Probe directly into the timber surface. In this photograph, the Protimeter display shows 8.4%.

Installation of the 5 mm plain hardwood dowels was undertaken on the 18 January 2013, completing the configuration of moisture measuring apparatus, as illustrated, as an example, for Panel B in Figure 100 and Figure 101 below. With the exception of periodically replacing the Hygrosticks, as discussed earlier, no further changes were made to the moisture measuring apparatus for the remainder of the monitoring period.

Figure 100: Panel B illustrating final configuration of the moisture measuring apparatus.

This photograph of test Panel B illustrates the final configuration of moisture measuring apparatus. The original equipment is in seven rows with each row comprising a Hygrostick, two 5 mm dia. holes to accommodate the pins of the Protimeter Deep Wall Probe, and a Timber Probe Type 1. In Panel B, an extra Hygrostick had been installed in row 3, an additional Timber Probe Type 1 and 9 mm dia. plain softwood dowel in row 4, and 5 mm dia. plain hardwood dowels inserted into one of each pair of the central holes following its enlargement to 6 mm.

Figure 101: Panel B's additional moisture measuring apparatus.

This photograph, a close up of the base of Panel B, shows the additional Hygrostick installed in row 3, the extra Timber Probe Type 1 and 9 mm dia. plain softwood dowel in row 3, and the 5 mm dia. plain hardwood dowels.

The data collection form was updated firstly to version 2 (Appendix 2) and finally to version 3 (Appendix 3) to accommodate the additional equipment. The spreadsheets of the Excel results workbook were similarly amended to accommodate these additional data.

6.7.5.   Issue 5: vacant house

In November 2013, the owner decided to sell the house. They granted permission for data collection to continue until the end of December 2013 but the house was vacant for this final month.

The environment within an empty house is dissimilar to one that is occupied because moisture production, heating, and ventilation associated with typical lifestyle activities will change. However, although it has been made explicit that these changes occurred, there are three reasons why this short vacancy does not affect this project's outcomes.

Firstly, with the exception of a brief period when it was occupied by two persons, the house had just a single occupant. Moisture vapour produced through single occupancy is typically modest (Garratt & Nowak, 1991, p. 47). The absence of the occupant for the final month is not significant.

Secondly, although vacating the house, the owner arranged for the heating system to continue operating, thus mitigating the potential rise in internal relative humidity that would result from environmental cooling (BSI, 2011, pp. 20-21; Garratt & Nowak, 1991, p. 5).

Thirdly, environmental changes that may occur are no different to those that transpired during earlier stages of data collection: the periods of high internal temperatures caused by the fault to the central heating thermostat and low internal temperatures when the house was unoccupied for brief periods.

Essentially, the foregoing are nuances of occupation that are well suited to a study designed to be set firmly in the real world. Occupants do occasionally vacate their houses and implement changes, purposely or otherwise, that influence the environmental conditions.

6.8. Stage 5: conclusion of on-site work

Stage 4, the data collection phase, covered a fifteen-month period, spanning from the 24 September 2012 to the 30 December 2013, and provided forty-four individual data sets. This fifth and final stage of the on-site work, which took place immediately after conclusion of Stage 4, required the moisture measuring apparatus to be dismantled, the

final moisture content of the test panels to be determined, and damage caused to the ground floor wall parts used for these panels to be made good. Although, removal of moisture monitoring apparatus was carried out in one operation, Stage 5 would essentially comprise five distinct steps:

1. Remove Lascar data loggers, download data, test, and record test results;

2. Remove Hygrosticks, test, and record test results;

3. Remove Timber Probes Type 1, 9 mm plain softwood dowels, and 5 mm plain hardwood dowels, determine their hygroscopic and capillary moisture contents using gravimetric analysis, and enter the results in the workbook spreadsheet;

4. Remove plaster, render, and masonry samples by drilling, determine their hygroscopic and capillary moisture contents using gravimetric analysis, and enter the results in the workbook spreadsheet;

5. Undertake necessary repairs to make good the test panel walls.

Midway through the monitoring period, the seven Lascar data loggers had been taken off site and their recorded data downloaded to a computer. This process was repeated for the data spanning the second half of the monitoring period. With their data extracted, each Lascar data logger was checked for calibration above a saturated salts solution using the method described in Chapter 4. All seven of the Lascar data loggers successfully passed this calibration test.

The Hygrosticks had been tested periodically for calibration, as described earlier in this chapter. On termination of the on-site work, all Hygrosticks currently in use underwent a final test with their results logged in the relevant Excel spreadsheet.

Across the five panels a total of forty Timber Probes Type 1, three 9 mm plain softwood dowels, and thirty-five 5 mm plain hardwood dowel had been installed. All of these

probes were removed. As suspected, many of the Type 1 probes, particularly those located in wetter regions of the walls, had to be forcibly removed from the walls.

Unsurprisingly, the dowel bodies of Type 1 probes located in dry masonry were in pristine condition; however, those that had been placed in wetter regions, essentially the bottom two rows, fared less well. For example, the dowel bodies of Type 1 probes A1, D1, D2, and E1 were discoloured, had softened, and displayed signs of fungal decay that, in the case of A1 and D1, had resulted in loss of timber. Fortunately, none of the Type 1 probes were so badly damaged to preclude examination or subsequent gravimetric moisture analyses. Illustrative examples of Timber Probes Type 1 from dry and wet regions of the panels are shown in Figure 102, Figure 103, Figure 104, and Figure 105 below.

Figure 102: Timber Probe Type 1 D4 following removal from Panel D.

Dowel body of Type 1 probe D4 unaffected by discolouration or fungal decay. The condition of this dowel was typical of Timber Probes Type 1 that had been installed in the upper, drier regions of the panels.

Figure 103: Timber Probe Type 1 reference D2 following removal from Panel D.

Dowel body of Type 1 probe D2 discoloured and displaying evidence of fungal decay. The condition of this dowel was typical of Timber Probes Type 1 that had been installed in the lower, wetter regions of the panels. This dowel was essentially intact, but other dowels had lost section.

Figure 104: Timber Probe Type 1 D1 following removal from Panel D.

Dowel body of Type 1 probe D2 discoloured, decayed, and has lost timber section. Of all of the Timber Probes Type 1 installed, this dowel body was the most severely affected by fungal decay.
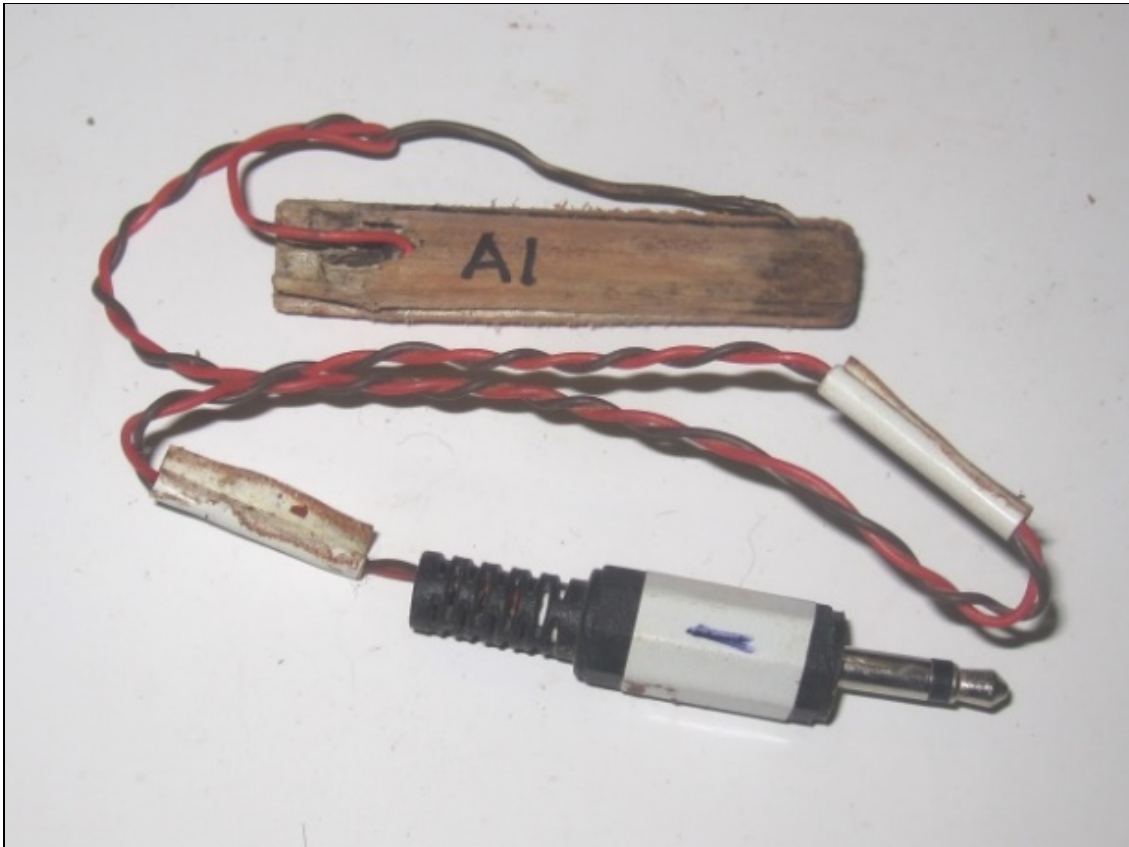
Figure 105: Timber Probe Type 1 A1 following removal from Panel A.
Dowel body of Type 1 probe A1 discoloured, decayed, and has lost timber section.

Protimeter, measure-mode readings were obtained from the 5 mm and 9 mm plain dowels and directly from the dowel bodies of the Type 1 probes, using the Heavy Duty Probe attachment, to provide final on-site values. Each of these components was placed into an individual, screw topped, air tight container, labelled, and taken off-site for subsequent gravimetric moisture analyses.

Three unused 5 mm hardwood dowels and four unused 9 mm softwood dowels were included in these analyses to enable the pre and post-hygroscopic moisture contents to be compared, thus providing a total batch of eighty-three dowels to process.

A full set of masonry samples needed to be taken for gravimetric analyses to determine the final moisture content of the test panels. These samples were obtained by drilling two 9 mm diameter holes between the former inner and outer holes of the moisture measuring apparatus at each row position, the holes for the measuring equipment

having been spaced sufficient apart for this purpose, as illustrated for Panel B, by way of example, in Figure 106 and Figure 107 below.
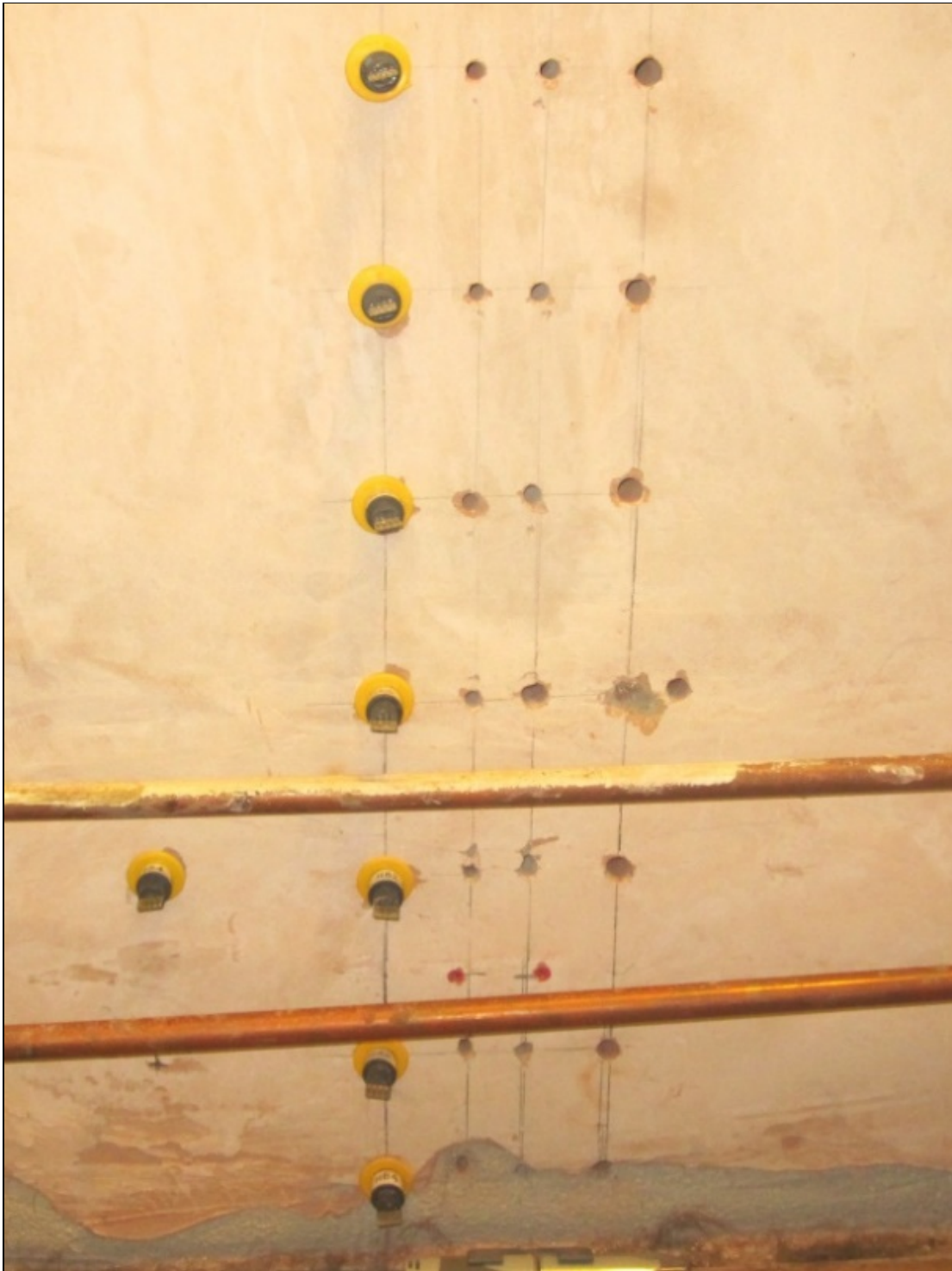
Figure 106: Test Panel B prior to removing final masonry samples.

Panel B following removal of the Timber Probes Type 1 and 5 mm and 9 mm plain dowels. The Hygrosticks and Humidity Sleeves are yet to remove.

Figure 107: Test Panel B following removal of final masonry samples.

Panel B on completion of the drilling required to provide the final masonry samples. Using a 9 mm dia. drill bit, two sample sets were removed at each row position from the region of the panel between the former inner and outer holes, which had been purposely spaced for this reason.

Damage caused by drilling to install equipment and take samples had to be made good. Rather than attempt to repair individual holes, it was simpler and would achieve a better quality finish to remove and replace the plasterwork from the entire central region of each panel.[34] In addition, this method meant that the brickwork comprising each panel was exposed and therefore enabled samples to be obtained from visible brick units, removing the uncertainty of accidentally sampling the mortar joints.

Thus final sampling was spilt into two parts: an initial drilling to obtain samples of the plasterwork[35] and, following its removal, a second drilling to remove samples from the underlying brick units. Figure 108 below illustrates the living room rear wall at the mid-point of this sampling process and Figure 109 the same wall following reinstatement work, which was completed on 22 January 2014 and concluded the on-site work.

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[34] In practice, the base of the living room rear wall and the understairs cupboard right hand side wall, those ground floor wall parts used for the test panels, were fully stripped and replastered.
[35] As explained previously, some parts of the panels were without plasterwork and therefore only brick samples could be taken.

Figure 108: Test Panels C, D, and E with plasterwork removed to facilitate masonry sampling.

With the plaster removed, samples could be removed from the brick units with certainty. In practice, the entire base of the living room rear wall and the understairs cupboard right-hand side wall, those ground floor wall parts used for the test panels, were stripped and replastered.

Figure 109: Test Panels C, D, and E following completion of reinstatement works.

Panels C, D, and E following completion of plastering and skirting board reinstatement. When wall decorations were subsequently applied, no visible evidence of the on-site work remained.

The plaster and brick drillings, totalling 130 separate samples, had been placed into individual, screw topped, air tight containers, labelled, and with the eighty-three dowels were processed using the gravimetric analyses method described in Chapter 4. These results, and the findings of the on-site work, are described in Chapter 7.

Chapter 7

Evaluating the Damp Proofing Treatments Part 2: Findings

7.1. Introduction

The five treatment types and their application to individual test panels were described in Chapter 6. The baseline (i.e. starting) moisture contents of the panels had been determined through gravimetric analyses undertaken at Stage 2 before any treatments were applied, and at Stage 3 following the application of low-permeability render to Panels B and C. Test panel set up was concluded through the installation of moisture measuring apparatus and the completion of damp proofing treatments to Panels A, C, and D, which essentially marked the start of the monitoring phase.

The moisture measuring apparatus installed in the panels was not intended to quantify moisture change that may occur over the duration of the on-site work but, instead, to serve two purposes: firstly, to determine how effectively each method was able to track moisture change when mapped against the results determined through gravimetric analyses and, secondly, to establish if moisture in the atmosphere correlated with moisture in a damp wall. These findings, which provided some interesting results, are discussed in Chapter 8.

The remainder of this chapter is concerned with the effectiveness of the applied treatments in controlling rising damp. To inform this evaluation the final moisture content of the test panels' masonry component at conclusion of the monitoring phase (the end of December 2013) was determined through Stage 5 gravimetric analyses to enable comparison with the moisture contents determined at the start.

For Stage 3 and Stage 5 analyses, two separate holes, 100 mm and 50 mm apart, respectively, were drilled in each row to extract samples. Given that the walls are constructed of handmade clamp bricks, it was anticipated that even when sampling just

50–100 mm apart the drill may penetrate bricks of differing sorptivity and therefore of dissimilar capillary moisture contents. Measures were implemented to ensure, as far as practicable, samples were only taken from brick units, but Stage 3 sampling was undertaken without removing plaster and there was the additional potential of inadvertently striking the more sorptive mortar joints in one or both hole positions of each row. Thus to mitigate variability as a result of sampling and to simplify presentation of data, each pair of results from any one row have been averaged. It is important to state that the use of averaging did not bias the outcome of treatment evaluation: the results are the same if single sample sets are compared; however, this latter method would require the presentation of twice the data with no benefit.

Construction moisture present in the low-permeability render and plaster materials applied to Panel B, and to a lesser extent Panel C, had temporarily raised their capillary moisture contents. This effect, visible in the values derived through Stage 3 analyses, was consistent over the height of the panel and is mitigated through reference to the results derived from Stage 2 analyses that were undertaken prior to the application of the render. The results of Stage 2 analyses, which were derived from single samples at each row position, are therefore included in the evaluation of the treatments alongside the averaged results at Stages 3 and 5.

Seven rows of samples were removed at all stages of analyses. At Stage 2, the height of the topmost sample was 750 mm above floor level. It was subsequently established that hygroscopic and capillary moisture contents were high at the base of the panels, extending to a maximum height of 300 mm above the floor (i.e. corresponding with the first four brick courses), but that these forms of moisture were essentially both absent and uniform in the wall parts in excess of 400 mm above floor level. For this reason, the upper row height was reduced to 545 mm, because there was nothing to be gained through monitoring the wall parts above. Therefore, the sampling heights of Stage 2 and stages 3 and 5 differed, as illustrated in Table 22 below.

Row	Stage 2 sampling heights (mm)	Stages 3 & 5 sampling heights (mm)
7	750	545
6	600	460
5	450	375
4	300	285
3	225	205
2	150	115
1	50	50
Table 22: Stage 2 and Stages 3 & 5 variations in sampling heights.		

To facilitate accurate comparison, the heights and therefore the derived moisture values of samples removed at Stage 2 need to be mapped against the comparative heights of samples removed at Stages 3 and 5. In practice, this is achieved simply by discarding the Stage 2 values from the fifth and seventh rows; the heights of the remaining rows align well across all three stages as illustrated in Table 23 below.

Row	Stage 2 sampling heights (mm)	Stages 3 & 5 sampling heights (mm)
7		545
6	450	460
5		375
4	300	285
3	225	205
2	150	115
1	50	50
Table 23: Stage 2 mapped equivalent sampling position at Stage 3.		

A discussion of each of the five treatments completes this chapter, commencing with the 'no treatment' of the control (Panel E) and progressing through each of the other four treatments, effectively mirroring the steps involved in the installation of a contemporary remedial chemical injection damp proof course:

1. Drill holes in mortar bed joint (Panel D);

2. Drill holes in mortar bed joint and install the damp proofing cream (Panel A);

3. Apply low-permeability render (Panel B).

4. Drill holes in mortar bed joint, install the damp proofing cream, and apply low-permeability render (Panel C).

To inform these discussions, the results of the gravimetric moisture analyses from Stages 2, 3, and 5 are compared in table and chart format using the following conventions:

1. Stage 2 values are derived from single masonry samples;

2. Stage 3 values are the average of the masonry values derived from the 9 mm diameter and 16 mm diameter holes at each row position;

3. Stage 5 values are the average of the masonry values derived from the two 9 mm diameter holes at each row position;

4. Each cell of the tables representing TMC, HMC, and CMC are colour filled blue, green, and red respectively. The coloured fill is scaled proportionally to the cell's value in the range 0.0-15.0%. This upper value representing the masonry TMC of Panel A row 1 (A1), the highest quantity of moisture found among the samples;

5. Negative CMCs can be assumed to be zero.

Treatment 1, allocated to test Panel E, was no treatment. The results from Panel E were nevertheless important because, in the absence of interventions, it was reasonable to expect that its capillary moisture content would be largely unchanged over the duration of the monitoring period. Indeed, the validity of claims made in respect of capillary moisture changes affecting Panels A, B, C, and D relied on the stability of Panel E. Table

24 below provides the moisture values for the masonry portion of Panel E at Stages 2, 3, and 5.

	Stage 2 Panel E: masonry			Stage 3 (average) Panel E: masonry			Stage 5 (average) Panel E: masonry		
Row	TMC	HMC	CMC	TMC	HMC	CMC	TMC	HMC	CMC
7	0.1%	0.2%	-0.1%	0.3%	0.3%	0.0%	0.0%	0.2%	-0.2%
6	0.1%	0.1%	0.0%	0.2%	0.3%	-0.2%	0.1%	0.2%	-0.1%
5				0.3%	0.4%	-0.1%	0.0%	0.2%	-0.2%
4	9.7%	6.3%	3.4%	2.1%	2.0%	0.1%	0.8%	1.5%	-0.7%
3	8.6%	6.3%	2.3%	6.7%	4.4%	2.4%	6.1%	4.3%	1.8%
2	3.4%	2.0%	1.4%	5.3%	1.3%	4.0%	1.4%	0.6%	0.8%
1	4.4%	2.0%	2.4%	5.6%	1.5%	4.1%	8.5%	0.4%	8.1%

Table 24: Panel E (masonry) gravimetric moisture analyses Stages 2, 3, and 5.

The masonry of Panel E contained significant moisture in rows 1-4 at Stage 2. The total moisture comprised elements of both capillary and hygroscopic moisture, and with the HMC concentrated in rows 3 and 4 and excessive CMC across rows 1-4, the moisture distribution was consistent with the rising damp model (Coleman, 1990, pp. 15-22; Kyte, 1987, p. 312; Trotman, 2007, pp. 5-6).

Results from Stage 3 essentially confirmed the earlier findings: significant total moisture that comprised excess capillary moisture and elevated hygroscopic moisture in row 3 and, to a lesser extent, row 4.

The Stage 5 results revealed that moisture continued to affect the masonry of Panel E at conclusion of the monitoring period: significant TMC in rows 1 and 3; significant CMC in row 1 and comparable values in rows 2 and 3; and elevated HMC in rows 3 and 4.

In comparing the results at Stage 2 to those of Stage 3 carried out only a few weeks apart some variation in the precise moisture values are evident. Similar discrepancies are apparent in the Stage 5 results, albeit that these latter values were determined fifteen-months after the former. These differences are to be expected given the varying sampling positions, the precise composition of the material tested, and the distribution

of contaminating salts. This latter issue is evident in row 4, with samples removed very close to the upper limits of the damp rise containing differing quantities of hygroscopic salts.

The significant increase in the capillary moisture of row 1 at Stage 5—8.1% in the masonry and contrasting with values of 2.4% and 4.1% derived at Stages 2 and 3, respectively—was unexpected and suggested that the base of Panel E had become wetter over the duration of the study. The aim of gravimetric analyses is to quantify moisture, but precise moisture values are less important than data which enables moisture change to be identified, and these results meet that criterion. This is illustrated by presenting the results from Table 5 in chart form, as shown in Figure 110, Figure 111, and Figure 112 below.

Figure 110 below charts the total moisture content of the masonry of each row position at Stages 2, 3, and 5. Variations in the TMC values at each stage are apparent, but importantly moisture was present across row positions 1-4 at the start of the monitoring phase and remained present at the end.
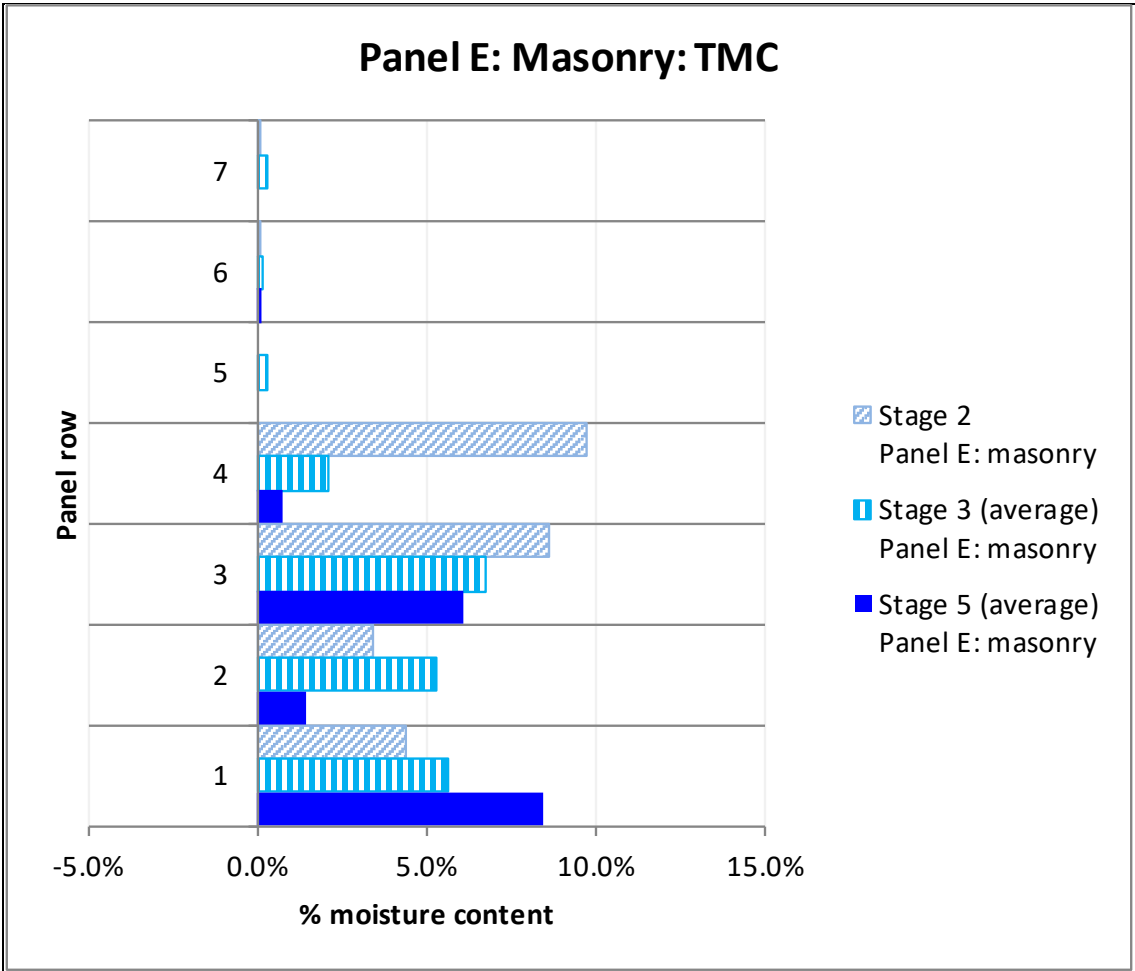
Figure 110: Panel E total moisture content of masonry at Stages 2, 3, and 5.

It would be excepted for the hygroscopic moisture content of Panel E to remain reasonably static over the monitoring period. This is confirmed in Figure 111 below, which shows the masonry HMCs to be relatively stable through Stages 2, 3, and 5 and, as is characteristic for rising damp, to be elevated in rows 3 and 4
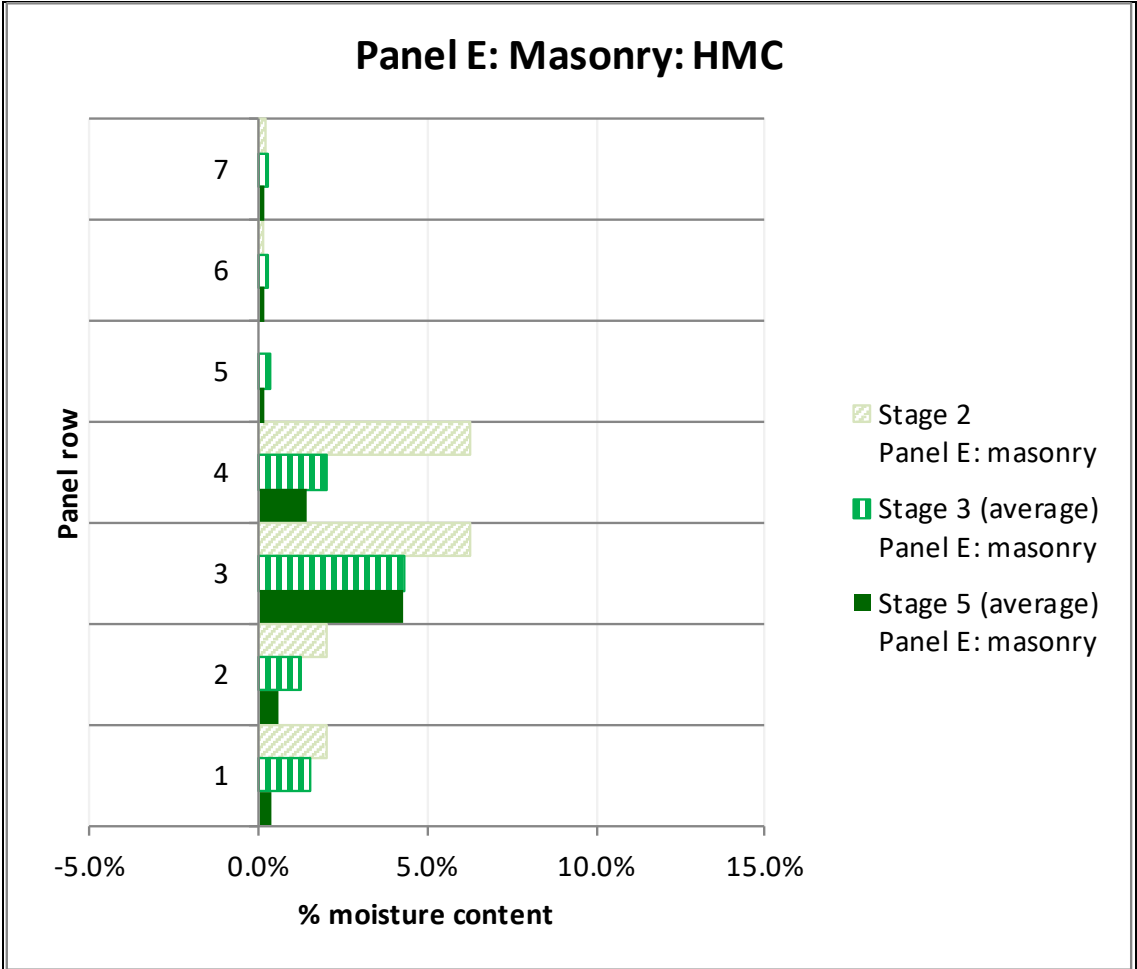
Figure 111: Panel E hygroscopic moisture content of masonry at Stages 2, 3, and 5.

Finally, Figure 112 below illustrates the results for the capillary moisture content of the masonry of Panel E at Stages 2, 3, and 5. Again, there are variations in the moisture values, but it is clear that capillary moisture—essentially moisture that should not be present—affected the masonry at row positions 1-4 at the start and end of the monitoring phase.
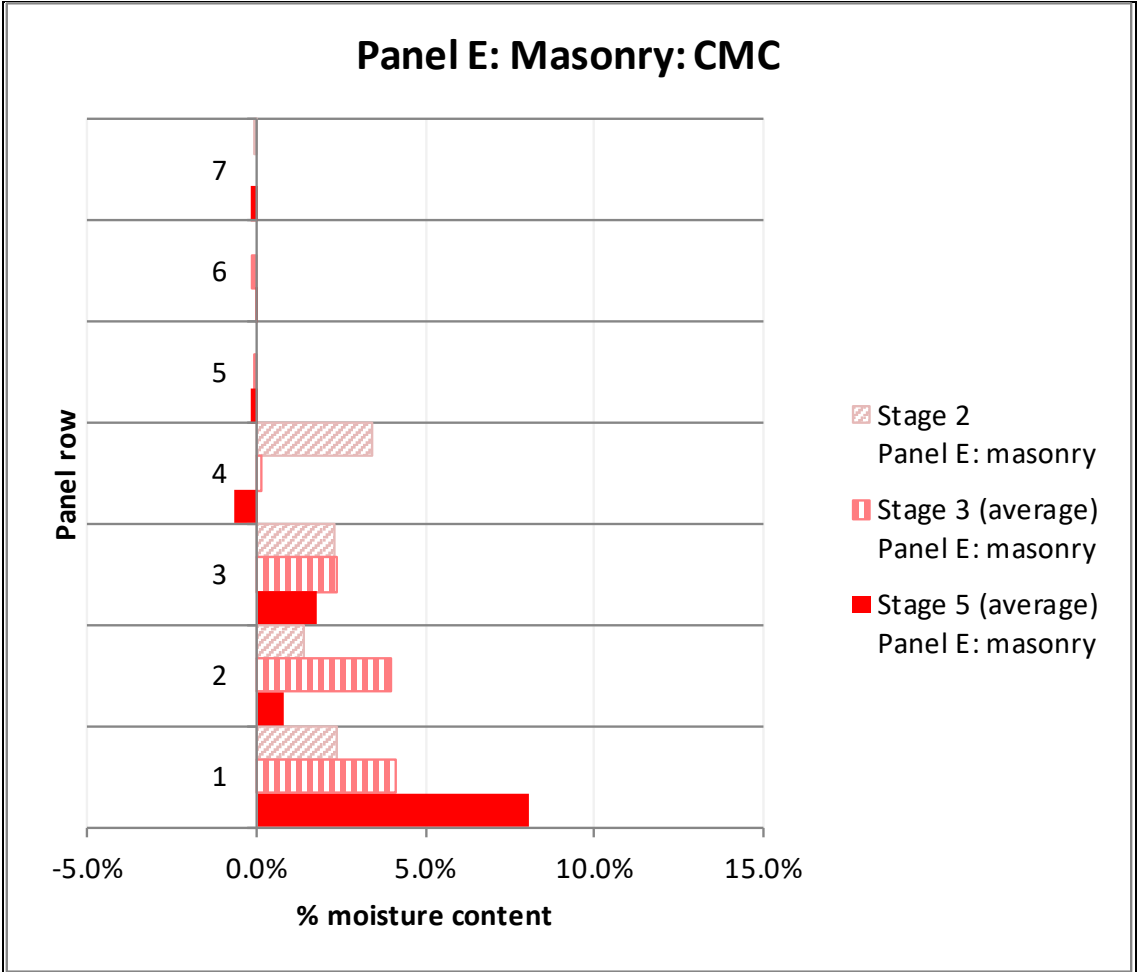
Figure 112: Panel E capillary moisture content of masonry at Stages 2, 3, and 5.

To evaluate the applied treatments, it is the results of the masonry portion of the panels that are most important: moisture changes that occurred at depth in the panels; nevertheless, for completeness of this discussion, Table 25 below summarises the gravimetric analysis results for the plasterwork portions of Panel E at Stages 2, 3, and 5.

	Stage 2 Panel E: plasterwork			Stage 3 (average) Panel E: plasterwork			Stage 5 (average) Panel E: plasterwork		
Row	TMC	HMC	CMC	TMC	HMC	CMC	TMC	HMC	CMC
7	0.9%	1.0%	-0.1%	0.4%	0.7%	-0.3%	0.2%	0.5%	-0.3%
6	0.8%	1.0%	-0.2%	0.9%	1.1%	-0.3%	0.3%	0.5%	-0.2%
5				0.7%	0.7%	-0.1%	0.2%	0.4%	-0.2%
4	2.6%	2.4%	0.2%	1.9%	2.2%	-0.3%	1.4%	2.3%	-0.9%
3	3.7%	4.0%	-0.3%	3.2%	3.0%	0.2%	2.3%	2.9%	-0.6%
2	3.1%	3.0%	0.1%	3.8%	2.9%	0.9%	2.3%	2.6%	-0.3%
1	4.2%	3.9%	0.3%	3.0%	1.9%	1.1%			

Table 25: Panel E (plasterwork) gravimetric moisture analyses Stages 2, 3, and 5.

At stage 2, plaster samples were not removed from a position corresponding with row 5. Similarly, because the bottom edge of the plasterwork had been trimmed during preparation of the panels, a sample could not be obtained from row 1 at Stage 5. Values for these rows are not included in Table 25. The remaining values for Panel E indicate uniformity of total, hygroscopic, and capillary moisture across all three stages, albeit that some moderate and insignificant reductions in capillary moisture had occurred by Stage 5. Care was taken at each stage of gravimetric analysis but some moisture loss from the samples and small errors in weighing are to be expected.

The results from the plasterwork are unsurprising. The original plaster had not been removed from Panel E, so no significant change in its HMC was expected over the monitoring period. Indeed, as shown in Figure 113 below, a photograph of Panel E after the Stage 5 samples had been taken, hygroscopic contamination of the plasterwork, in the form of visible damp staining, was apparent in the region of rows 3 and 4.

Figure 113: Panel E at Stage 5.

Panel E following removal of Stage 5 samples. The damp staining resulting from hygroscopic contamination is clearly visible in the region between rows 3-4.

Given that hygroscopic moisture is the dominant moisture source in this plaster, it would be reasonable to anticipate that its total moisture content, with the exception of variations attributable to differing sampling positions or those inherent of the method used, would also remain stable.

Panel E, as the control, was intended to provide a datum against which moisture change, if found in the other four panels, could be vindicated. Panel E received no treatment and thus capillary moisture affecting the masonry at the start of the monitoring period was anticipated to be present at the end. That is precisely what the moisture analyses found and confirms that this method can be relied upon to identify moisture changes in Panels D, A, B, and C occurring as a result of applying treatments 2, 3, 4, and 5, respectively.

7.2. Treatment 2 (Panel D): drill holes in mortar bed joint

Treatment 2, allocated to test Panel D, involved drilling holes into its lowest horizontal mortar bed joint in the configuration typically required for the installation of silane/siloxane damp proofing cream (i.e. 12 mm diameter holes drilled to a nominal depth of 100 mm at the intersection with each perpendicular mortar joint). The cream was <u>not</u> installed. The purpose of this treatment was to establish if simply drilling holes in this mortar bed joint would depress rising damp. Table 26 below provides the moisture values for the masonry portion of Panel D at Stages 2, 3, and 5.

	Stage 2 Panel D: masonry			Stage 3 (average) Panel D: masonry			Stage 5 (average) Panel D: masonry		
Row	TMC	HMC	CMC	TMC	HMC	CMC	TMC	HMC	CMC
7	0.5%	0.7%	-0.2%	0.3%	0.3%	0.1%	0.1%	0.2%	-0.2%
6	0.0%	0.1%	-0.1%	0.2%	0.3%	-0.2%	0.0%	0.1%	-0.1%
5				1.6%	1.6%	0.1%	0.9%	1.4%	-0.5%
4	3.5%	2.3%	1.2%	9.9%	6.4%	3.5%	6.0%	5.3%	0.7%
3	4.6%	2.6%	2.0%	4.8%	1.8%	3.0%	1.3%	1.3%	-0.1%
2	11.8%	2.7%	4.6%	9.4%	1.3%	8.1%	7.6%	1.6%	6.0%
1	11.7%	0.9%	10.8%	10.9%	0.7%	10.2%	10.0%	0.5%	9.5%

Table 26: Panel D (masonry) gravimetric moisture analyses Stages 2, 3, and 5.

The masonry of Panel D contained significant moisture in rows 1-4 at Stage 2. The TMC comprised of both capillary and hygroscopic moisture, the former concentrated in rows 1 and 2 and the latter across rows 2-4, a distribution consistent with the rising damp model.

Stage 3 results provided a similar profile to that found at Stage 2. Variations in the precise values attributable to small disparities in the sampling positions.

Stage 5 results, when compared to the earlier Stage 2 and 3 values, revealed little difference in the quantity of moisture present in the masonry of Panel D at the end of the monitoring period, the capillary moisture content of rows 1 and 2 at all three stages

being almost identical. In addition, the hygroscopic moisture content at stage 5 essentially mirrored the results determined at Stage 3.

The characteristic distribution of moisture was evident across all three stages of analysis. Figure 114 below demonstrates how moisture present in the masonry of rows 1-5 of Panel D at Stages 2 and 3 persisted through to Stage 5.

Figure 114: Panel D total moisture content of masonry at Stages 2, 3, and 5.

Figure 115 below illustrates the results for the hygroscopic moisture content of the masonry of Panel D at Stages 2, 3, and 5. There was little change in the distribution of this HMC over the monitoring period and it is clearly concentrated in row 4, marking the highest point of damp rise.
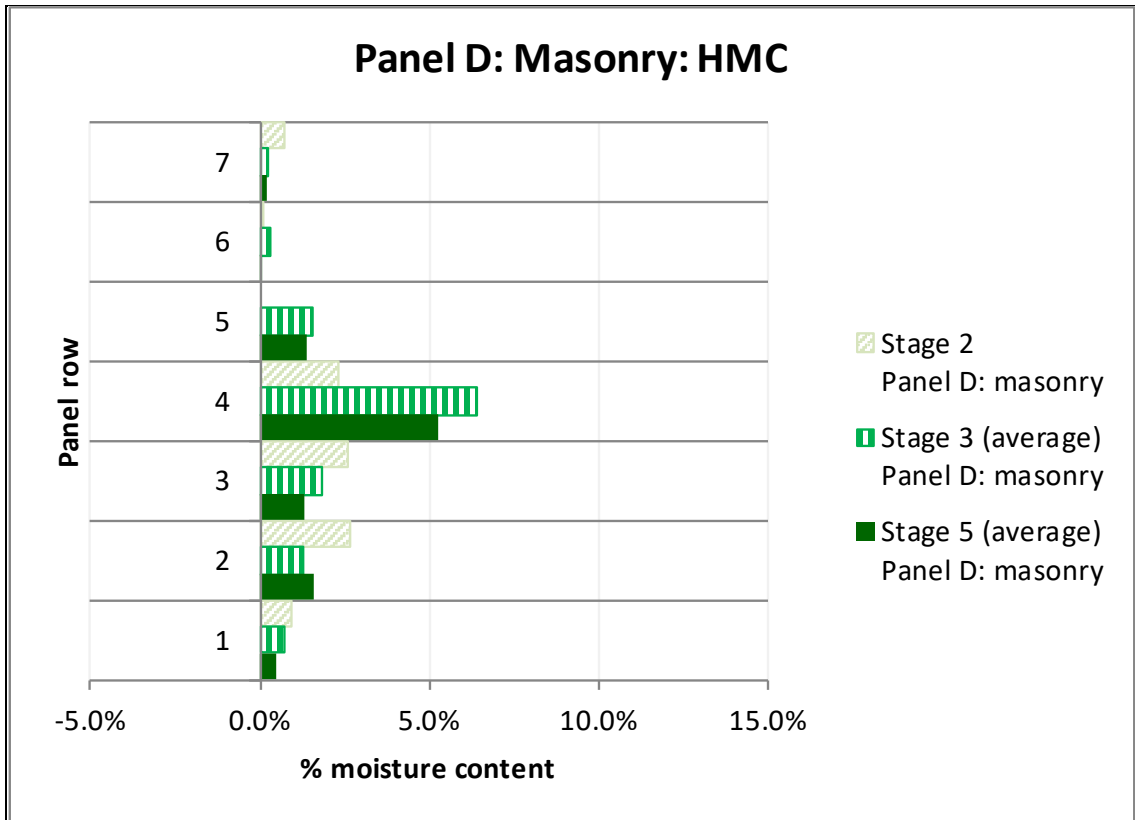
Figure 115: Panel D hygroscopic moisture content of masonry at Stages 2, 3, and 5.

Figure 116 below illustrates the results for the capillary moisture content of the masonry of Panel D at Stages 2, 3, and 5. In the bottom two rows, the CMCs are largely unchanged over the monitoring period. However, row 3 is anomalous, having similar CMC values of 2.0% and 3.0%, respectively, at Stages 2 and 3 but a value of -0.1%[36] at Stage 5. In addition, the CMC of row 4, which was established to be 1.2% and 3.5% at Stages 2 and 3, respectively, had fallen to 0.7% at Stage 5.

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[36] Minus capillary moisture content values are quirks of the calculation method and can be considered zero.
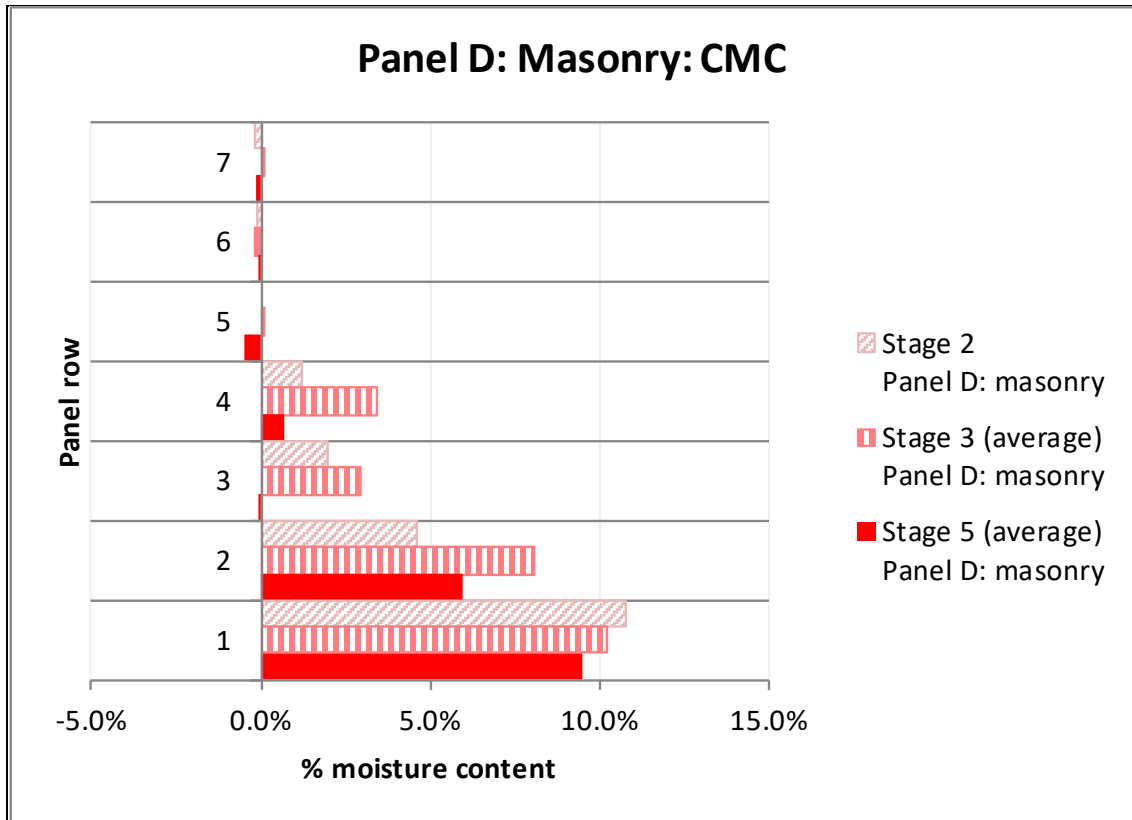
Figure 116: Panel D capillary moisture content of masonry at Stages 2, 3, and 5.

Some of the variations in capillary moisture content may be attributed to rounding errors introduced by averaging each pair of the stage 3 and 5 values. As an example, the two row 4 values at Stage 3 were 2.6% and 4.3% (average 3.5%) and for this same row at Stage 5, -0.3% and 1.7%. Technically, the average of these latter two values is 0.7%, but if the minus value is considered to be zero the average would increase to 0.9%. Granted that this is still lower than the Stage 3 average in this same location, but there is not a great deal of difference between the single 2.6% row 4 value derived at Stage 3 and the 1.7% value at Stage 5.

Clearly, there is a risk of becoming overly concerned with respect to individual values. Masonry is not a homogenous material and precise uniformity of moisture distribution cannot be a realistic expectation. With respect to the results obtained from the masonry of Panel D, what is important is that moisture was present at the start of the monitoring period and was confirmed to remain at conclusion.

For Panel D's treatment, holes were drilled into the horizontal mortar bed joint between the first and second courses of bricks. If it were assumed that drilling these holes would depress rising damp, the capillary moisture content of row 1, located in the first course of bricks beneath the line of holes, would not be expected to change; however, it would be reasonable to expect that the capillary moisture content of row 2, located in the second course of bricks above the line of holes, would fall.

Technically, there may have been some decrease in capillary moisture in Panel D rows 3 and 4, but explanation has been provided why this may not necessarily be the case. The results do show that the CMCs of rows 1 and 2 were high at the outset and remained high at the end of the fifteen-month monitoring period. In many respects the results from Panel D are no different to those found in Panel E, the control.

The damp proofing cream was installed in Panels A and C and, as will be described later in this chapter, their results with respect to capillary moisture content changes were markedly different from those determined from Panel D. While it is acknowledged that there may have been some reduction in the capillary moisture content of rows 3 and 4 of Panel D, there is insufficient evidence to claim that this resulted from the applied treatment. In consideration of the results obtained from the control Panel E and treatment Panels A and C, it is concluded that the drill hole treatment applied to Panel D did not provide any significant control of rising damp in this study.

The evaluation of the applied treatments is essentially informed through changes in the moisture content of the masonry portion of the panels; the analyses results of the plasterwork portions do not affect the outcome or the conclusion made. Nevertheless, for completeness of this discussion, to enable comparison with the control, and to conclude this section, Table 27 below provides the moisture values for the plasterwork portion of Panel D at Stages 2, 3, and 5.

	Stage 2 Panel D: plasterwork			Stage 3 (average) Panel D: plasterwork			Stage 5 (average) Panel D: plasterwork		
Row	TMC	HMC	CMC	TMC	HMC	CMC	TMC	HMC	CMC
7	0.7%	1.1%	-0.4%	1.1%	1.3%	-0.2%	0.2%	0.4%	-0.2%
6	0.9%	1.2%	-0.3%	0.4%	0.7%	-0.4%	0.2%	0.4%	-0.2%
5				0.9%	1.1%	-0.2%	0.6%	0.6%	0.0%
4	2.4%	2.3%	0.1%	2.0%	2.0%	0.1%	1.2%	1.6%	-0.4%
3	2.1%	1.9%	0.2%	2.7%	2.5%	0.3%	1.4%	1.7%	-0.3%
2	3.5%	2.6%	0.9%	4.1%	2.6%	1.6%	2.3%	1.7%	0.7%
1	4.6%	2.4%	2.2%	3.8%	2.5%	1.3%			

Table 27: Panel D (plasterwork) gravimetric moisture analyses Stages 2, 3, and 5.

At stage 2, plaster samples were not removed from a position corresponding with row 5. Similarly, because the bottom edge of the plasterwork had been trimmed during preparation of the panels, a sample could not be obtained from row 1 at Stage 5. Values for these rows are not included in Table 27. The moisture profile of the plasterwork of Panel D is very similar at all three stages. This was to be anticipated because its original plaster was not removed; essentially, Panel D and Panel E were identical and the former provided the same result as the latter, discussed in the previous section.

7.3. Treatment 3 (Panel A): installation of damp proofing cream

Treatment 3, allocated to test Panel A, involved drilling holes into its lowest horizontal mortar bed joint in the configuration typically required for the installation of silane/siloxane damp proofing cream <u>and</u> installing the damp proofing cream. The purpose of this treatment was to establish if installing the damp proofing cream without implementing measures to control hygroscopic moisture—specifically, stripping and replacing the plaster with a low-permeability cement render—offered any benefit with respect to controlling rising damp. Table 28 below provides the moisture values for the masonry portion of Panel A at Stages 2, 3, and 5.

Row	Stage 2 Panel A: masonry			Stage 3 (average) Panel A: masonry			Stage 5 (average) Panel A: masonry		
	TMC	HMC	CMC	TMC	HMC	CMC	TMC	HMC	CMC
7	0.1%	0.1%	0.0%	0.2%	0.3%	-0.1%	0.0%	0.1%	-0.1%
6	0.9%	1.0%	-0.1%	0.5%	0.6%	-0.1%	0.1%	0.3%	-0.2%
5				1.9%	1.7%	0.2%	0.6%	1.6%	-1.1%
4	6.3%	5.6%	0.7%	7.2%	6.1%	1.1%	2.7%	4.6%	-1.9%
3	7.5%	5.2%	2.3%	8.2%	3.8%	4.4%	2.7%	2.6%	0.1%
2	12.9%	1.5%	11.4%	12.8%	1.6%	11.2%	3.2%	0.9%	2.3%
1	14.8%	1.0%	13.8%	15.0%	1.0%	14.0%	13.8%	0.4%	13.4%

Table 28: Panel A (masonry) gravimetric moisture analyses Stages 2, 3, and 5.

The masonry of Panel A contained significant moisture in rows 1-4 at Stage 2. The total moisture comprised elements of both capillary and hygroscopic moisture and, as was found for Panels E and D, in a distribution consistent with the rising damp model: hygroscopic moisture concentrated in rows 3-4 and capillary moisture predominant in the lowest rows.

Stage 3 results provided an almost identical profile to that found at Stage 2.

Stage 5 results demonstrated a sharp reduction in capillary moisture in rows 2 and 3, causing a corresponding fall in the TMCs across rows 2-4. In contrast, the HMC values, elevated in the region of rows 3 and 4, mirrored those determined at Stage 3. Given that HMC values are influenced by hygroscopic salts and the concentration of these salts in the masonry remained unchanged over the monitoring period, this result is expected.

Figure 117 below illustrates how the total moisture content of the masonry of Panel A rows 2-4, which had been identical at Stages 2 and 3, had receded to much lower levels by Stage 5, with only row 1 unchanged.
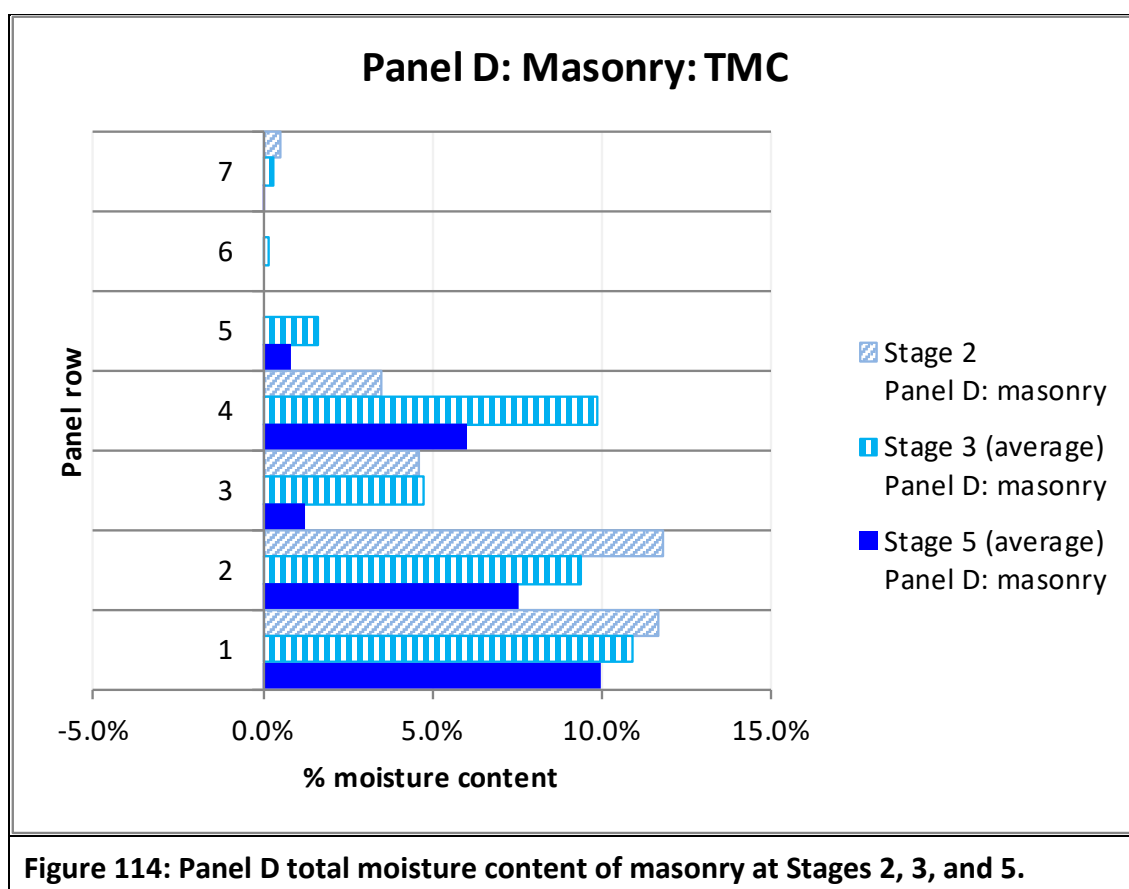
Figure 117: Panel A total moisture content of masonry at Stages 2, 3, and 5.

Figure 118 below shows that the hygroscopic moisture content of the masonry across all seven rows of Panel A remained largely unchanged through all three Stages of analyses. Therefore, if the total moisture content of the masonry of Panel A had reduced, this change must be caused by a fall in capillary moisture content.
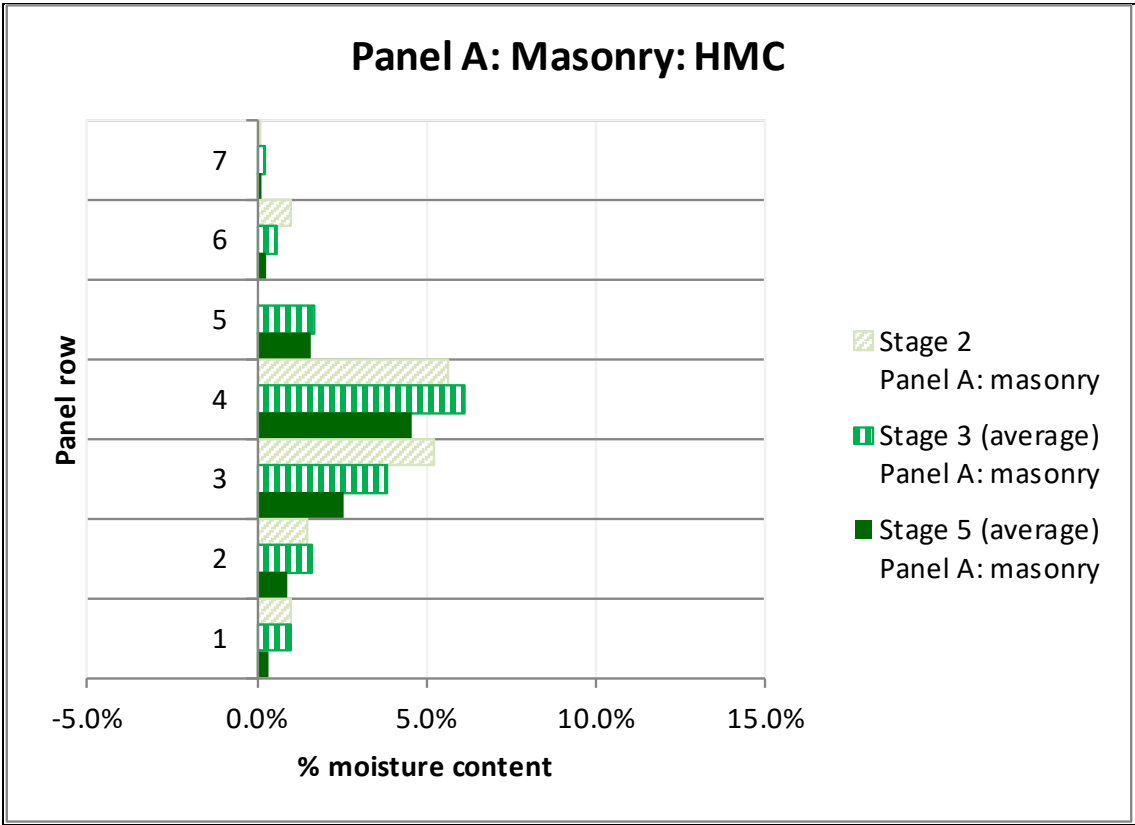
Figure 118: Panel A hygroscopic moisture content of masonry at Stages 2, 3, and 5.

This fall in capillary moisture contents is clearly evident in Figure 119 below. The masonry CMCs of row 1 remained both high and stable throughout Stages 2, 3, and 5, at 13.8%, 14.0%, and 13.4%, respectively, but the capillary moisture content of rows 2-4 above had decreased significantly by Stage 5.
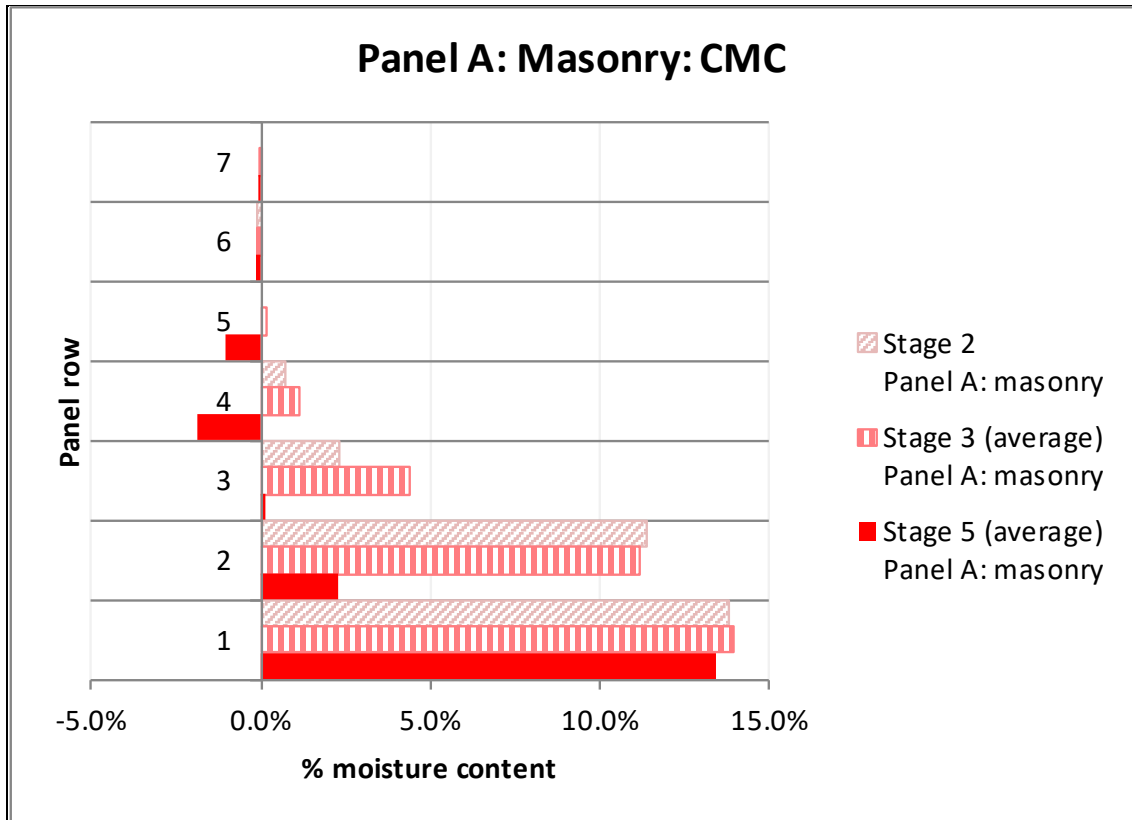
Figure 119: Panel A capillary moisture content of masonry at Stages 2, 3, and 5.

As with the treatment for Panel D, holes were drilled into the horizontal mortar bed joint at the base of Panel A between the first and second courses of bricks, corresponding, respectively, with rows 1 and 2. However, unlike Panel D, a silane/siloxane damp proofing cream was inserted into Panel A's holes, as described in Chapter 6, to form a remedial damp proof course at this mortar bed joint.

If effective, this damp proof course should have a controlling effect on rising damp or, more specifically, on capillary moisture, which should reduce in the masonry above the treated joint. This is precisely what the moisture analysis confirms. At Stage 5, there is a significant reduction in the CMC values of the masonry in row 2 upwards (i.e. the row positions of Panel A above the line of the damp proof course); conversely, there is no change in the CMCs at row 1, the course of bricks beneath the damp proof course.

In comparing this result with Panel E, the control, and Panel D, the drill only treatment, it is concluded that the installation of the silane/siloxane damp proofing cream in Panel A did provide a significant controlling effect with respect to capillary moisture associated with rising damp.

At commencement of this study, Panel A's plasterwork was both in poor condition and damp stained. Despite the significant reduction in capillary moisture that occurred following the installation of the damp proofing cream, dampness that affected the plasterwork did not practically change over the course of the monitoring period. This is a direct result of its elevated hygroscopic moisture content, as illustrated in Table 29 below.

	Stage 2 Panel A: plasterwork			Stage 3 (average) Panel A: plasterwork			Stage 5 (average) Panel A: plasterwork		
Row	TMC	HMC	CMC	TMC	HMC	CMC	TMC	HMC	CMC
7	4.8%	5.1%	-0.3%	0.7%	1.0%	-0.3%	0.3%	0.8%	-0.6%
6	2.8%	2.7%	0.1%	1.7%	2.2%	-0.5%	0.9%	1.4%	-0.5%
5				2.1%	2.4%	-0.3%	1.8%	2.3%	-0.5%
4	6.3%	5.6%	0.7%	6.2%	6.6%	-0.4%	2.1%	3.0%	-1.0%
3							2.9%	3.2%	-0.3%
2									
1									

Table 29: Panel A (plasterwork) gravimetric moisture analyses Stages 2, 3, and 5.

Table 29 provides the moisture values for the plasterwork portion of Panel A (where plaster was present) at Stages 2, 3, and 5. Essentially, capillary moisture is absent and all moisture is derived from the HMCs. Contamination from hygroscopic salts as a consequence of rising damp is assumed to have elevated the plasterwork's hygroscopicity and, because it remains in place, it continues to cause significant dampness irrespective of the efficacy of the damp proof course. It is for this reason that a remedial damp proof course comprises a two part process and replastering, using specialists methods, is the important second component of this system (Safeguard Europe Ltd., 2007, p. 5). The final two treatments are concerned with this method of plaster reinstatement.

7.4. Treatment 4 (Panel B): application of low-permeability render

Treatment 4, allocated to test Panel B, involved removing the plaster and reinstating it using the specification typically applied following the installation of a remedial damp proof course (i.e. low-permeability cement render containing a proprietary salt inhibiting additive, finished with a coat of gypsum plaster). The purpose of this treatment was two-fold: firstly, to establish if the low-permeability render controlled rising damp independently of the installation of the damp proofing cream, and, secondly, to determine if the render caused the height attained by rising damp to increase. Table 30 below provides the moisture values for the masonry portion of Panel B at Stages 2, 3, and 5.

	Stage 2 Panel B: masonry			Stage 3 (average) Panel B: masonry			Stage 5 (average) Panel B: masonry		
Row	TMC	HMC	CMC	TMC	HMC	CMC	TMC	HMC	CMC
7	0.1%	0.3%	-0.2%	4.5%	0.5%	4.0%	0.0%	0.1%	-0.1%
6	0.3%	0.3%	0.0%	2.1%	0.4%	1.7%	0.1%	0.2%	-0.1%
5				3.8%	1.1%	2.7%	0.2%	0.6%	-0.4%
4	4.6%	4.8%	-0.2%	8.8%	2.5%	6.3%	3.1%	4.1%	-1.0%
3	0.8%	1.2%	-0.4%	5.3%	2.7%	2.7%	3.4%	2.6%	0.8%
2	9.8%	3.3%	6.5%	10.6%	1.5%	9.1%	9.4%	1.5%	7.9%
1	10.8%	0.1%	10.7%	10.9%	1.2%	9.7%	10.8%	0.3%	10.6%

Table 30: Panel B (masonry) gravimetric moisture analyses Stages 2, 3, and 5.

The Stage 2 results of Table 30 were derived from samples removed from Panel B before its existing plasterwork was stripped. They indicated that the distribution of moisture in the masonry aligned with that of the other panels and was consistent with the rising damp model: elevated moisture in rows 1-4 of which hygroscopic moisture was highest in rows 2-4 and capillary moisture highest in rows 1 and 2.

Stage 3 sample results, removed after the render had been applied, were similar to those found at Stage 2 in rows 1 and 2 but differed in the upper rows 3-7, where the capillary moisture content, and by extension the total moisture content, was higher; an effect that is attributed to construction moisture in the render. Unsurprisingly, this

construction moisture was more evident in the render portion of the samples, and its effect was not apparent in rows 1 and 2, presumably because capillary moisture was already elevated at the base of Panel B.

Clearly, the presence of construction moisture at Stage 3, the point at which the base line moisture content of the panels was to be determined, is unfortunate; however, it is a relatively simple process to remove its effect by considering the difference in the Stage 2 and Stage 3 CMC values of the upper rows. At Stage 2, the CMC of rows 5, 6, and 7 were effectively zero but had increased at Stage 3 to 2.7%, 1.7%, and 4.0%, respectively. An average increase of 2.8%.

Stage 3 CMC of row 3 is 2.7%. Reducing this value by 2.8% provides a corrected figure of -0.1%, effectively aligning it with the Stage 2 value of -0.4. Similarly, the Stage 3 CMC of row 2 is 9.1%. Reducing this value by 2.8% provides a corrected value of 6.3%, offering good alignment with 6.5% determined for row 2 at Stage 2. Essentially, adjusting the Stage 3 values by subtracting 2.8% removes the construction moisture effect

In practice, a comparison of the Stage 5 values to those found at Stage 2 is sufficient to determine that there was no change in the capillary moisture content of Panel B over the duration of the monitoring period. The final moisture content of Panel B's masonry was to all intents and purposes identical to that at the start, and it only increased temporarily at Stage 3 as a result of construction moisture.

Figure 120 below illustrates how the total moisture content of the masonry of Panel B rows 1-2 was the same across all three stages and that the higher moisture values in the upper rows were attributable to construction moisture present in the Stage 3 samples.

Despite the erroneous Stage 3 values, this result illustrates two significant findings: firstly, the total moisture content of the masonry of Panel B rows 1-4 was high at the start of the monitoring phase and remained high at the end and, secondly, the masonry

of rows 5-7 above was unaffected by moisture at the start and remained unaffected by moisture at the end.
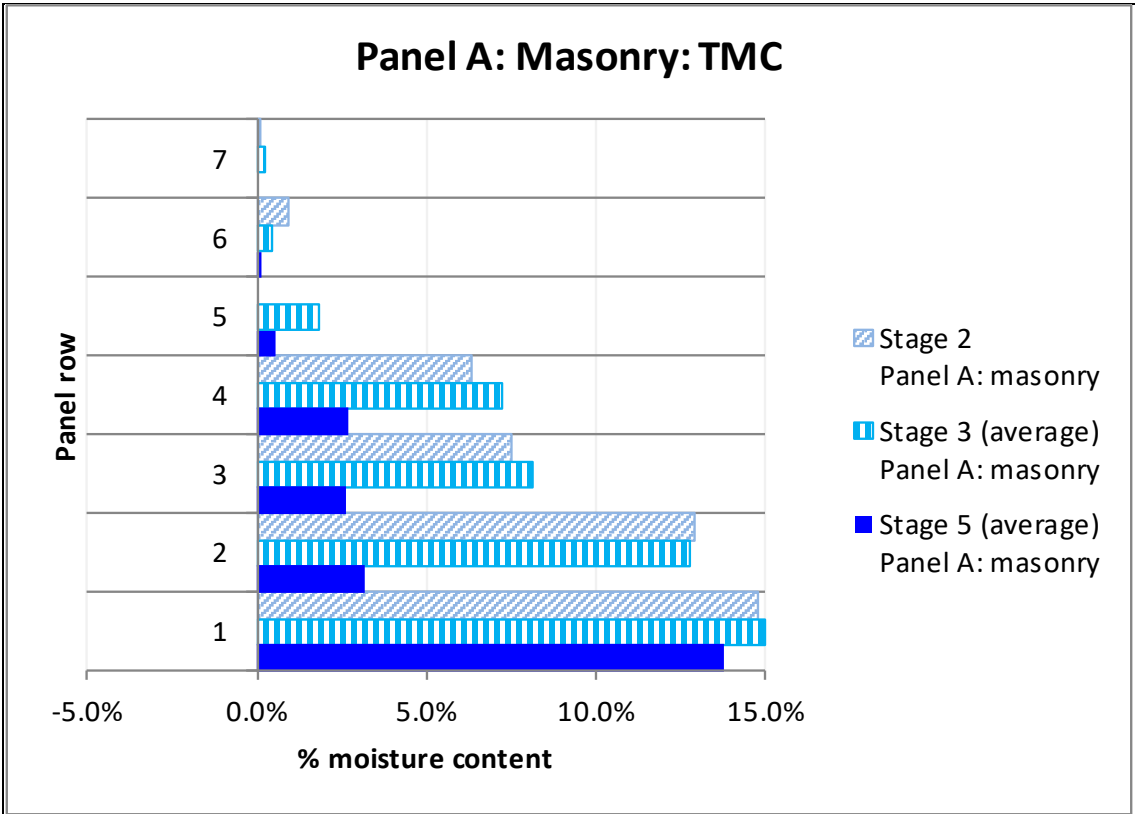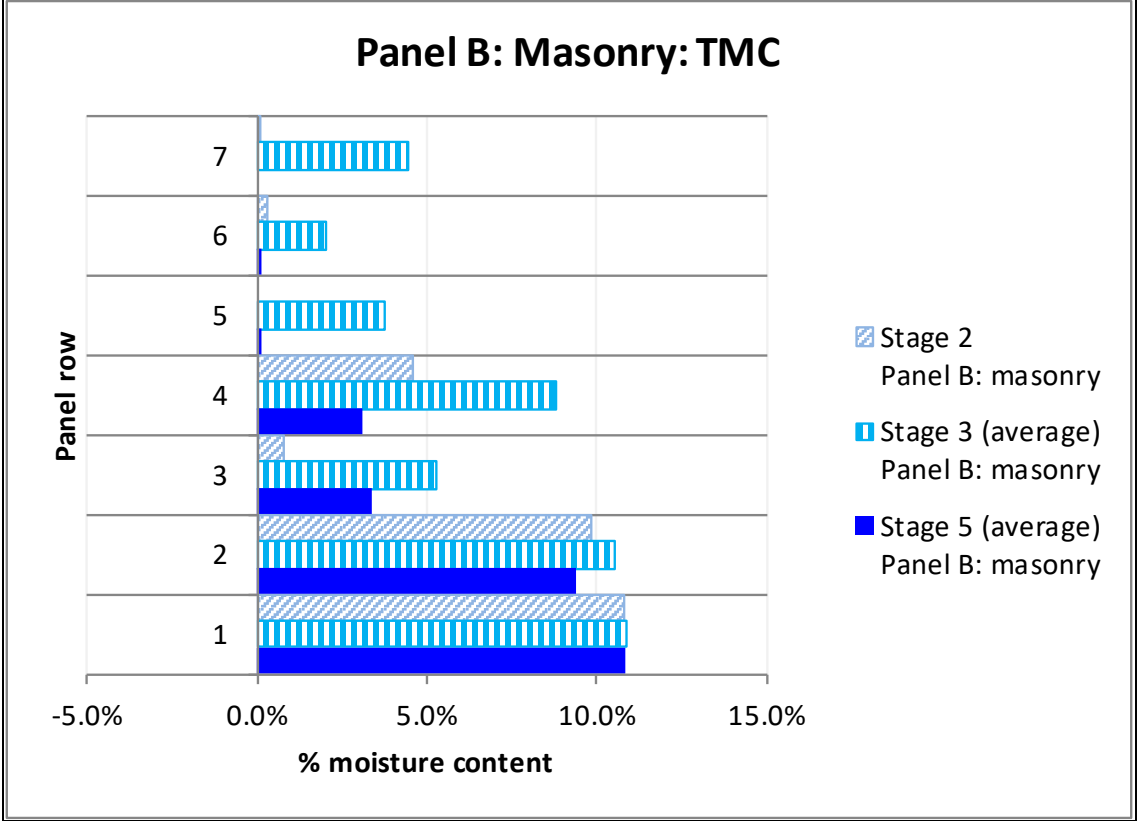

Figure 120: Panel B total moisture content of masonry at Stages 2, 3, and 5.

Figure 121 below demonstrates that that hygroscopic moisture content of the masonry over the full height of Panel B rows 1-7 remained largely unchanged through all three stages of analyses. Construction moisture essentially comprises capillary moisture and it is therefore independent of hygroscopic moisture and, as this chart illustrates, the HMC values were not affected by it.
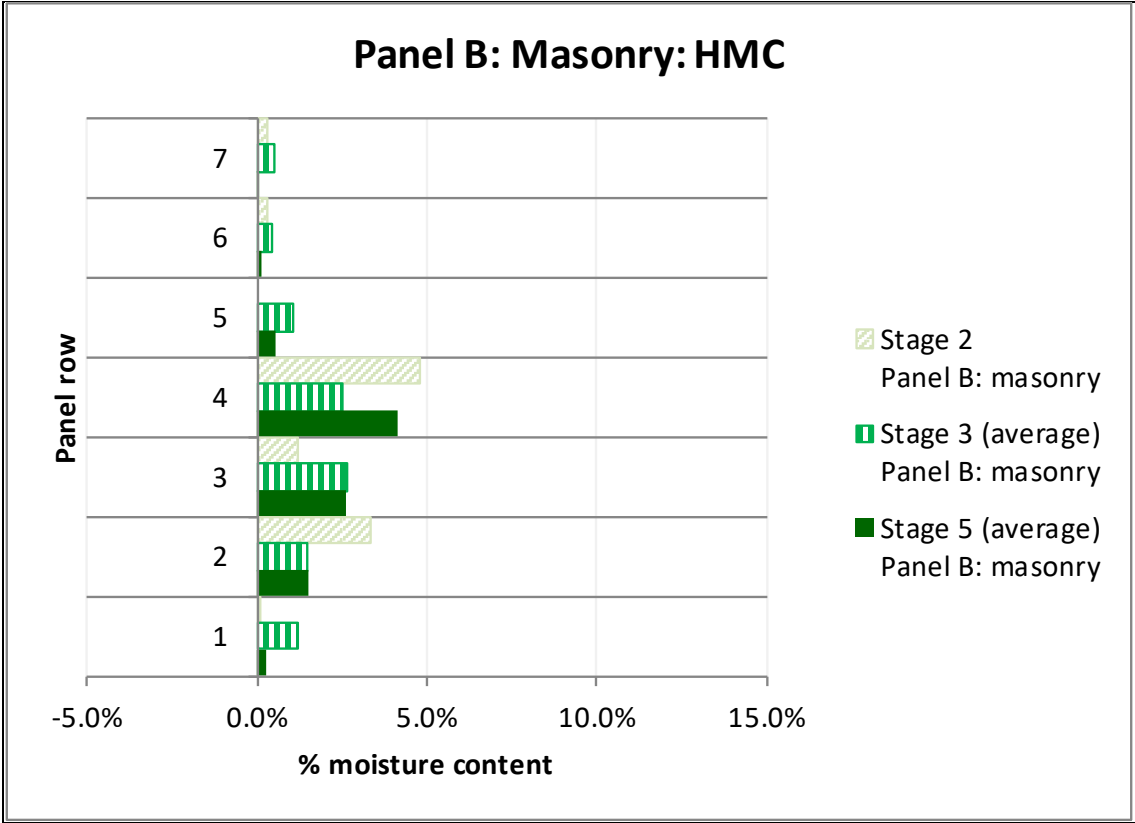
Figure 121: Panel B hygroscopic moisture content of masonry at Stages 2, 3, and 5.

Figure 122 below illustrates the earlier discussion: at Stage 3, the masonry CMCs, with the exception of rows 1 and 2 where the construction moisture effect is not apparent, are elevated.
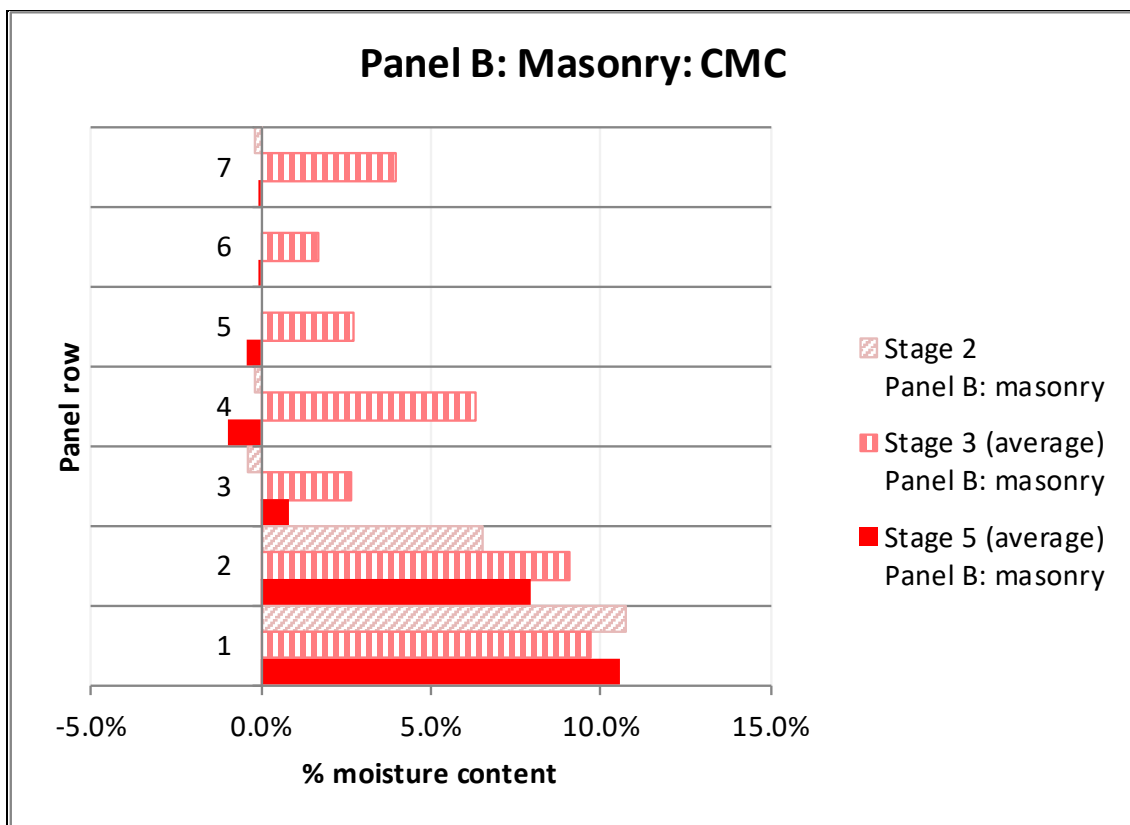
Figure 122: Panel B capillary moisture content of masonry at Stages 2, 3, and 5.

If Figure 122 is amended to omit the anomalous Stage 3 results, as illustrated by the chart in Figure 123 below, it is clear that the capillary moisture content of Panel B's masonry did not change over the monitoring period (i.e. between Stages 2 and 5). Furthermore, that the CMC of row 3, or indeed any of the upper rows, did not rise.

That the capillary moisture content of rows 4-7 had not risen at Stage 5 is a significant finding because it confirms that the application of low-permeability render did not cause the height attained by rising damp in Panel B to increase.
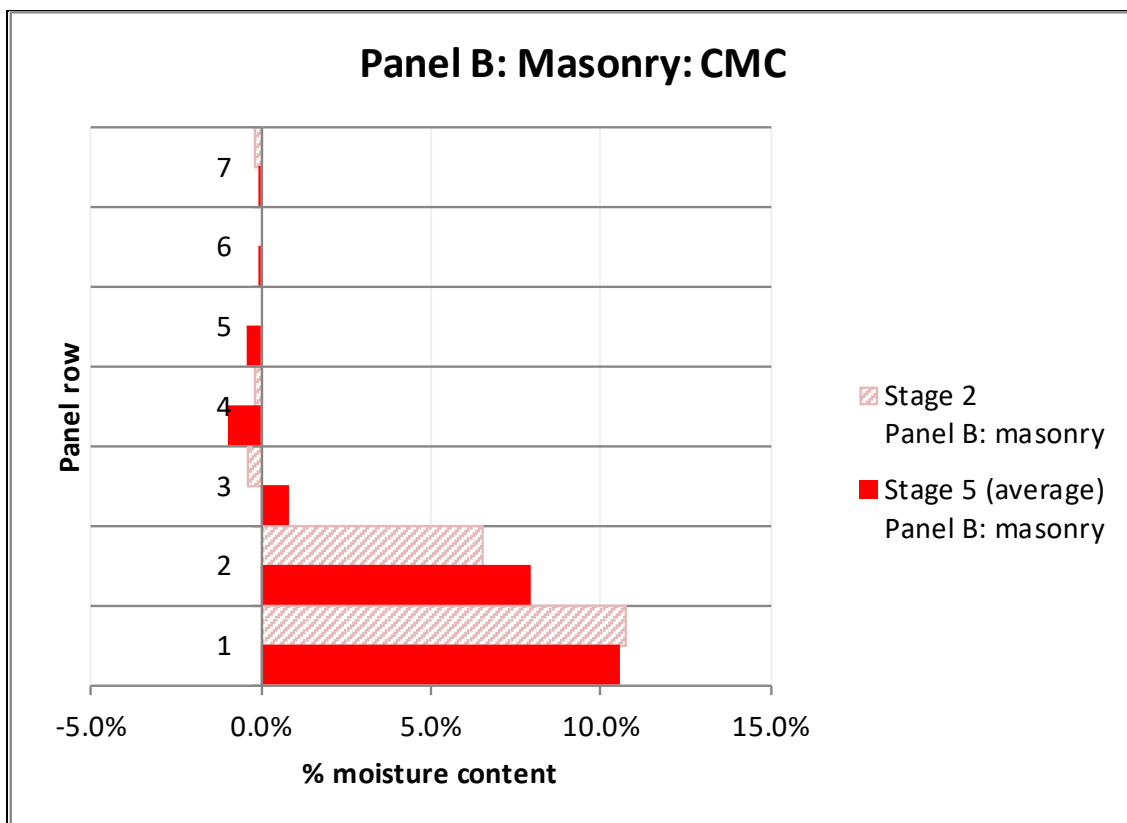
Figure 123: Panel B capillary moisture content of masonry at Stages 2 and 5.

For the previous three treatments, results of Stage 2, 3, and 5 moisture analyses for the plasterwork portion of each panel had been provided, essentially for completeness of those discussions. However, in the case of Panel B, where the damp controlling effect of applying low-permeability cement render was to be tested, the results are more important. Table 31 below provides the moisture values for the plasterwork of Panel B.

Row	Stage 2 Panel B: plasterwork			Stage 3 (average) Panel B: plasterwork			Stage 5 (average) Panel B: plasterwork		
	TMC	HMC	CMC	TMC	HMC	CMC	TMC	HMC	CMC
7	2.9%	3.3%	-0.4%	2.2%	2.2%	0.0%	0.3%	0.6%	-0.3%
6	3.7%	3.9%	-0.2%	2.7%	2.4%	0.3%	0.4%	0.6%	-0.2%
5				4.5%	3.0%	1.5%	0.4%	0.7%	-0.3%
4	4.8%	4.8%	0.0%	6.3%	3.8%	2.5%	1.0%	1.1%	-0.1%
3				6.6%	3.5%	3.1%	0.6%	0.7%	-0.1%
2				7.1%	3.8%	3.3%	1.7%	1.3%	0.4%
1				8.2%	4.1%	4.2%	1.6%	1.3%	0.3%

Table 31: Panel B (plasterwork) gravimetric moisture analyses Stages 2, 3, and 5.

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At Stage 2, the plasterwork samples were taken from the original plaster; at Stages 3 and 5 they were taken from the newly applied render. For this reason, Stage 2 values cannot be directly compared to those derived at Stages 3 and 5. In addition, the original plasterwork was missing from Panel B rows 1-3 and there is no direct equivalent for the Stage 2 row 5 result. Values for these rows are not provided in the Stage 2 results which nevertheless, demonstrated that moisture was present and comprised wholly of hygroscopic moisture in rows 4, 6, and 7.

The Stage 3 results shown in Table 31 were derived from samples taken from the newly applied cement render and plaster finish. Because, by design, the render was extended down to meet the floor, a value was obtained at row 1. Construction moisture is evident by way of elevated capillary moisture that can be seen to be both present and to fall consistently over the height of Panel B from rows 1-6. Unsurprisingly, the TMC values of the render mirrored the profile of the capillary moisture: elevated quantities that gradually receded from the base to the top of the panel. What was unexpected, however, were the relative high quantities of hygroscopic moisture and the way that these values presented an identical profile to that of the total moisture content, falling from the base to the top of Panel B.

The hygroscopic moisture content of the original plasterwork on all five panels had aligned with the rising damp model, displaying elevated values in the region of rows 3-4. The newly applied render could not be contaminated with hygroscopic soil salts, so it is assumed that its elevated HMCs result from incomplete hydration of the cement component of the render at the time the samples were removed. At the end of the monitoring phase, fifteen months after the low-permeability render was first applied, its HMC values, derived at Stage 5, had fallen to low levels.

Given the gravimetric analyses results of both the masonry and plasterwork components of Panel B at Stages 2, 3, and 5 the following conclusions are drawn:

1. The masonry wall forming Panel B was affected by rising damp at the start of the study and continued to be affected by this form of moisture at conclusion; essentially, the quantity of capillary moisture present in the masonry wall did not change over the fifteen-month monitoring period;

2. Although the newly applied low-permeability cement render and plaster finish applied to Panel B initially contained construction moisture and had relatively high hygroscopicity, neither significant hygroscopic moisture nor capillary moisture were present in this material on conclusion of the monitoring period;

3. Given that, at the end of the monitoring period, capillary moisture remained present in the masonry wall but was entirely absent from the plasterwork, it can be concluded that low-permeability render provides a significant controlling effect over rising damp; in other words, the application of low-permeability cement render provides a dry wall surface despite the continued presence of capillary and hygroscopic moisture in the underlying substrate;

4. Given that, at the end of the monitoring period, capillary moisture present in the masonry wall, determined at Stage 5, had not risen above the heights found at Stage 2 and Stage 3, it can be concluded that over a fifteen-month period the application of low-permeability render to a wall affected by rising damp did not increase the maximum height to which moisture had previously risen.

7.5. Treatment 5 (Panel C): installation of damp proofing cream and application of low-permeability render

Treatment 5, allocated to test Panel C, essentially combined treatments 2, 3, and 4 and involved removing plaster from the base of the wall, nominally extending to a height of one metre, and replacing with a low-permeability cement render and plaster finish coat using a specification typical of that applied following the installation of a remedial damp proof course; drilling holes in the base of the wall in a pattern suitable for the installation of a silane/siloxane damp proofing cream; and installing the damp proofing cream. The purpose of this treatment was to establish if this combination, a typical specification for damp proofing remedial works, would control rising damp. Table 32 below provides the moisture values for the masonry portion of Panel C at Stages 2, 3, and 5.

	Stage 2 Panel C: masonry			Stage 3 (average) Panel C: masonry			Stage 5 (average) Panel C: masonry		
Row	TMC	HMC	CMC	TMC	HMC	CMC	TMC	HMC	CMC
7	0.4%	0.6%	-0.2%	1.7%	0.4%	1.4%	0.0%	0.1%	-0.1%
6	0.0%	0.1%	-0.1%	0.1%	0.1%	0.0%	0.1%	0.0%	0.1%
5				2.2%	0.9%	1.3%	0.4%	1.0%	-0.7%
4	4.8%	4.5%	0.3%	7.8%	3.7%	4.1%	1.5%	2.5%	-1.0%
3	10.6%	6.0%	4.6%	11.1%	4.2%	6.9%	1.9%	3.2%	-1.3%
2	11.8%	2.7%	9.1%	11.9%	1.3%	10.6%	0.5%	1.1%	-0.6%
1	11.3%	0.5%	10.8%	10.4%	0.8%	9.7%	0.6%	0.5%	0.1%

Table 32: Panel C (masonry) gravimetric moisture analyses Stages 2, 3, and 5.

The Stage 2 results of Table 32 were derived from samples removed from Panel C before its existing plasterwork was stripped. The distribution of moisture in the masonry aligned with the profile found on the other four test panels: high moisture levels in rows 1-4 of which hygroscopic moisture was highest in rows 2-4 and capillary moisture highest in the panel's base, from row 1 to row 3. Again, this is a moisture profile consistent with the rising damp model.

The Stage 3 samples were removed from Panel C after the low-permeability cement render and plaster finish coat had been applied. For this reason, they did contain some

construction moisture but unlike Panel B this additional moisture was modest and was neither a concern nor required any special action to mitigate its effect. Indeed, the total and capillary moisture contents of the upper rows 4, 5, and 7, when compared to results from Stage 2, demonstrated a small, insignificant rise, but rows 1-3 were essentially unchanged. The hygroscopic moisture profile was similar enough to be claimed as identical.

Stage 5 results for the masonry of Panel C demonstrate a sharp reduction in CMC values with a complete absence of capillary moisture in all seven rows at the end of the monitoring period. In contrast, the masonry HMCs at stage 5 essentially mirrored those determined at Stages 2 and 3 and, importantly, indicate that hygroscopic moisture continued to be concentrated around rows 3 and 4. Given that the HMC values are influenced by hygroscopic salts and that the concentration of these salts in the masonry would be stable over the monitoring period, this result is to be expected.

Following the convention used for the other four panels, Figure 124, Figure 125, and Figure 126 below provides Panel C masonry results in chart format. Figure 124 illustrates how the total moisture content of rows 1-4, which had been high at Stages 2 and 3, had fallen significantly at the end of the study when the Stage 5 results were determined.
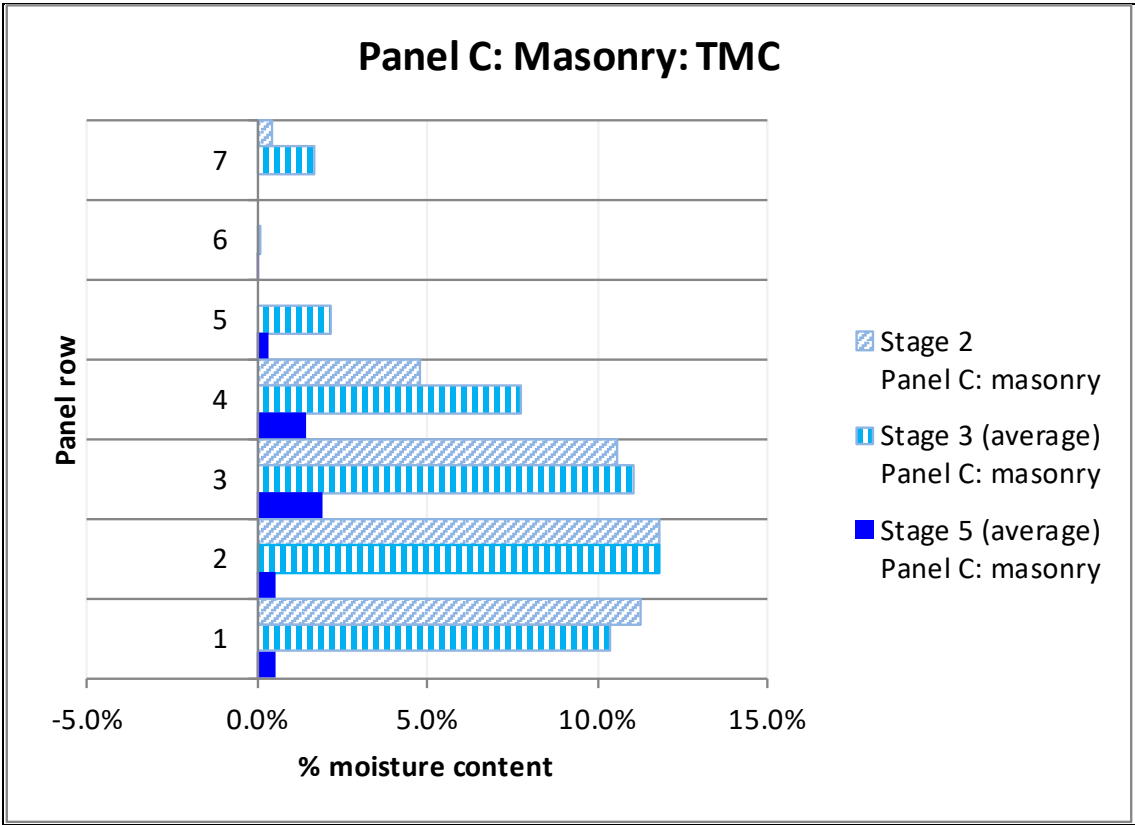
Figure 124: Panel C total moisture content of masonry at Stages 2, 3, and 5.

Figure 125 below demonstrates that that the hygroscopic moisture content of the masonry over the full height of Panel C rows 1-7 remained largely unchanged through all three Stages of analyses. This result suggests that the reduction in total moisture content, illustrated above in Figure 124 at Stage 5, can only be attributable to a fall in the capillary moisture content.
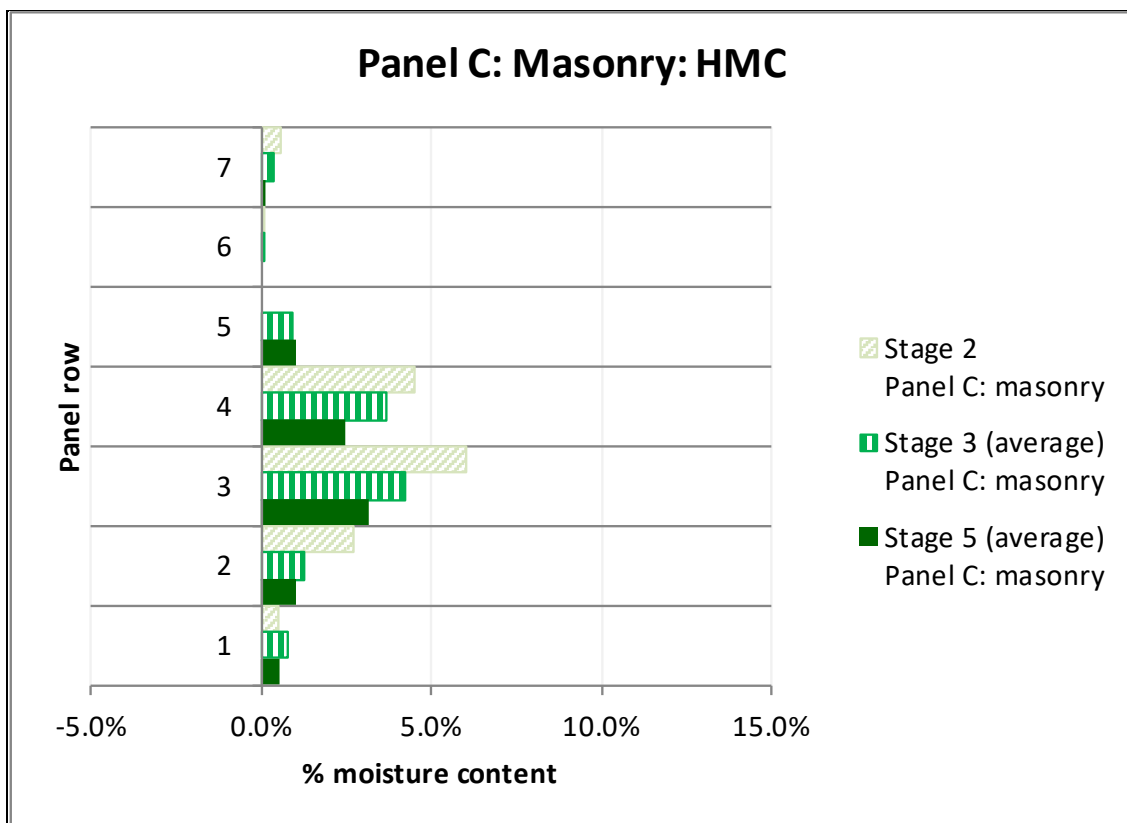
Figure 125: Panel C hygroscopic moisture content of masonry at Stages 2, 3, and 5.

The data in Table 32 above revealed a sharp fall in Panel C's masonry capillary moisture content over the monitoring period. Figure 126 below makes this patently clear: at Stages 2 and 3 the CMCs of rows 1, 2, 3, and 4 provide averages of 10.3%, 9.9%, 5.8%, and 2.2%, respectively, contrasting with a complete absence of capillary moisture[37] at Stage 5.

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[37] The negative capillary moisture content values to the left of the vertical axis can be considered zero.
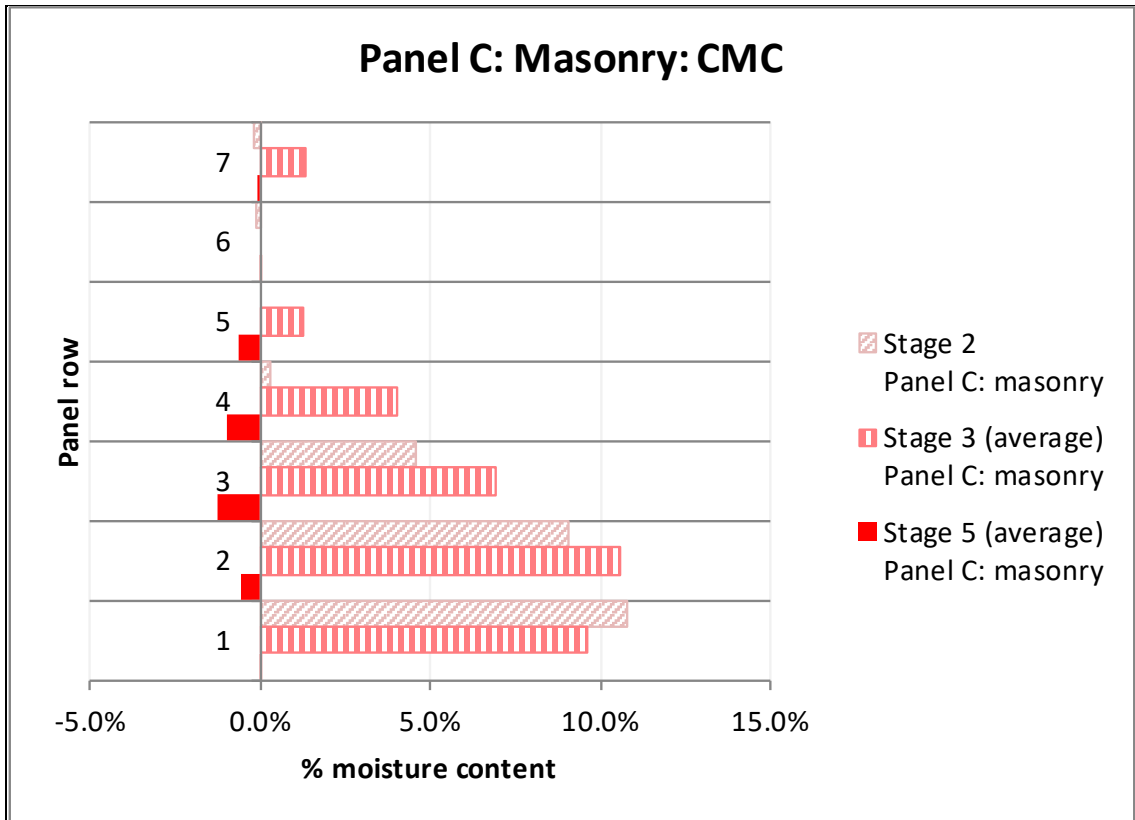
Figure 126: Panel C capillary moisture content of masonry at Stages 2, 3, and 5.

Panel C had a damp proofing cream inserted into holes drilled into the horizontal mortar bed joint between the first and second courses of bricks, corresponding, respectively, with rows 1 and 2. Assuming that this damp proof course was effective in controlling rising damp then a reduction of capillary moisture in the masonry, and thus the rows, above the damp proof course would be expected and thus be consistent with the results of Stage 5 moisture analyses. Conversely, it would seem reasonable to assume that the course of bricks beneath the damp proof course, corresponding with row 1, would continue to be affected by rising damp and therefore display elevated capillary moisture. Indeed, this was the result found for Panel A, which had also been treated with the damp proofing cream.

Paradoxically, for Panel C, the Stage 5 results clearly show that the masonry comprising row 1 was unaffected by capillary moisture at the end of the study. Significant capillary moisture was confirmed to be present in row 1 at Stage 2 and Stage 3 at 10.8% and 9.7%

respectively, so, how can this significant fall in the masonry of Panel Cs row 1 be accounted for?

One possible explanation is that the samples were taken from bricks with differing CMCs. In other words, that the samples removed at Stages 2 and 3 were obtained from damp bricks and contrasted with those obtained at Stage 5, which were taken from bricks that were dry. However, this theory seems unlikely given that the CMCs of samples removed from row 1 across the panels at all three stages of analyses were generally significant, as shown in Table 33 below.

Masonry % CMC row 1			
Panel ref.	Stage 2	Stage 3	Stage 5
Panel A	13.8%	14.1%	13.2%
		13.8%	13.6%
Panel B	10.7%	11.7%	9.8%
		7.7%	11.3%
Panel C	10.8%	1.5%	
		7.8%	
Panel D	10.8%	9.8%	9.2%
		10.6%	9.8%
Panel E	2.4%	3.6%	8.8%
		4.6%	7.3%
Maximum	13.8%	14.1%	13.6%
Average	9.7%	8.5%	10.4%
Minimum	2.4%	1.5%	7.3%
Median	10.8%	8.8%	9.8%

Table 33: Panels A-E capillary moisture content of masonry in row 1 at Stages 2, 3, and 5.

In this table the Stage 5 result from Panel C's row 1 is omitted.

The bottom section of Table 33 summarises the results across the three stages of gravimetric moisture analyses: the maximum capillary moisture content is in the range

13.6%-14.1%, the average 8.5%-10.4%, and the median values 10.8%, 8.8%, and 9.8%, respectively. The minimum values on one pair set from Panel C and Panel E are relatively low at 1.5% and 2.4%, respectively, but it is clear from these data, generally, that significant capillary moisture was present in row 1 of all of the test panels and with the exception of Panel C remained high at the end of the monitoring period.

Given that all of the samples removed for analyses were taken from a relatively narrow, 100 mm wide strip of the panels' central section, it seems improbable that Panel C's row 1 Stage 5 samples would inadvertently have been taken from bricks unaffected by capillary moisture. This seems even more unlikely given the precise position of the sampling points of row 1 of Panel C, which indicate that the Stage 5 samples were removed from the same brick unit as that used for the Stage 2 and Stage 3 samples, as shown in Figure 127 below.

Figure 127: Panel C sampling positions at Stages 2, 3, and 5.

Base of Panel C following removal of the low-permeability render. The close proximity of the masonry sampling holes for Stages 2, 3, and 5 can be seen. In row 1 (the lowest brick), the two centrally located, freshly drilled holes are those made for the Stage 5 masonry samples and are essentially directly adjacent to the earlier sampling holes.

Instead, the reduction in the capillary moisture content of the masonry forming row 1 of Panel C can be attributed to the effect of the damp proofing cream. As described elsewhere, this damp proofing cream was inserted into holes drilled into the horizontal mortar bed joint between the first two courses of bricks, which can be seen located between rows 1 and 2 in Figure 127 above.

The damp proofing cream is formulated to enable it to diffuse into the masonry parts adjacent to the line of injection (Safeguard Europe Ltd., 2007, p. 10). Given the absence of capillary moisture in row 1 of Panel C at the end of the monitoring period, a course of bricks that had been established, through gravimetric analysis at Stages 2 and 3, to

contain significant capillary moisture, this can be attributed to the effect of the damp proofing cream.

Information with respect to precisely how long the damp proofing cream required to produce a reduction in the capillary moisture content of test Panels A and C is not readily apparent. However, Protimeter measure-mode readings recorded from the substrate of Panel C, row 2, indicated an otherwise unexplained decline of capillary moisture content in March 2013, five months after the damp proofing cream had been inserted. This time frame aligns with manufacturer's claims for a post-treatment drying time of one month per 25 mm thickness of masonry wall, the walls treated having a nominal thickness of 110 mm (Safeguard Europe Ltd., 2007, p. 17).

Following the convention used in the previous sections, Table 34 below provides the moisture values for the plasterwork portion of Panel C at Stages 2, 3, and 5 to complete this discussion.

Row	Stage 2 Panel C: plasterwork			Stage 3 (average) Panel C: plasterwork			Stage 5 (average) Panel C: plasterwork		
	TMC	HMC	CMC	TMC	HMC	CMC	TMC	HMC	CMC
7	0.8%	1.3%	-0.5%	2.2%	2.7%	-0.5%	0.3%	0.6%	-0.3%
6	0.6%	0.7%	-0.1%	2.4%	2.7%	-0.3%	0.3%	0.6%	-0.3%
5				3.6%	3.1%	0.5%	0.6%	0.8%	-0.2%
4	2.0%	2.3%	-0.3%	4.1%	3.9%	0.2%	0.6%	0.8%	-0.3%
3	3.8%	3.6%	0.2%	3.9%	3.7%	0.2%	0.8%	1.0%	-0.3%
2	3.8%	2.9%	0.9%	5.4%	4.1%	1.4%	0.7%	1.0%	-0.3%
1	2.8%	1.6%	1.2%	5.6%	3.9%	1.7%			

Table 34: Panel C (plasterwork) gravimetric moisture analyses Stages 2, 3, and 5.

Stage 2 analyses of Panel C's plasterwork was carried out on samples removed from the existing plaster before it was stripped and replaced with low-permeability render. For this reason, Stage 2 values cannot be directly compared to those derived at Stages 3 and 5. However, the Stage 2 results demonstrate that although moisture was present in rows 1-4, it largely comprised hygroscopic moisture that was concentrated across rows 2-4.

Stage 3 samples were taken from the newly applied cement render and plaster finish coat that contained some construction moisture, albeit not in quantities as great as those that affected the Panel B results. What is interesting in the case of Panel C, however, is that this construction moisture is almost wholly a result of the renders' hygroscopic moisture content. As discussed in the previous section, the elevated HMCs are assumed a consequence of incomplete hydration of the cement component of the render at the time the samples were removed.

The results of Stage 5 analyses for the plasterwork component of Panel C, which comprised the low-permeability cement render and plaster finish coat, found it did not contain any significant quantities of hygroscopic or capillary moisture.

Given the gravimetric analyses results of both the masonry and plasterwork components of Panel C at Stages 2, 3, and 5 the following conclusions are drawn:

1. The masonry wall forming Panel C was affected by rising damp at the start of the monitoring period, prior to the installation of the damp proofing cream. The absence of capillary moisture at the end of the monitoring period suggests that rising damp no longer affected Panel C, a result consistent of an effective damp proofing treatment;

2. Although the newly applied low-permeability cement render and plaster finish coat applied to Panel C initially contained construction moisture and had relatively high hygroscopicity, neither hygroscopic moisture nor capillary moisture were present in this material on conclusion of the monitoring period.

7.6. Evaluating the Damp proofing treatments: closing comments

Previously, it had been established that rising damp affected all five test panels. The work described in this chapter was aimed at testing how effectively the contemporary

method of remedial damp proof course treatment alleviated this rising damp. In this respect, the quasi-experiment was designed, not only to evaluate the two-part process that comprises this method (i.e. the installation of a damp proofing cream and the application of low-permeability render) but also to test, individually, each of its component parts.

As the results have shown, drilling holes into the lowest, horizontal mortar bed joint without installing the damp proofing cream has no effect over moisture in the wall; conversely, applying a low-permeability cement render delivers a dry wall surface despite moisture remaining present in the underlying masonry. Surprisingly, although logic would suggest that this latter method, by restricting evaporation, would cause capillary moisture to rise higher up the wall, no such effect was apparent over the fifteen-month monitoring period of this study.

Importantly, installing the damp proofing cream was found to significantly reduce the capillary moisture content of the wall base; in other words, it is a method that effectively controls rising damp. However, in the absence of measures to address hygroscopic moisture, there is no perceivable benefit with respect to the removal of dampness from the affected walls: in practical terms, they remained damp. It is for this reason that optimum results were achieved when the damp proofing cream was installed and the hygroscopic salt contaminated plaster was removed and replaced with low-permeability cement render.

These findings are significant for practice because, as the preceding commentary clearly demonstrates, despite the criticisms levied with respect to the effectiveness and indeed the appropriateness of the contemporary method of damp proof course treatment, this two-part system, by addressing both capillary and hygroscopic moisture, is both warranted and effective.

Chapter 8

Evaluating the Moisture Measuring Apparatus

8.1. Introduction

The evaluation of the moisture measuring apparatus was essentially concerned with the effectiveness of this equipment for the purposes of moisture measurement and monitoring. However, this is a practice-based project with the intention of only using equipment generally available to building surveyors; therefore, the equipment's accessibility, ease of operation, and affordability were also important concerns: it was not acceptable to employ techniques that were cost prohibitive or impractical for use in similar studies.

This chapter commences with a brief discussion of these matters before describing the performance of each individual component of the on-site apparatus. The chapter concludes in its final section by considering, through analyses of data from the Hygrosticks and Lascar data loggers, if there is any correlation between moisture in the environment and moisture in a damp wall.

8.2. Apparatus accessibility, ease of operation, and cost

In Chapter 4 the methods required to use and construct the apparatus were described in detail. Neither their operation nor manufacture should pose any difficulties for a competent person and further comment with respect to these matters is unnecessary. With respect to affordability, the costs of equipment used for the on-site work is broken down as follows:

1. Protimeter Surveymaster and MMS meters: £380.40 and £675.60, respectively (Survey Express Services, 2015b, 2015c);

2. Protimeter Hygrosticks: £60.00 each or £234.00 per pack of five (Survey Express Services, 2015a);

3. Protimeter Humidity Sleeves: £36.00 per pack of twenty (Survey Express Services, 2015a);

4. Timber Probes Type 1: the total cost of all materials did not exceed £50.00 and including a soldering iron, no more than £70.00;

5. 9 mm diameter plain softwood dowels: less than £1.00;

6. 5 mm diameter plain hardwood dowels: £1.00;

7. Lascar ELB-USB-2+ data loggers: £62.95 each (Lascar Electronics Ltd., 2015).

This project required forty Hygrosticks and seven Lascar data loggers. Technically, this equates to £1,944.00 and £440.65, but Amphenol applied a generous 40% discount to the Hygrosticks, following a polite request.

For quantification of moisture, the gravimetric analysis method, described in Chapter 4, was employed. This technique requires an airtight vessel containing a saturated salts solution, a scientific balance, a laboratory drying oven, containers to store and transport samples, and receptacles to facilitate weighing. A budget of £2,000.00 to £3,000.00 would be more than adequate; in practice, I purchased my equipment for less than £1,000.00. However, it is feasible to use a calcium carbide meter to quantify moisture.[38]

A carbide meter retails at £823.20, although it is an instrument that building surveyors who investigate dampness may well possess (Survey Express Services, 2015d). Drilling machines and masonry bits needed to remove samples are also likely to be pre-owned, but even if these costs were included, a budget of around £1,000.00 to £1,200.00 is

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[38] The carbide meter method is described in Chapter 4.

adequate to purchase equipment that would enable quantitative moisture analysis to be undertaken.

Affordability is perhaps subjective, but the cost of the apparatus used in this project is not thought to be onerous and therefore to preclude its use in future studies of this type. Furthermore, costs can be offset through instruments that are already owned, that have uses beyond the remit of a research project, and through the generosity of suppliers, particularly where they are keen to support research work.

The discussions in earlier chapters highlights both the importance and value of the gravimetric method of moisture analyses. It is a technique for the quantification of moisture in construction materials that is cost effective, simple, and extremely efficient. However, the cost benefit of individual items of equipment used for moisture monitoring is ultimately determined by their effectiveness. The six methods used for this purpose are summarised as follows:

1. Protimeter measure-mode function using the Heavy Duty Probe.[39]

2. Protimeter measure-mode function using the Deep Wall Probes.[40]

3. Protimeter search-mode function.[41]

4. Timber Probes Type 1.[42]

5. Plain timber dowels.[43]

6. Protimeter Hygrosticks.[44]

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[39] Used to record measure-mode readings on the surface of the panels.
[40] Used to record measure-mode readings from the substrate of the panels.
[41] Applied to the surface of the panels.
[42] Read using the Heavy Duty Probes of the Protimeter as measure-mode readings.
[43] Read using the Heavy Duty Probes of the Protimeter as measure-mode readings.
[44] Inserted into humidity sleeves and read using the Protimeter MMS meter.

Following an explanation of the conventions used to process data and to present these results in chart form, each of these methods is evaluated in a separate section of this chapter.

8.3. Results and chart conventions

The evaluation required the trend determined by the values obtained from each piece of equipment over the fifteen-month monitoring period to be compared to the actual moisture changes in the five test panels.

This exercise was facilitated by plotting these values as charts: each chart representing the readings from a single piece of equipment in each of the seven rows of a specific panel. Some of the raw data was extremely volatile, which tended to obscure the underlying trend. For this reason, the data has been smoothed by applying a 4-period moving average to values from the 44 part sets and a 240-period moving average to the far larger 11,257 part sets of the Lascar data loggers. This averaging does not affect the results, but it significantly improves readability.

The moisture values determined at the start and end of the monitoring period through gravimetric analyses at Stages 2, 3, and 5 have been overlaid onto charts for individual items of equipment. For consistency with the evaluation of the treatments described in Chapter 7, the values of the Stage 3 and 5 sample pairs have been averaged. For some panels, moisture change only occurred in the base of the panels; in such cases, it was only necessary to compare data from rows 1-4 to confirm trends.

On each chart, the Y-axis represents the equipment's values and the X-axis represents time with both increasing from the origin. This convention typically means that values at the top of the Y-axis represent the lower rows of the panels and vice versa. In other words, the charts form an inverted representation of the panels. When gravimetric

analyses results are overlaid, their values are shown on a secondary Y-axis at the right-hand side of the charts.

Consistently high (i.e. maximal) Protimeter readings were obtained from some panel rows. Not only did these readings produce straight line graphs but these graphs overlapped, obscuring individual rows. To mitigate this issue, maximal readings from more than a single row are adjusted using the following formulas:

- For measure-mode: 100%[45] + row-number (i.e. row 1 uses 101%, row 2 uses 102%, row 3 uses 103%, and so on).

- For search-mode: 1000[46] + (row number x 10) (i.e. row 1 uses 1010, row 2 uses 1020, row 3 uses 1030, and so on).

This convention does not influence the results, but it greatly assists readability.

8.4. Protimeter measure-mode function using the Heavy Duty Probe

The Protimeter measure-mode function used with the Heavy Duty Probe, shown in Figure 138 below, would seem to offer a means of testing for moisture that is none invasive, quick, and easily repeatable.

Unfortunately, as experienced surveyors will attest, and as has been described in earlier chapters, this is not necessarily the case for two distinct reasons. Firstly, for plaster and masonry materials, measure-mode readings can only be compared relatively (Burkinshaw & Parrett, 2003, p. 217; Oliver, Douglas, & Stirling, 1997, p. 264). Secondly, because this function is actually measuring electrical resistance, measure-mode

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[45] For convenience, maximum measure-mode values are shown as 100%; technically, the maximum reading obtainable from the Protimeter Surveymaster used in this project was 98.2%.
[46] The Protimeter search-mode scale is 0-1000 for the MMS model and 60-999 for the Surveymaster model. Variations at the upper end of the range are academic, and for convenience 1000 is used for maximum values.

responds to any form of moisture or any electrical conducting substance; it will therefore always return high values on materials contaminated with hygroscopic salts (Burkinshaw, 2002, p. 162 & 171).

From the outset it was expected that the test panels would be contaminated with hygroscopic salts as a consequence of rising damp. Indeed, salts analyses undertaken at Stage 2 found significant levels of hygroscopic nitrate salts to be present in their base. Thus, given the functions' operating limitations and knowledge that hygroscopic salts were present in the original plaster, would measure-mode readings taken on the surface of the panel's provide any useful indication of moisture change occurring over the monitoring period?

Figure 128: Panel E Protimeter measure-mode function using the Heavy Duty Probe.

Protimeter measure-mode readings obtained with the Heavy Duty Probe fell sharply from high to low values at the boundary line between the damp hygroscopic salt contaminated parts at the panel's base and the drier, uncontaminated parts above. Readings taken on this boundary, which on Panel E coincided with row 4, tended to fluctuate dependent on precisely where the needles of the probe were inserted.

In practice, surface measure-mode readings were taken from two different materials: on Panels A, D, and E, from the original plasterwork, and on Panels B and C, from the newly applied plaster finish coat, which overlaid the low-permeability cement render.[47] It was expected that the profile of readings from these two panel sets would differ because hygroscopic salts that contaminated Panel B's and C's original plasterwork were no longer present. This is precisely what was confirmed with similarity of measure-mode

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[47] The existing plaster had fallen away from the base of Panel A in the region of rows 1-3. In addition, with the exception of Panel B, where the low-permeability render had been extended down to meet the floor, the bottom edge of the plaster had been trimmed in the region of row 1, exposing the underlying brickwork. Thus, measure-mode readings obtained from row 1 of Panels C, D, and E and rows 1-3 of Panel A could only be recorded directly on the brick face.

readings across the three panel group A, D, and E and similarity of these readings across the two panel group B and C.

For the three panel group, these readings were high in the wall base with a pronounced fall at the boundary between the hygroscopic salt contaminated plaster and the uncontaminated plaster above. Particular care was required when taking readings on this boundary as the value displayed by the meter would fluctuate depending on the precise insertion point of the Heavy Duty Probes' needles, as shown in Figure 128 above.

A further issue on Panels A, D, and E was the tendency for measure-mode readings to vary significantly from one data collection visit to the next, a phenomenon attributed to the plaster's hygroscopic moisture content responding to changes in environmental conditions. This volatility of measure-mode readings meant that interpretation of raw data was confusing, an issue that was rectified by applying a 4-period moving average, as illustrated for Panel A in Figure 129 and Figure 130 below.
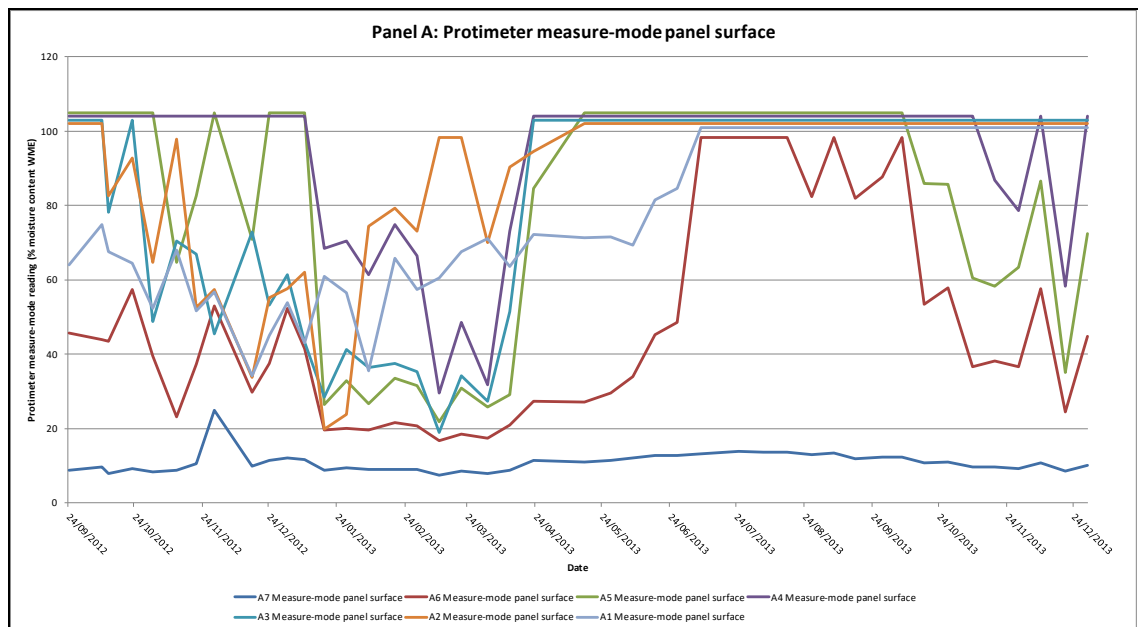
Figure 129: Panel A rows 1-7 Protimeter measure-mode readings from panel surface.

Chart of the raw surface measure-mode values for Panel A over the fifteen-month monitoring period. The volatility of the raw data hampers interpretation.
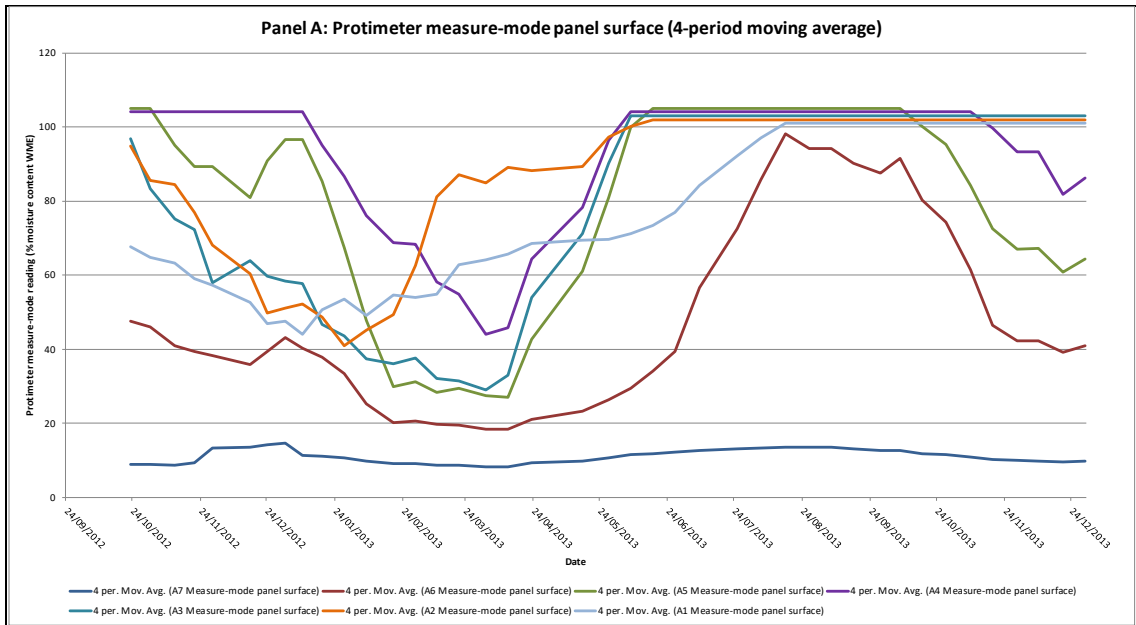
Figure 130: Panel A rows 1-7 Protimeter measure-mode readings from panel surface (4-period moving average).

Chart of the 4-period moving average surface measure-mode values for Panel A over the fifteen-month monitoring period. The trend for each row is far clearer.

In contrast to Panels A, D, and E, the measure-mode values recorded on the surface of Panels B and C were both lower and far more consistent over their seven rows. To illustrate this trend, Figure 131 below provides the 4-period moving averages for the measure-mode readings recorded on Panel B.
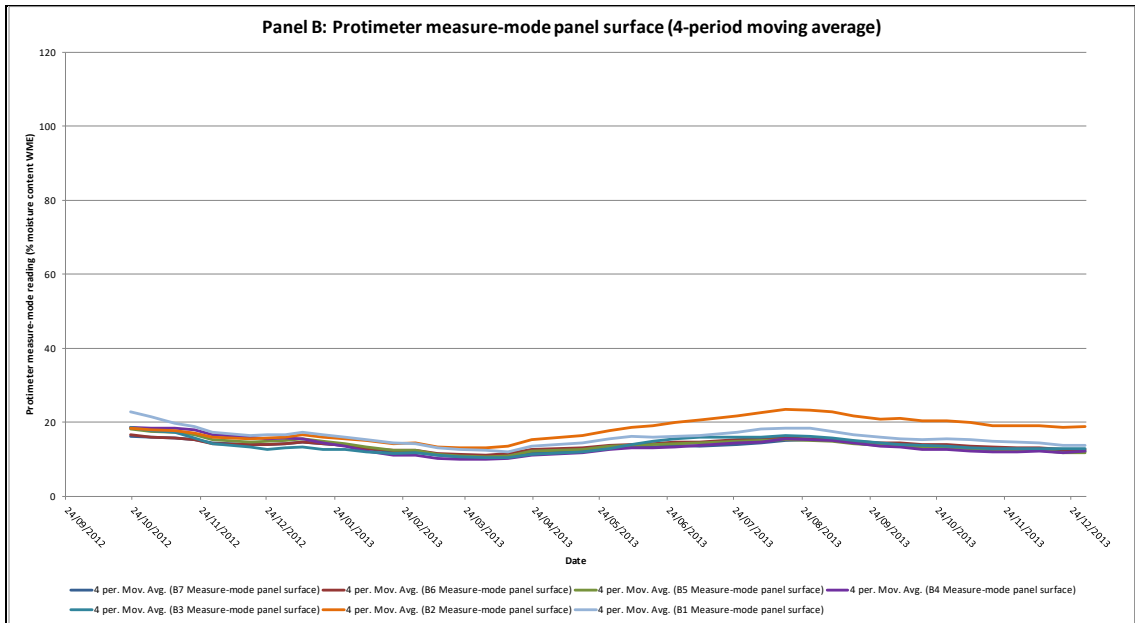
Figure 131: Panel B rows 1-7 Protimeter measure-mode readings from panel surface (4-period moving average).

The surface measure-mode readings from Panel B were low suggesting that neither capillary nor hygroscopic moisture was present in the plasterwork (i.e. the newly applied low-permeability render and plaster finish coat).

To determine the accuracy in the trend of surface measure-mode readings against the actual moisture change in the panels, these measure-mode values were plotted alongside the capillary moisture values determined through analyses at Stages 2, 3 and 5.

In practice, only Panels A and C, the two panels which received the damp proofing cream treatment, demonstrated a fall in capillary moisture and because this effect was restricted to the bottom four rows, data from the upper three rows has been omitted. Figure 132 and Figure 133 below are the charts of these data for Panel A and Panel C, respectively.

The chart for Panel A, in Figure 132 below, shows that the capillary moisture content of rows 2-4 falls over the monitoring period and this contrasts with the surface measure-mode readings, which initially fell but subsequently rose to maximum values. Row 1's CMC did not change but its measure-mode readings followed the trend displayed in rows 2-4. Essentially, the surface measure-mode readings showed no correlation with the fall in capillary moisture content that occurred in the underlying masonry wall.

Figure 132: Panel A rows 1-4 Protimeter measure-mode readings from panel surface (4-period moving average) v CMC of masonry.

The surface measure-mode readings for Panel A rows 2-4 display an initial fall followed by a subsequent increase to the maximum 100% value, despite an overall fall in their capillary moisture contents**.**

The chart for Panel C in Figure 133, again displays no correlation between the surface measure-mode values and the actual capillary moisture content. The former suggests low moisture levels from the outset and the latter demonstrating a fall over the monitoring period.

Figure 133: Panel C rows 1-4 Protimeter measure-mode readings from panel surface (4-period moving average) v CMC of masonry.

The surface measure-mode readings for Panel C rows 1-4 display a low, flat trend, despite initially high capillary moisture contents that fell over the monitoring period.

The application of low-permeability render to Panel C both removed the original salt contaminated plaster and effectively isolated the new plaster finish coat from the underlying masonry wall. This effect was also apparent on Panel B, as shown in Figure 134 below: Panel B's low-permeability render effectively masking capillary moisture that remained present in the underlying masonry wall.

Figure 134: Panel B rows 1-4 Protimeter measure-mode readings from panel surface (4-period moving average) v CMC of masonry.

The surface measure-mode readings for Panel B rows 1-4 displays a low, flat trend, despite initially high capillary moisture contents that fell over the monitoring period.

Measure-mode readings correctly showed that the plasterwork of Panels B and C was dry, but in the case of Panel B this function did not account for moisture that remained present in the underlying masonry wall.

On the older, existing plasterwork of Panels A, D, and E, the measure-mode readings from the upper regions, occupied by rows 7, 6, and 5, where moisture was not present, were meaningful; yet, in the central region of the panels, rows 3 and 4, the high surface measure-mode readings where simply a response to total moisture, irrespective of whether this was in the form of hygroscopic or capillary moisture.

In practice, it is quite possible for high measure-mode readings to be obtained on plasterwork that is unaffected by capillary moisture if hygroscopic moisture is present. Conversely, the application of low-permeability render provides a dry surface that effectively masks capillary moisture present in the underlying masonry wall. Thus, where high surface measure-mode readings were obtained at the base of a test panel, it was not possible to determine if these readings were attributable to capillary or hygroscopic

moisture or, more importantly, to provide accurate diagnosis with respect to moisture changes. Indeed, this was clearly evident on Panels A and C where, despite testing plasterwork of two inherently different types, the measure-mode function was unable to accurately track the fall in capillary moisture that occurred in the masonry. Similarly, following the early drying out phase after application of low-permeability render, persisting capillary moisture in the underlying masonry wall forming Panel B was invisible to measure-readings obtained from the newly plastered surface.

Low measure-mode readings will always mean that the material tested is unaffected by both hygroscopic and capillary moisture. Yet, it is feasible that these forms of moisture could be present in the underlying substrate, especially where low-permeability materials have been applied to the walls. Furthermore, because it is necessary for the needles of the probe to make good contact with the material under test to return accurate values, falsely low readings can result in the case of dense materials where penetration of the needles is inadequate. Supplementing the measure-mode function with readings obtained using the search-mode function to identify the potential for substrate moisture to be present is perhaps one method of mitigating these limitations. The success of using search-mode for this purpose is discussed in a later section.

Ultimately, in the absence of other electrically conducting materials, it can be concluded that elevated measure-mode readings essentially indicate that the material tested contains either hygroscopic and / or capillary moisture and thus would prompt further investigation and quantification of moisture using other methods such as gravimetric analysis. Furthermore, that a rapid change in a material from initial low measure-mode readings to those that are significantly higher—for example, as a result of a plumbing leak—would be useful in correctly identifying an increase in capillary moisture. For these reasons, the Protimeter measure-mode function is a useful and arguably indispensable tool for dampness investigation, but it cannot be relied upon as a method to monitor the reduction of moisture in a rising damp affected wall following remedial damp proof course treatment.

8.5. Protimeter measure-mode function using the Deep Wall Probes

The Protimeter measure-mode function using the Deep Wall Probes is identical to its use with the Heavy Duty Probes, the only difference is that the former returns readings from the substrate rather than the surface of the material under test, as illustrated for Panel C in Figure 135 below. This similarity means that the measure-mode function's limitations in responding to any form of moisture, contaminating salts, and other materials that are electrically conducting apply equally to the Deep Wall Probes.
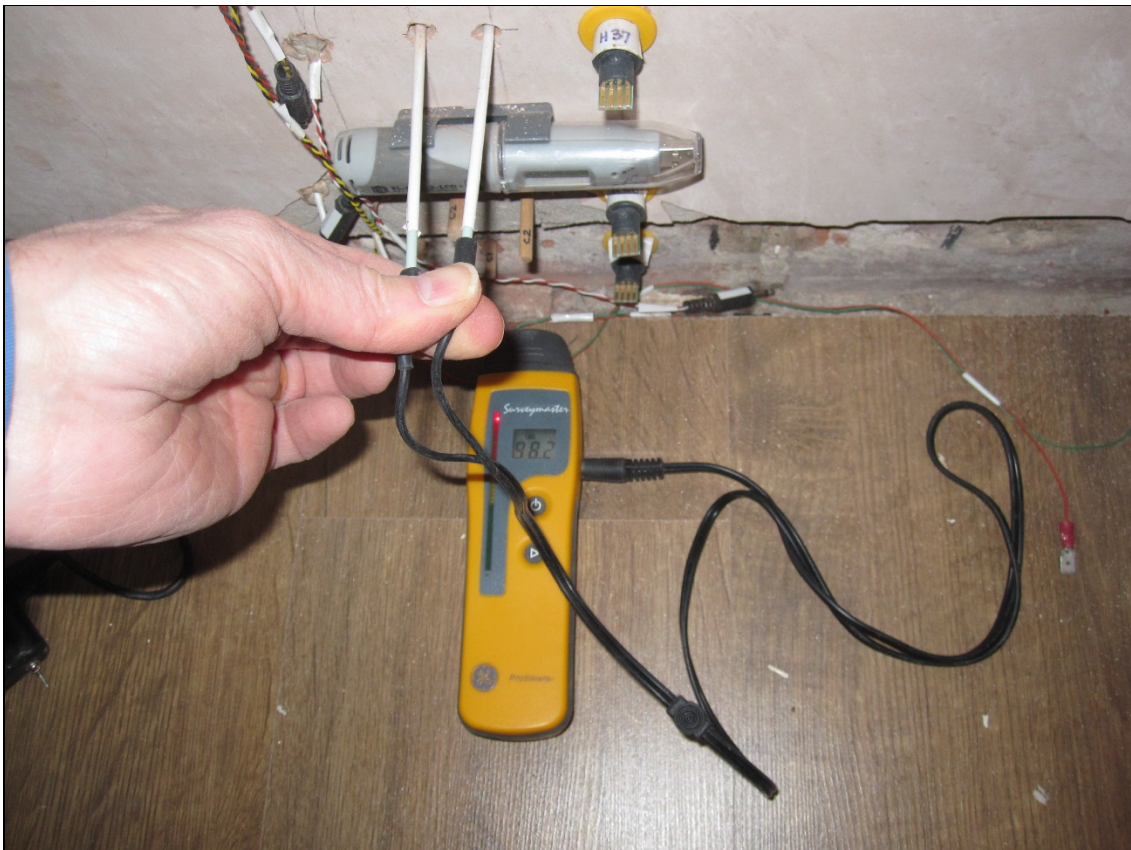
Figure 135: Panel C Protimeter measure-mode function using the Deep Wall Probes.

Protimeter measure-mode readings are obtained from the substrate by inserting the needles of the Deep Wall Probes into two 5 mm dia. holes, drilled for this purpose at the mid-point of each of the seven rows of the apparatus.

The findings demonstrated this confounding effect of hygroscopic moisture. For example, as illustrated in Figure 136 below, the substrate measure-mode readings for

rows 1-4 of Panel A remained at 100% over the full duration of the fifteen-month monitoring despite a clear reduction in capillary moisture.
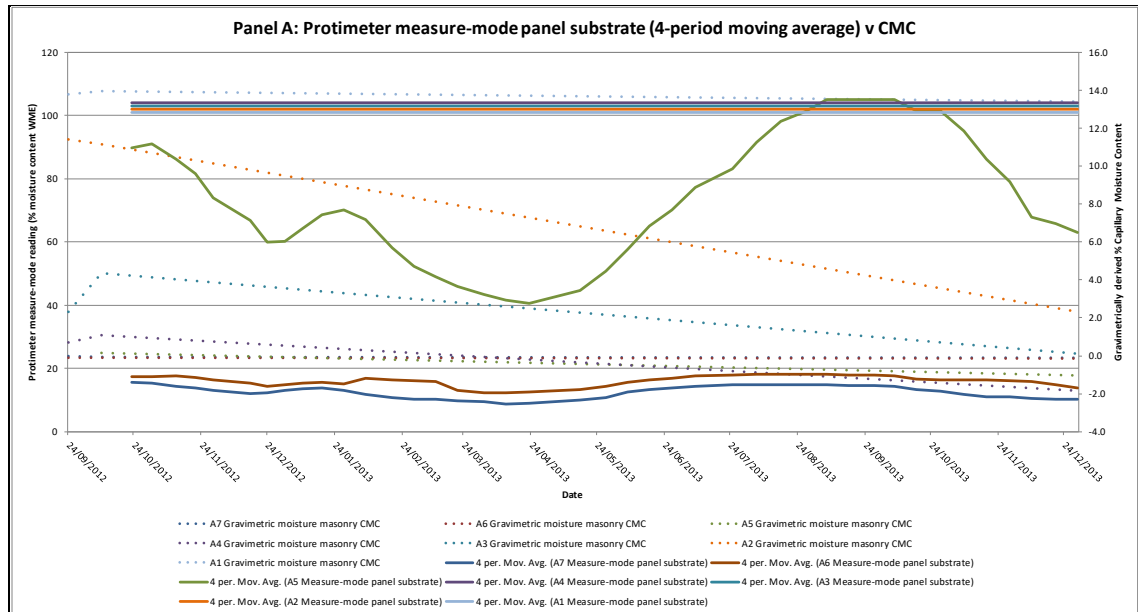
Figure 136: Panel A rows 1-7 Protimeter measure-mode readings from panel substrate (4-period moving average) v CMC of masonry.

Substrate measure-mode values for Panel A rows 1-4 were maximum throughout the monitoring phase despite a fall in their capillary moisture contents.

To further illustrate this hygroscopic effect, in Figure 137 below, the total moisture contents derived at Stages 2, 3, and 5 (i.e. the combined value of the capillary and hygroscopic moisture contents) are plotted against the substrate measure-mode values. The higher TMCs of rows 2, 3, and 4, as a result of elevated hygroscopic moisture, provide justification for the high substrate measure-mode readings. This finding confirms that even moderate levels of hygroscopic moisture can produce erroneously high measure-mode readings.
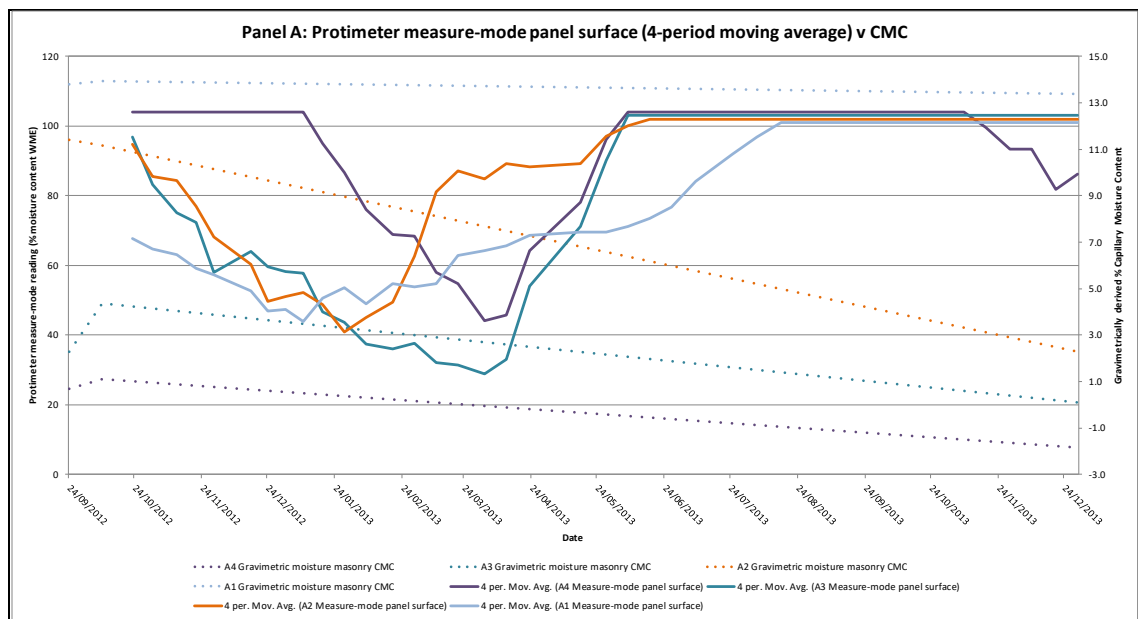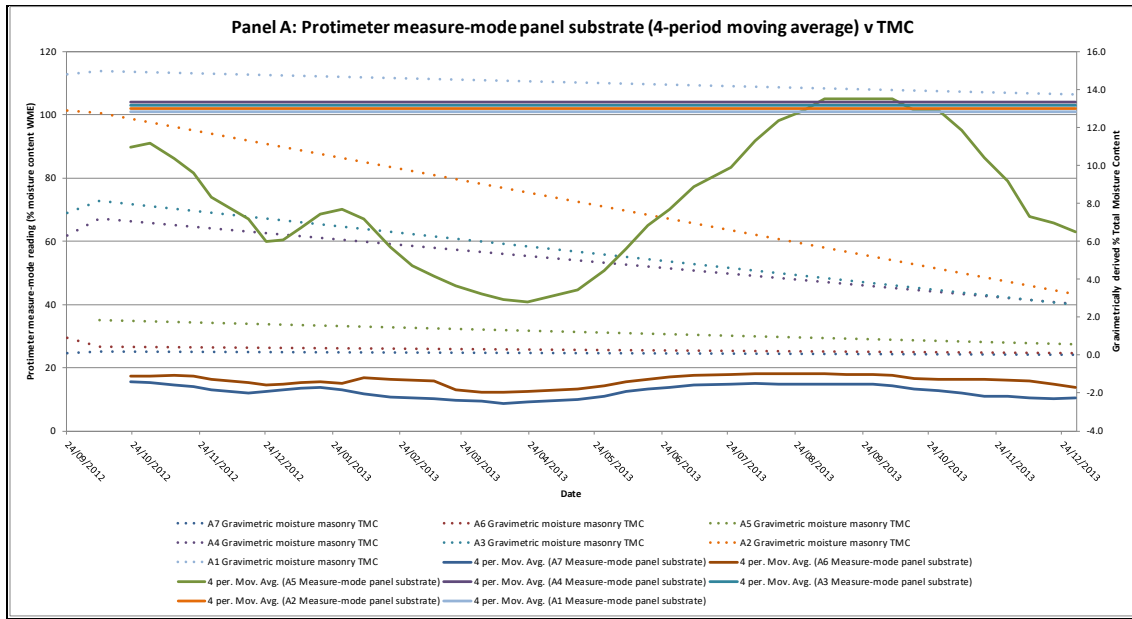
Figure 137: Panel A rows 1-7 Protimeter measure-mode readings panel substrate (4-period moving average) v TMC of masonry.

The total moisture contents, elevated through the inclusion of their hygroscopic moisture contents, provides justification for the high substrate measure-mode readings of Panel A rows 1-4.

For Panel B, shown in Figure 138 below, the substrate measure-mode readings obtained from rows 5-7 fell from initial highs of 50-100% to 14-20%, and, therefore, appeared to track the reduction in capillary moisture. However, capillary moisture did not essentially change in Panel B; instead, as discussed in Chapter 7, there was an initial increase resulting from construction moisture in the applied render. At conclusion of the monitoring period, substrate measure-mode readings from rows 3 and 4 were unchanged at 100%, despite construction moisture having long since dissipated[48] and capillary moisture across rows 3-7 having effectively fallen to zero.

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[48] Following application of the low-permeability render, construction moisture is likely to have evaporated within the first few weeks; however, this was not confirmed because stage 5 gravimetric analysis, to determine the final moisture content of the masonry wall, was not carried out until the end of the monitoring period.
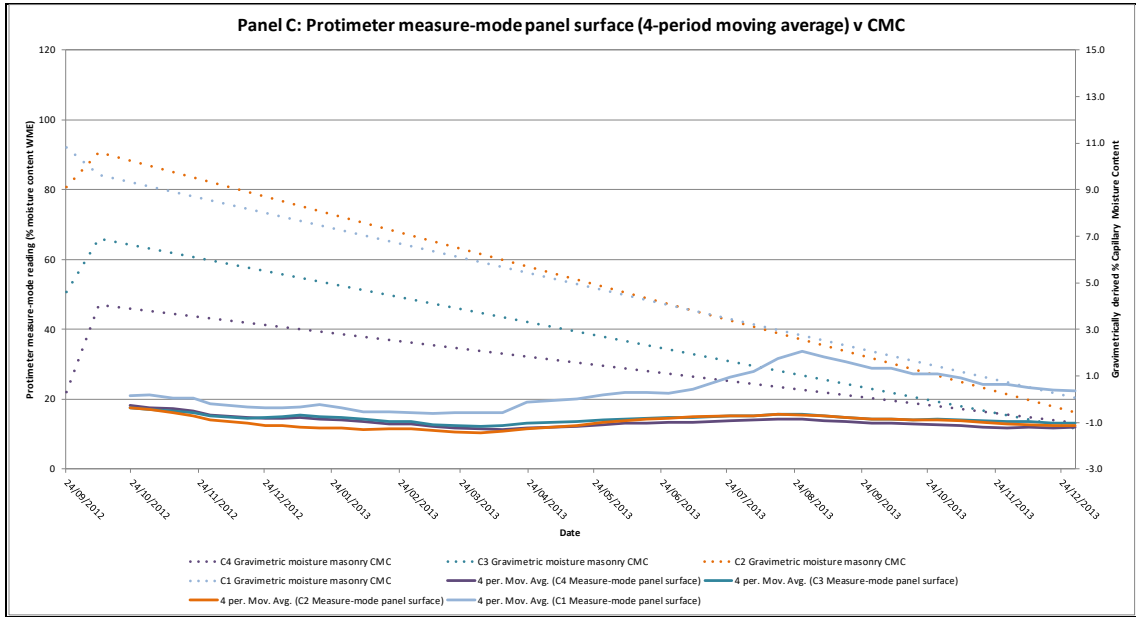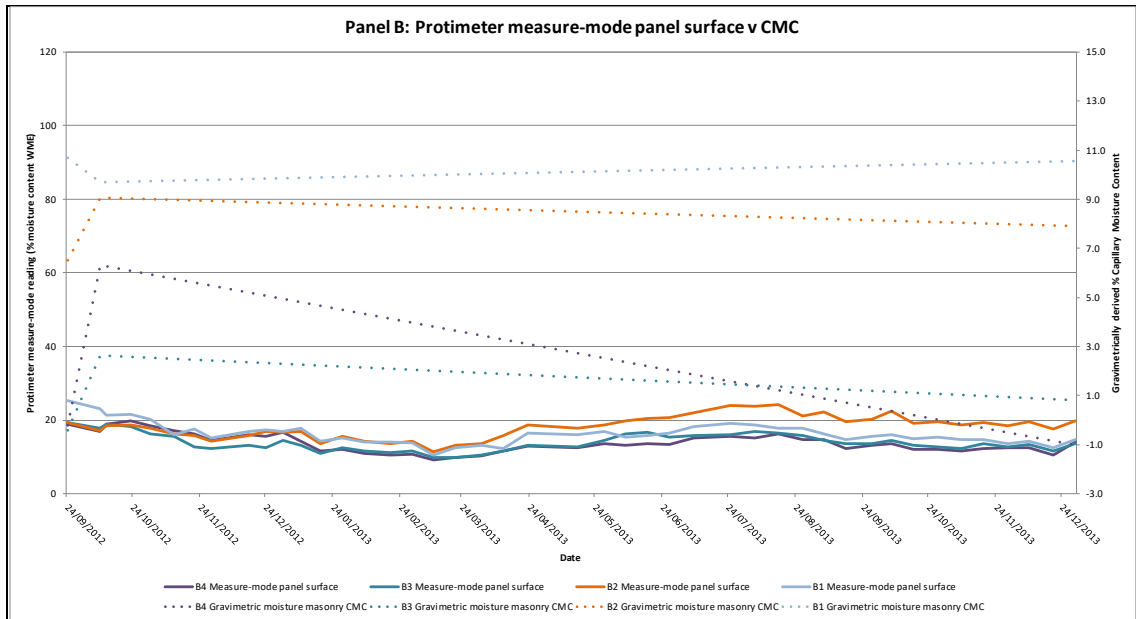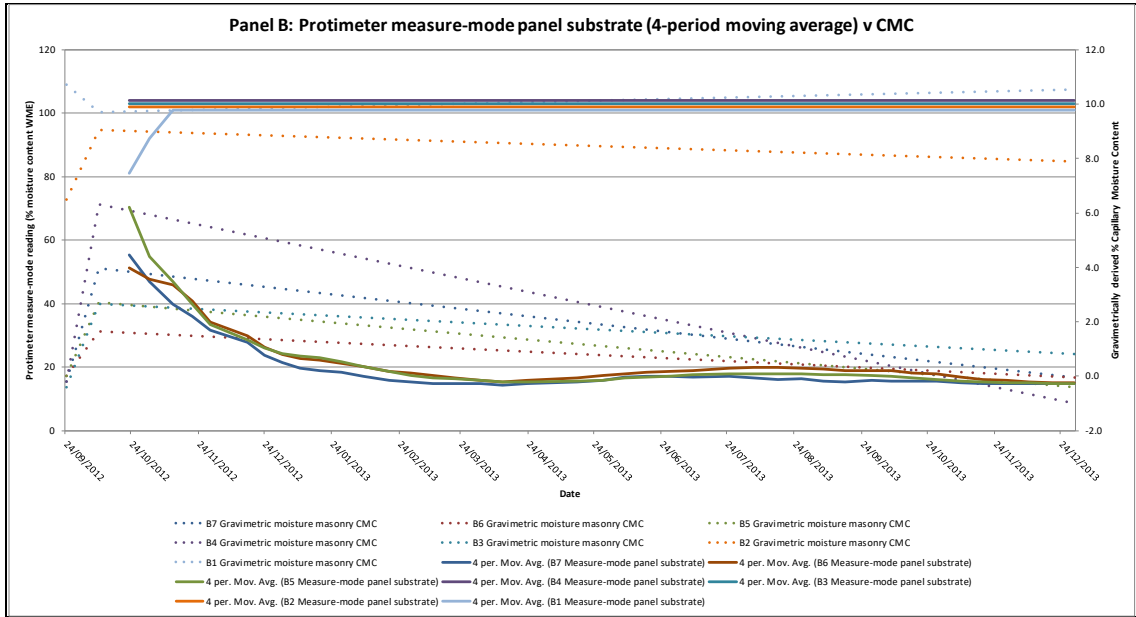
Figure 138: Panel B rows 1-7 Protimeter measure-mode readings panel substrate (4-period moving average) v CMC of masonry.

Substrate measure-mode values for Panel B rows 3 and 4 were maximum throughout the monitoring phase despite a fall in their capillary moisture contents. Substrate measure-mode values for rows 5-7 appeared to show correlation with the capillary moisture content but this fall was attributed to evaporation of construction moisture from the applied render.

Instead, it is the hygroscopic moisture content of Panel B rows 3 and 4, which ranged from 2.6-4.1%, that is the cause of their high substrate measure-mode readings, as illustrated in Figure 139.
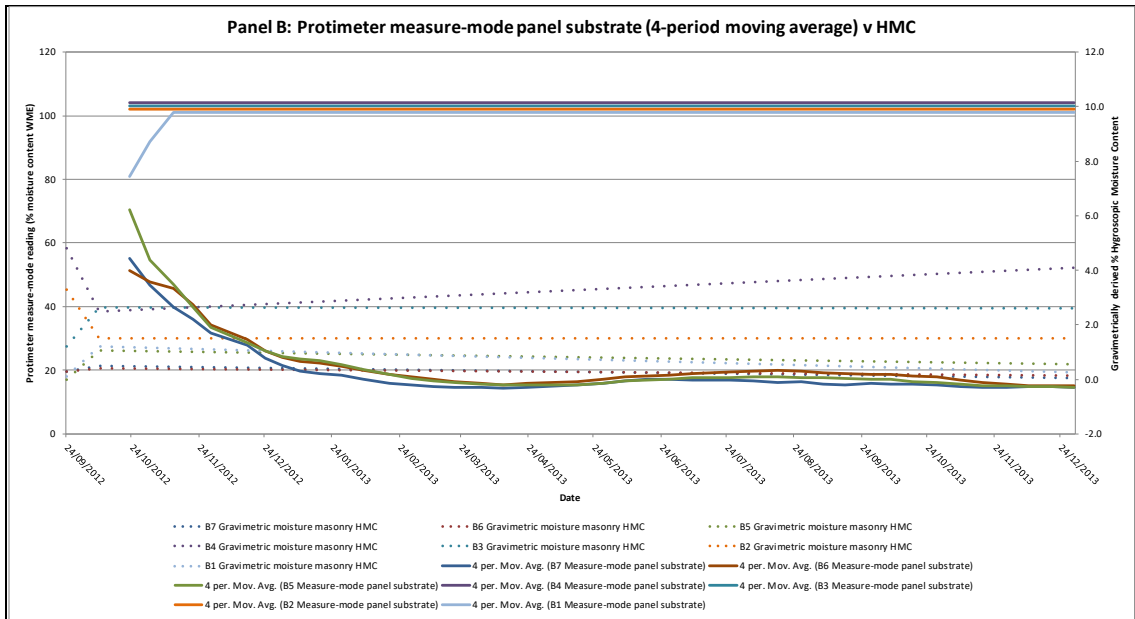
Figure 139: Panel B rows 1-7 Protimeter measure-mode readings panel substrate (4-period moving average) v HMC.

Maximum substrate measure-mode values for Panel B rows 3 and 4 are attributable to their elevated hygroscopic moisture contents which were in the range of 2.6-4.1%.

Panel C's capillary moisture content was known to have temporarily risen as a result of construction moisture in the applied render and to have fallen in rows 1-3 following application of the damp proofing cream treatment. Figure 140 below illustrates how the substrate measure-mode readings for row 7 fell rapidly and early in the monitoring phase and how this was followed by later falls in rows 1, 5, and 2.
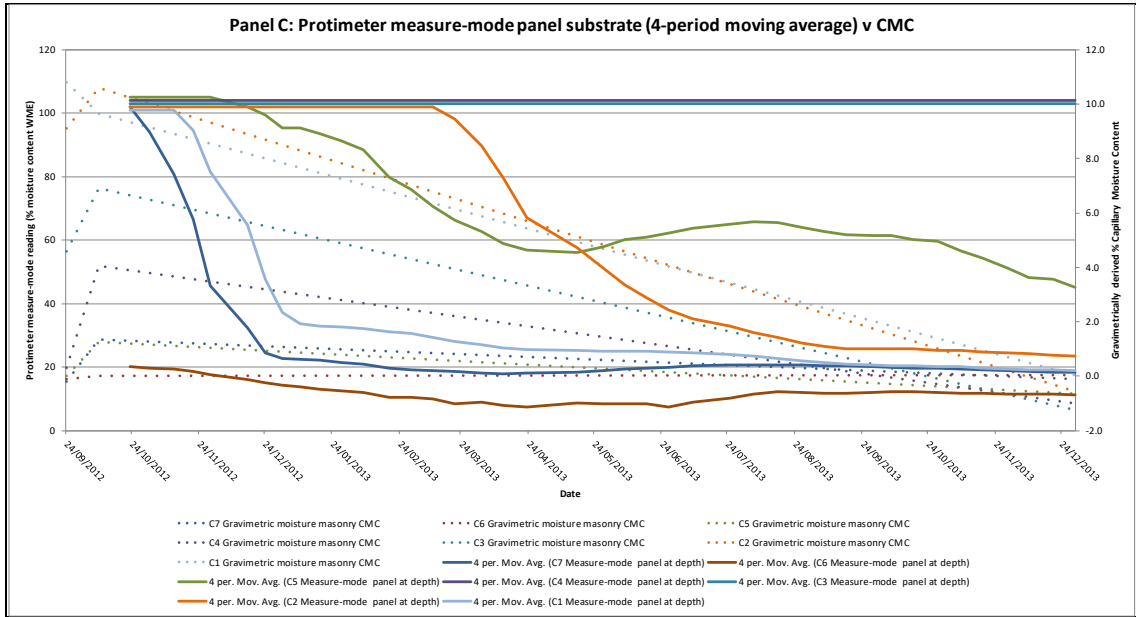
Figure 140: Panel C rows 1-7 Protimeter measure-mode readings panel substrate (4-period moving average) v CMC of masonry.

The substrate measure-mode readings of Panel C row 7 fell rapidly in the monitoring phase. This was followed by later falls in the values obtained from rows 1, 5, and 2.

The high substrate measure-mode readings of Panel C rows 3 and 4 were unaffected by capillary moisture changes and instead attributable to elevated hygroscopic moisture contents, as illustrated in Figure 141 below.
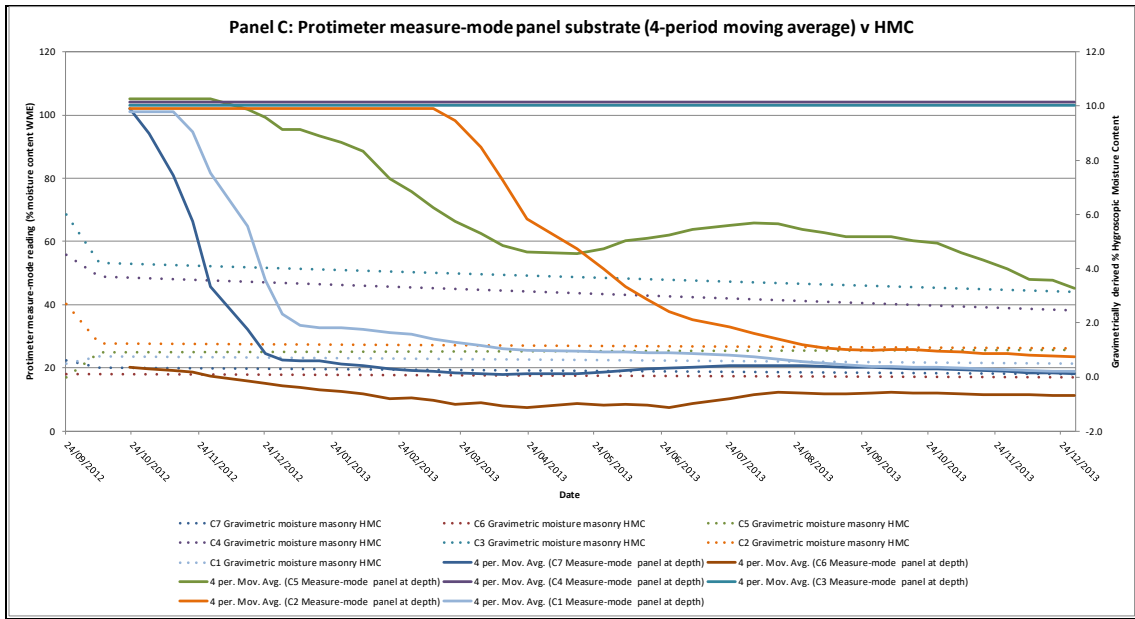
Figure 141: Panel C rows 1-7 Protimeter measure-mode readings panel substrate (4-period moving average) v HMC.

Maximum substrate measure-mode values for Panel C rows 3 and 4 are attributable to their elevated hygroscopic moisture contents.

The early, sharp falls in the substrate measure-mode readings of Panel C can be attributed to evaporation of construction moisture, but the slower decline of these values in row 2, occurring five months after treatment, could be an effect of the damp proofing cream.

Gravimetric analyses had confirmed the capillary moisture content of row 2 to be 9.1% at Stage 2, 10.6% at Stage 3, and 0.0% at Stage 5, so moisture reduction was not in question. Unfortunately, there is insufficient data to confidently conclude that the reduction in these substrate measure-mode readings were a result of the damp proofing cream; indeed, no such falls were evident in the substrate measure-mode readings from Panel A, which also received the cream treatment.

The foregoing clearly illustrates that for Panels A, B, and C the measure-mode function produces erroneous values when hygroscopic moisture or contaminating hygroscopic salts are present, and the same effect was apparent on Panels D and E.

The measure-mode function used in conjunction with Deep Wall Probes will accurately track a reduction in capillary moisture when hygroscopicity is low. In practice, there is no way of determining if such conditions apply, and anomalous measure-mode readings will be obtained where hygroscopic moisture or, indeed, hygroscopic salts are present even when the quantity of this form of moisture is modest. For this reason, the same caveats have to be applied to the measure-mode function when used with Deep Wall Probes as they do for surface readings using the Heavy Duty Probe: it is a useful tool for dampness investigation but cannot be relied upon as a method to monitor the reduction of moisture in a rising damp affected wall following remedial damp proof course treatment.

8.6. Protimeter search-mode function

Like the Protimeter measure-mode function, the search-mode function, illustrated in Figure 142 below, is intended to offer a means of testing for moisture that is none invasive, quick, and easily repeatable. The search-mode sensor, located on the back of the instrument, is placed against the surface of the material under test and, depending on the specific model used, scans to a nominal depth of 15-19 mm and displays a value on a scale of 60-999 or 0-1000[49] relative to the quantity of moisture present (GE Sensing, 2005, p. 17; 2009, p. 3).

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[49] In terms of the meaning of search-mode readings, the differences between these two scales is academic. For convenience, 1000 has been used for its maximum value.

Figure 142: Panel C Protimeter search-mode function.

Protimeter search-mode reading using the Surveymaster model. The sensor on the back of the instrument is placed against the wall surface and displays a relative reading in the 60-999 range; here, displaying 140.

The search-mode function shares the same limitations as measure-mode: at best the readings reflect the total moisture content of the material under test with no indication as to the individual hygroscopic and capillary moisture contents; at worst they reflect the material's conductivity independently of its moisture content.

Interestingly, although the scale used to provide values for search-mode differs from that of the measure-mode function, and therefore the two cannot be directly matched, the pattern of readings of these two functions was comparable with respect to individual panels. As discussed in the previous two sections, measure-mode was unreliable as a method to measure the reduction of moisture overtime. To determine if search-mode provided better results, Panels A, B, and C are considered.

Panel A displayed a fall in capillary moisture in rows 2-4 following the installation of the damp proofing cream. Figure 143 below plots the search-mode readings against the Stage 2, 3, and 5 derived capillary moisture contents. The search-mode values of rows 1-4 displayed an initial fall followed by a declining trend over the first six months of data collection after which the values stabilised in the range of 600-1000. In contrast, the capillary moisture content of rows 2-4 fell over the monitoring period. Row 1's CMC was unchanged.
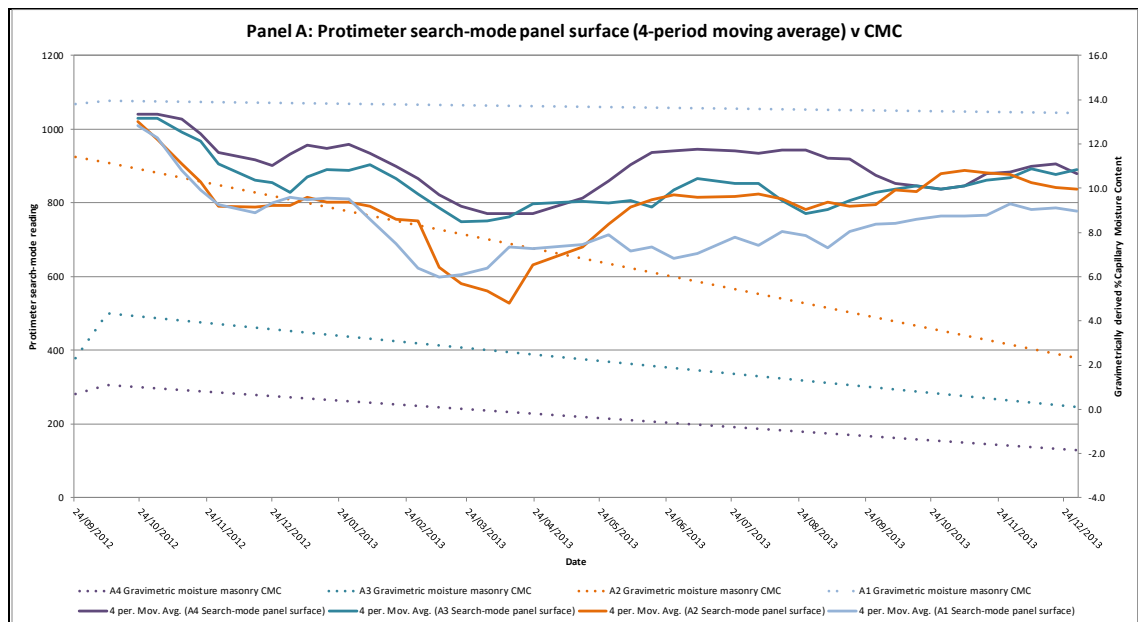
Figure 143: Panel A rows 1-4 Protimeter search-mode readings (4-period moving average) v CMC of masonry.

Search-mode values for Panel A rows 2-4 displayed an initial fall but stabilized in the in the range of 600-1000 for the remainder of the monitoring phase despite a fall in the capillary moisture contents.

Taken in isolation, the search-mode readings from Panel A provide no definitive indication of a reduction in substrate capillary moisture. Indeed, in the absence of other factors, search-mode values in the range recorded would suggest persisting moisture. However, these readings followed the trend of the surface measure-mode readings, which were strongly influenced by the hygroscopicity of the plaster and masonry materials comprising Panel A.

For Panel B, illustrated in Figure 144 below, the capillary moisture in all seven rows displayed an initial rise following application of the low-permeability render. In rows 3-7, this construction moisture had dissipated within the first four weeks but remained high in rows 1 and 2, at 8.5% and 10.2%; essentially, because they contained capillary moisture in addition to that associated with construction moisture.

The search-mode readings followed the trend of the construction moisture, showing a rapid fall followed by a plateau of low readings. Despite a nominal scan depth of 19 mm, the low-permeability render applied to Panel B effectively separated capillary moisture present in the masonry substrate from detection at the panel surface; a factor that also affected the surface measure-mode readings.
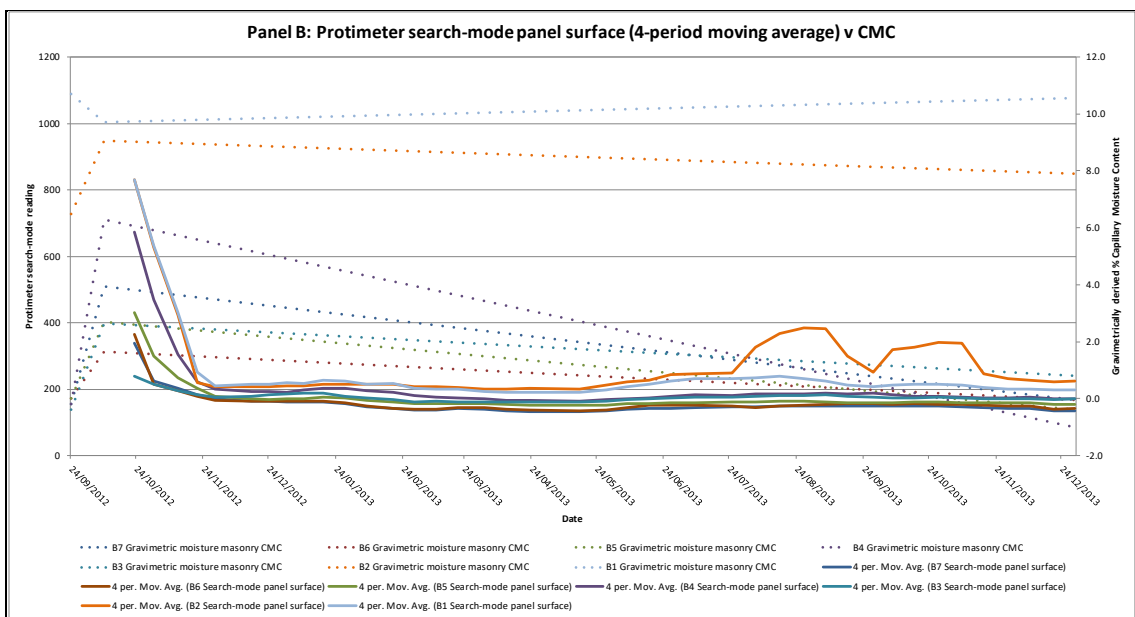
Figure 144: Panel B rows 1-7 Protimeter search-mode readings (4-period moving average) v CMC of masonry.

Search-mode readings in all seven rows demonstrated a rapid fall as construction moisture in the low-permeability render dissipated. Capillary moisture remained high in rows 1 and 2, at 8.5% and 10.2% respectively; this was not reflected in the search-mode readings.

Panel C received both the low-permeability render and the damp proofing cream. Stage 2 analyses, undertaken before the render was applied, determined that significant

capillary moisture was present in rows 1, 2, and 3 at 10.8%, 9.1%, and 4.6%, respectively. However, despite establishing at Stage 5 that capillary moisture associated with rising damp was absent from the masonry by the end of the monitoring phase, a decline of capillary moisture following installation of the damp proofing cream is not reflected in the search-mode readings; instead, as illustrated in Figure 145 below, the values display a fall consistent with evaporation of construction moisture in the early stages of data collection and then a plateau of low readings identical to those recorded on Panel B.
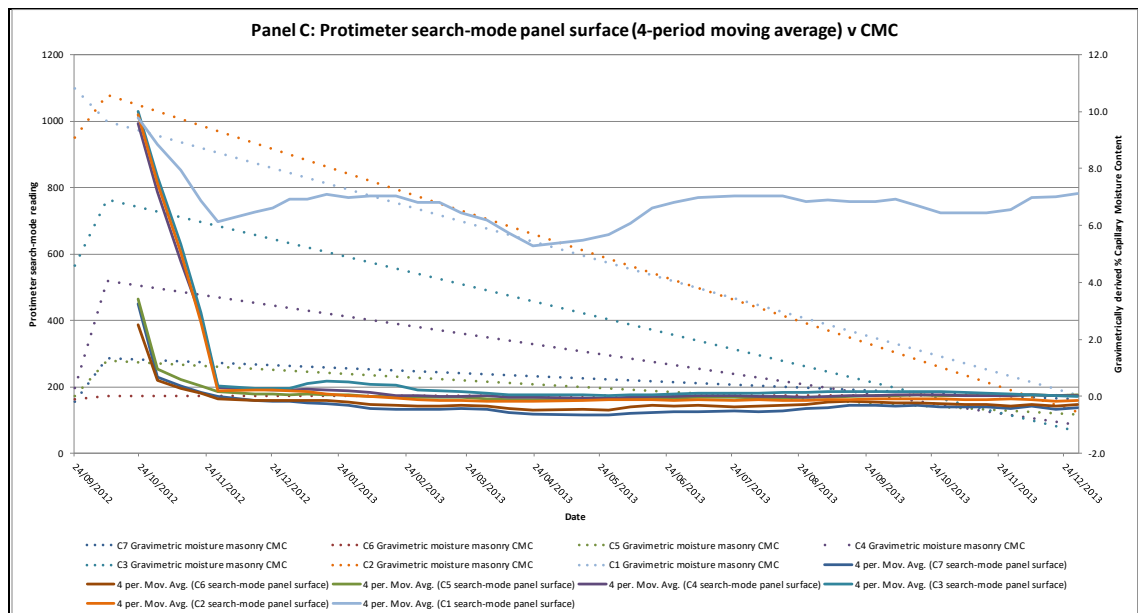
Figure 145: Panel C rows 1-7 Protimeter search-mode readings (4-period moving average) v CMC of masonry.

Search-mode readings in all seven rows demonstrated a rapid fall consistent with the dissipation of construction moisture from the low-permeability render rather than as an effect of the damp proofing cream. Persistently high search-mode values obtained from row 1 were unexplained.

One inconsistency of Panel C were high search-mode readings obtained from row 1. It was thought that this may result from placing the sensor of the meter against the exposed brickwork at the panel base rather than the face of the applied render and thus enabling it to penetrate deeper into the wall. However, both the capillary and hygroscopic moisture content of the masonry were determined to be low at Stage 5,

which is not reflected in the search-mode readings. The elevated search-mode readings from Panel C row 1 remain unexplained.

Search-mode and measure-mode share two significant limitations: firstly, the presence of hygroscopic salts strongly influences their values irrespective of the capillary moisture content of the substrate; secondly, the application of low-permeability render effectively isolates the wall surface from capillary moisture and hygroscopic contamination that may affect the substrate; in other words, significant moisture can be present in the substrate of a wall that is essentially undetectable to the measure-mode or search-mode functions. For these reasons, the search-mode function, although useful as an aid to dampness investigation, cannot be relied upon as a method to monitor the reduction of moisture in a rising damp affected wall following remedial damp proof course treatment.

8.7. Timber Probes Type 1

The Protimeter measure-mode function is calibrated for timber rather than masonry materials and therefore, within certain parameters, values obtained from timber are reasonably accurate (Burkinshaw & Parrett, 2003, pp. 75-76; GE Sensing, 2005, p. 4; Trotman, Sanders, & Harrison, 2004, p. 40). This feature was to be exploited by the Timber Probes Type 1 by allowing their dowel bodies to absorb moisture from the surrounding masonry, which could then be measured with some accuracy using the Protimeter measure-mode function, as illustrated in Figure 146 below, and thus provide a mechanism to monitor capillary moisture changes in the masonry of the five test panels.

Figure 146: Panel E measure-mode reading of a Timber Probe Type 1.
Timber Probes Type 1 read using the measure-mode function of the Protimeter.

However, the ability of the Type 1 probes to absorb moisture meant that they would also be susceptible to contamination from hygroscopic salts and at risk from fungal decay. Chapter 4 included a discussion of certain issues that affected the Timber Probes Type 1 during the data collection phase. Further comment with respect to these issues, which included fungal decay, is not provided here; instead, this section is concerned primarily with the success of the Type 1 probes as a method for monitoring moisture change and therefore will cover the effects of hygroscopic contamination.

Rows 5-7 (the upper rows) of all five panels contained neither capillary moisture nor significant amounts of hygroscopic moisture: the masonry parts were effectively dry. Unsurprisingly, with the exception of Panels B and C, which were temporarily affected by construction moisture present in the applied render, measure-mode readings obtained from the Type 1 probes in these upper rows were consistently low.

The construction moisture in Panels B and C dissipated early in the data collection phase, and although this effect was far less pronounced on Panel C, it was reflected by a clear decline in the Type 1 probes' measure-mode readings for Panel B rows 5-7, as shown in Figure 147 below.

Panel B: Protimeter measure-mode Timber Probe Type 1 (4-period moving average) v TMC
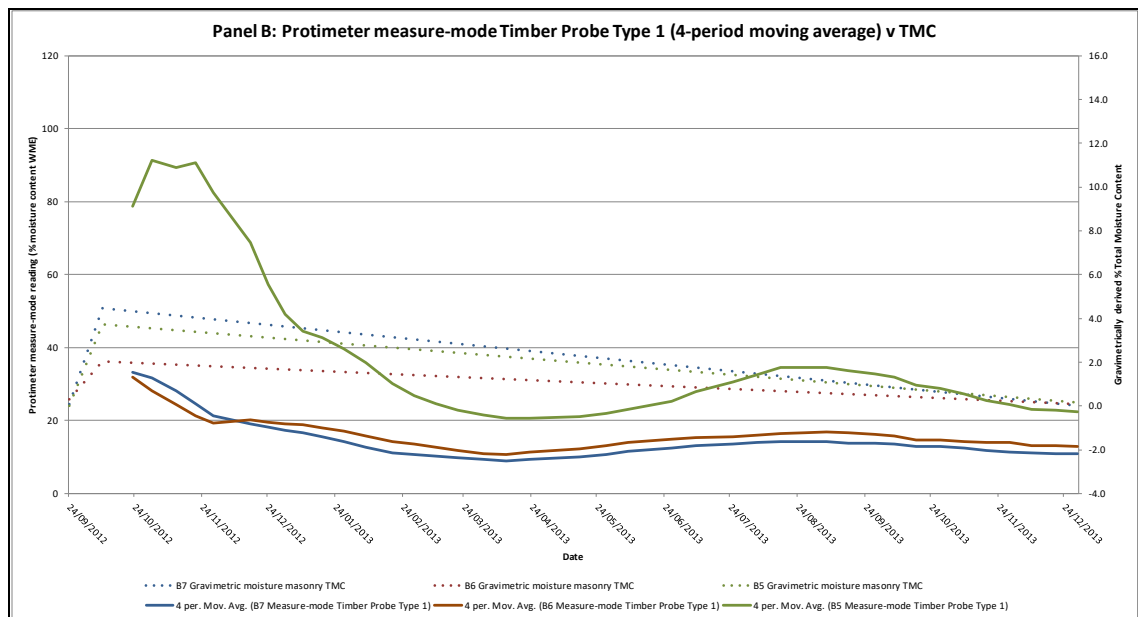
Row	Minimum		Average		Maximum	
	M-M	TMC	M-M	TMC	M-M	TMC
B7	8.4%	0.0%	15.1%	1.5%	34.9%	4.5%
B6	10.5%	0.1%	16.6%	0.8%	35.8%	2.1%
B5	19.9%	0.2%	38.4%	2.0%	100%	3.8%

Figure 147: Panel B rows 5-7 Protimeter measure-mode readings Timber Probe Type 1 (4-period moving average) v TMC.

The initial, rapid decline in the measure-mode readings from the Type 1 probes in Panel B rows 5-7 was consistent with evaporation of construction moisture from the applied render.

What is interesting is that the Protimeter measure-mode readings from the Type 1 probes in rows 3-5, across all five test panels, correlated with the actual moisture content of the masonry determined through gravimetric analyses, as shown in Table 35 below. This relationship is not perfect but is sufficiently aligned to suggest that the timber probes accurately reflected the masonry's moisture content.

Row	Minimum			Average			Maximum	
	M-M	TMC		M-M	TMC		M-M	TMC
A7	6.0%	0.0%		7.7%	0.1%		10.8%	0.2%
A6	6.0%	0.1%		9.1%	0.5%		12.3%	0.9%
A5	7.2%	0.6%		11.4%	1.2%		14.2%	1.9%
B7	8.4%	0.0%		15.1%	1.5%		34.9%	4.5%
B6	10.5%	0.1%		16.6%	0.8%		35.8%	2.1%
B5	19.9%	0.2%		38.4%	2.0%		100.0%	3.8%
C7	6.0%	0.0%		13.1%	0.7%		28.5%	1.7%
C6	6.0%	0.0%		9.0%	0.1%		14.5%	0.1%
C5	14.6%	0.4%		16.6%	1.3%		18.6%	2.2%
D7	6.0%	0.1%		8.3%	0.3%		10.8%	0.5%
D6	7.2%	0.0%		10.1%	0.1%		11.8%	0.2%
D5	14.2%	0.9%		19.2%	1.2%		25.6%	1.6%
E7	6.0%	0.0%		8.3%	0.1%		10.9%	0.3%
E6	6.0%	0.1%		8.7%	0.1%		11.0%	0.2%
E5	6.0%	0.0%		9.4%	0.1%		11.2%	0.3%

Table 35: Panels A-E rows 5-7 minimum, average, and maximum Timber Probe Type 1 measure-mode readings v TMC.

For panel row positions 5-7, the distribution of the minimum, average, and maximum of the measure-mode values obtained from the Type 1 probes demonstrate correlation with their gravimetrically derived moisture contents. The cells of the tables are annotated in blue, this fill scaled to represent the cells value, to illustrate this effect.

Unlike measure-mode readings obtained directly on the surface of the original plasterwork, hygroscopic salts did not affect the measure-mode readings of the Type 1 probes in rows 5-7 and they were able to map the moisture trend. However, of more importance is how effectively the Type 1 probes tracked moisture changes in the lower rows of Panels A and C, where capillary moisture fell following installation of the damp proofing cream, and how they responded when inserted into masonry parts known to be contaminated with hygroscopic salts.

For Panel A, illustrated in Figure 148 below, the capillary moisture content of row 1 was high throughout the monitoring period. The measure-mode readings returned from the Type 1 probe in this location displayed a rise commensurate with the steady absorption of moisture from the masonry wall, buts its maximum values fell well short of what would be expected for masonry with capillary moisture contents of 13.8%, 14.0%, and 13.4% at stages 2, 3, and 5, respectively.
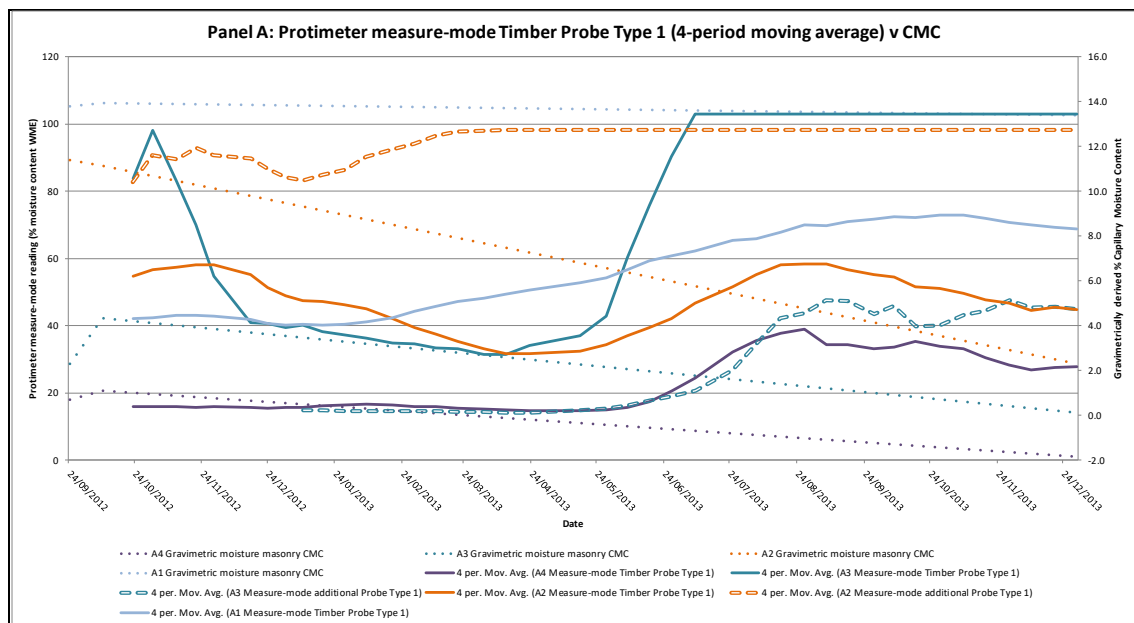
Figure 148: Panel A rows 1-4 Protimeter measure-mode readings Timber Probe Type 1 (4-period moving average) v CMC of masonry.

The measure-mode readings from the Type 1 probes in rows 2 and 3 displayed a decline consistent with a reduction in capillary moisture. The Type 1 probe in row 1 showed a steady rise but not of the magnitude reflected by the masonry's CMC. The measure-mode values of all of the Type 1 probes in the lower rows displayed a rise approximately six months into the monitoring phase.

The Type 1 probes in rows 2 and 3 followed the downward trend in capillary moisture content, albeit with a rapid reduction for row 3 during the first few weeks of monitoring; nevertheless, for rows 1 and 2, both the fall in capillary moisture content and the measure-mode values of the Type 1 probes were consistent of masonry drying following the insertion of a chemical damp proof course (Building Research Establishment, 1974, p. 3; Safeguard Europe Ltd., 2007, p. 17). This decline, however, was followed by a rise

in the measure-mode readings returned from all Type 1 probes located on the lower rows of Panel A around six months into the monitoring period.

This latter rise in measure-mode readings also applied to the two additional Type 1 probes that were installed in Panel A: row 2 in September 2012, at the start of the monitoring phase, and row 3, in January 2013, four months after this phase began. Interestingly, the additional row 3 probe demonstrated an increase in its measure-mode readings towards the end of May 2013, leading to a more significant rise in July 2013. Essentially, the upward trend that occurred in the original Type 1 probes of rows 2 and 3 ultimately affected the additional row 3 Type 1 probe.

In the knowledge that the masonry capillary moisture content at the base of Panel A had fallen then there must be some other reason for the subsequent increase in the Type 1 probe's measure-mode readings. The obvious cause was absorption of hygroscopic salts. This contamination was confirmed through tests carried out after the timber probes had been removed from the panels.

Technically, not only did the measure-mode readings of the Type 1's probes in the lower rows display a rise a few months into the monitoring period but they subsequently displayed a similar fall or fluctuating trend, as can be seen for Panel A in Figure 148 above. It was suspected that these fluctuations may be caused by the hygroscopic salts that contaminated the dowels responding to environmental moisture. To test this effect, relative humidity and vapour pressure data from the Lascar data loggers, mounted on the face of each panel, were overlaid onto the charts of the Type 1 Probe's measure-mode values.

Figure 149 and Figure 150 below illustrate these two charts for Panel A and clearly reveal that the relative humidity and vapour pressure influences the measure-mode readings obtained from the dowel bodies of the Type 1 probes. This same correlation was apparent for rows 2-4 of Panels B-E with the rise and fall of the measure-mode readings

in the latter half of the monitoring period corresponding with rise and falls in relative humidity and vapour pressure.

This fluctuating effect was localised to the upper region of rising damp and thus the parts of the panels where hygroscopic ground salts would be most concentrated (Alfano, Chiancarella, Cirillo, et al., 2006, pp. 1060-1061; Coleman, 1993, p. 6; Kyte, 1997, pp. 5-8; Safeguard Europe Ltd., 2007, p. 5). It is for this reason that it was not apparent in the rows located in the dry, upper regions of the panels because hygroscopic contamination had not affected these parts. Furthermore, where significant capillary moisture was present, and therefore high or maximal measure-mode readings would be recorded from the Type 1 probes, changes in hygroscopic moisture would not be evident.
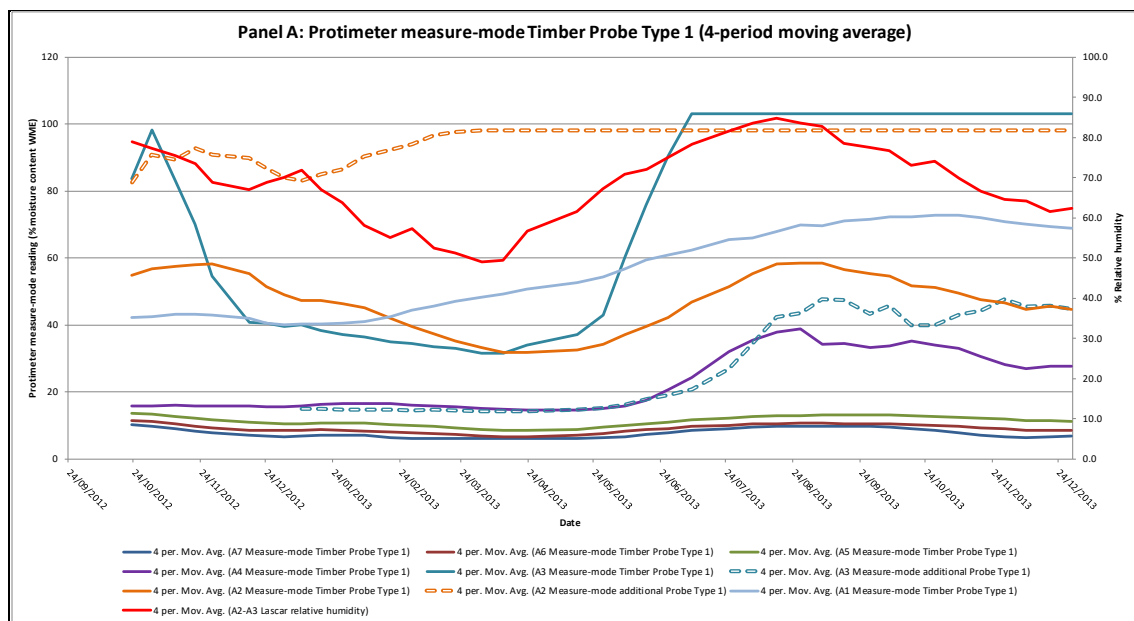
Figure 149: Panel A rows 1-7 Protimeter measure-mode readings Timber Probe Type 1 (4-period moving average) v boundary layer relative humidity (4-period moving average).

The thick red lined graph represents the relative humidity values recorded by the Lascar data logger. Its shape clearly mirrors the trend of the measure-mode values obtained from the Type 1 probes in rows 2-4.
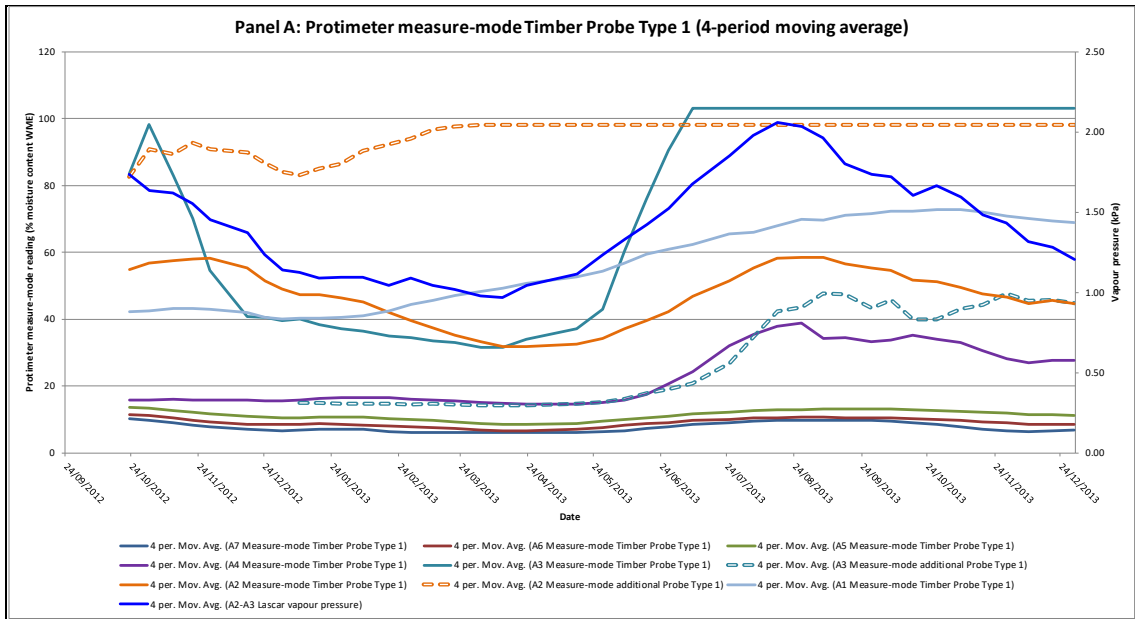
Figure 150: Panel A rows 1-7 Protimeter measure-mode readings Timber Probe Type 1 (4-period moving average) v boundary layer vapour pressure (4-period moving average).

The thick blue lined graph represents the vapour pressure values derived from the Lascar data, and thus remove the effect of temperature. The graph's shape clearly mirrors the trend of the measure-mode values obtained from the Type 1 probes in rows 2-4.

For Panel C, illustrated in Figure 151 below, the measure-mode readings recorded from the Type 1 probes in rows 1-4 indicated an initial rise, which, in rows 1 and 2 was followed by a steady decline until May 2013. Panel C row 3 also had an initial increase that was followed by a plateau period and a later fall, occurring in late summer 2013. Panel C row 5 displayed a similar effect to row 3, albeit with lower values, reflecting its position in the drier, upper region of the panel. The upward and subsequent downward trend of the Type 1 probe measure-mode readings from Panel C essentially mirrored those obtained from the probes in Panel A. This pattern is attributed in part to hygroscopic contamination but also to changes in the airborne moisture content, as described above.
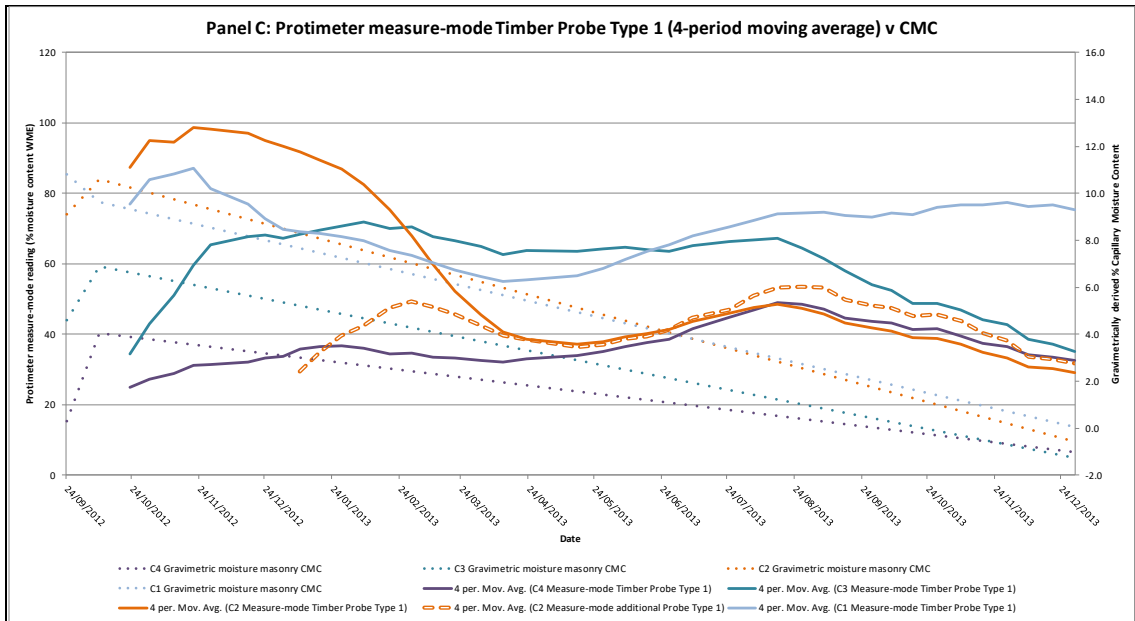
Figure 151: Panel C rows 1-4 Protimeter measure-mode readings Timber Probe Type 1 (4-period moving average) v CMC of masonry.

The measure-mode readings from the Type 1 probes in rows 1-4 displayed an initial rise followed in rows 1 and 2 by a decline consistent with a reduction in capillary moisture. The trend of the measure-mode readings in the latter period of the monitoring phase was confirmed to be an effect of hygroscopic contamination and the influence of environmental moisture.

At the end of the monitoring phase, and to conclude data collection from the Type 1 probes, the following six values were obtained:

1. Prior to removal from the panels:

    1.1. final measure-mode reading using the attached lead.

2. Immediately after removal from the panels:

    2.1. Second measure-mode reading using the attached lead;

    2.2. Third measure-mode reading but directly from probe's dowel body using the Protimeter Heavy Duty Probe attachment.

3. Off-site Stage 5 moisture analyses to determine the following:

3.1. Total moisture content;

3.2. Hygroscopic moisture content;

3.3. Capillary moisture content.

Four, short, unused lengths of dowel, identical to the bodies of the Type 1 probes, were included in the above tests to provide base line values.

The combined results from these tests are set out in Table 36 below, which uses the following conventions to aid readability:

1. The data for each panel is grouped and sorted in highest to lowest row order;

2. Type 1 probes originally installed are referenced as '*1.0*';

3. Type 1 probes installed later during data collection are referenced '*1.1*';

4. Unused, control dowels are referenced 'Panel X', row numbers 1-4, and version '9 mm' (these dowels were not installed, and the notation is simply to enable identification);

5. The wiring of Type 1 probes B4, B3, and E4 was damaged on removal from their panels. Because this damage may have affected their post-removal measure-mode readings, these values are highlighted in red;

6. Each cell is filled with a colour scaled to represent the magnitude of its value.

Panel	Row	Version	Measure-mode reading: final on site	Measure-mode reading: checked with integral jack plug lead	Measure-mode reading: checked with heavy duty probe	Stage 5: TMC	Stage 5: HMC	Stage 5: CMC
A	7	1.0	7.0%	7.6%	7.4%	5.6%	8.1%	-2.5%
A	6	1.0	8.3%	8.8%	8.2%	6.6%	8.7%	-2.1%
A	5	1.0	10.7%	11.3%	10.5%	7.9%	10.5%	-2.6%
A	4	1.0	27.7%	22.9%	42.0%	9.4%	13.0%	-3.6%
A	3	1.0	98.2%	68.4%	68.3%	13.5%	13.9%	-0.4%
A	3	1.1	39.8%	21.5%	54.5%	12.3%	12.4%	-0.1%
A	2	1.0	42.1%	36.8%	36.1%	16.5%	12.3%	4.2%
A	2	1.1	98.2%	72.0%	71.8%	19.3%	12.6%	6.7%
A	1	1.0	69.1%	60.1%	60.7%	26.9%	12.6%	14.3%
B	7	1.0	11.0%	12.2%	11.7%	7.0%	9.1%	-2.1%
B	6	1.0	13.2%	14.3%	11.8%	7.8%	9.5%	-1.7%
B	5	1.0	21.9%	21.4%	20.7%	8.7%	12.5%	-3.8%
B	4	1.0	82.4%	44.5%	60.2%	11.3%	14.4%	-3.1%
B	4	1.1	15.9%	17.1%	13.7%	10.4%	11.2%	-0.8%
B	3	1.0	86.7%	64.5%	92.3%	14.7%	13.2%	1.5%
B	2	1.0	98.2%	81.1%	86.4%	19.5%	12.6%	6.9%
B	1	1.0	42.8%	37.4%	37.4%	22.5%	12.9%	9.6%
C	7	1.0	9.9%	11.2%	9.7%	7.0%	9.6%	-2.6%
C	6	1.0	7.9%	9.4%	8.9%	7.1%	9.7%	-2.6%
C	5	1.0	14.6%	16.3%	16.5%	8.5%	10.1%	-1.6%
C	4	1.0	30.8%	28.5%	33.4%	10.3%	12.8%	-2.5%
C	3	1.0	31.8%	28.0%	27.1%	11.1%	13.2%	-2.1%
C	2	1.0	27.2%	28.4%	28.2%	10.5%	12.0%	-1.5%
C	2	1.1	31.5%	28.9%	24.6%	11.7%	12.1%	-0.4%
C	1	1.0	72.8%	66.7%	71.8%	18.0%	12.3%	5.7%
D	7	1.0	8.8%	9.8%	9.5%	7.1%	8.5%	-1.4%
D	6	1.0	10.1%	10.9%	10.2%	7.8%	8.8%	-1.0%
D	5	1.0	22.7%	17.8%	17.3%	9.6%	10.7%	-1.1%
D	4	1.0	45.1%	38.2%	50.3%	11.7%	12.2%	-0.5%
D	3	1.0	55.6%	48.0%	58.5%	12.8%	12.8%	0.0%
D	3	1.1	43.0%	33.0%	46.4%	13.2%	12.8%	0.4%
D	2	1.0	98.2%	98.2%	98.2%	29.9%	13.1%	16.8%
D	1	1.0	98.2%	60.5%	62.2%	30.2%	12.8%	17.4%
E	7	1.0	6.6%	9.2%	8.7%	7.2%	9.3%	-2.1%
E	6	1.0	8.1%	9.8%	8.8%	7.7%	9.5%	-1.8%
E	5	1.0	9.5%	10.1%	9.7%	7.6%	8.6%	-1.0%
E	4	1.0	57.2%	30.7%	48.5%	15.7%	13.3%	2.4%
E	3	1.0	52.2%	53.3%	54.9%	13.1%	13.0%	0.1%
E	2	1.0	80.1%	98.2%	98.2%	17.1%	13.5%	3.6%
E	1	1.0	73.1%	71.7%	59.9%	27.6%	13.0%	14.6%
X	1	9 mm			9.5%	7.5%	9.2%	-1.7%
X	2	9 mm			8.3%	6.4%	8.5%	-2.1%
X	3	9 mm			7.9%	6.4%	8.5%	-2.1%
X	4	9 mm			7.9%	6.2%	8.1%	-1.9%

Table 36: Timber Probes Type 1 final measure-mode and moisture values.

The results from Table 36 show that the measure-mode readings of the Type 1 probes were essentially the same both before and after removal from the panels. This finding confirms that Type 1 probes in row positions B4, C2, and D3, which had previously been suspected of returning erroneous measure-mode values, were not actually faulty.

Unsurprisingly, Type 1 probes with high TMCs tended to return high measure-mode readings; however, elevated measure-mode readings were also recorded from probes with relatively low CMCs. This anomaly results from their hygroscopic moisture content which, with four exceptions, A1, D1, D2, and E1, was the primary moisture source.

The four control dowels, X1, X2, X3, and X4, had low measure-mode values of 9.5%, 8.3%, 7.9%, and 7.9%, respectively, aligning almost perfectly with their hygroscopic moisture contents of 9.2%, 8.5%, 8.5%, and 8.1%.

The Type 1 probes' hygroscopic moisture contents increased over the data collection phase. Furthermore, Type 1 probes with the highest HMCs tended to be located around rows 3-4, the precise location of the panels where hygroscopic salt contamination of the masonry was greatest.

The findings suggest that Timber Probes Type 1 do offer some benefits and in some circumstances may provide useful data—for example, they respond well when inserted into masonry that is dry and unaffected by hygroscopic salts and they are able to track receding construction moisture—but they are susceptible to contamination from hygroscopic salts. Not only do these salts produce erroneous measure-mode values but their nature means that the hygroscopic moisture contents of contaminated dowels fluctuates as environmental conditions change. Given that hygroscopic salts must always be present in walls affected by rising damp, Timber Probes Type 1 cannot be relied upon as a method to monitor the reduction of moisture in a rising damp affected wall following remedial damp proof course treatment.

8.8. Plain timber dowels

Three plain 9 mm diameter softwood dowels were initially installed, on the 1 January 2013, because of concerns regarding the integrity of measure-mode readings obtained from the Timber Probes Type 1 at positions B4, C2, and D3. These plain dowels had to be removed from the test panels to enable their Protimeter measure-mode readings to be recorded and, therefore, any concerns with respect to the validity of the values recorded were eliminated.[50] For this reason, on the 18 January 2013, this plain timber dowel method was extended through the installation of hardwood dowels, as illustrated in Figure 152 below.

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[50] Protimeter measure-mode readings were obtained from the plain timber dowels by pushing the pins of the Heavy Duty Probe attachment into their surface, in contrast to the Type 1 probes, which required direct attachment to the meter.

Figure 152: Panel E 5 mm diameter plain hardwood dowels.

5 mm dia. plain hardwood dowels, inserted into one of the pairs of the central pairs of holes, were removed and measure-mode readings obtained by inserting the needles of the Heavy Duty Probe into their bodies.

Once equilibrated with the masonry, the plain timber dowels in each panel exhibited a similar profile of Protimeter measure-mode readings: generally low but with readings gradually increasing from the topmost to the bottommost row position, as illustrated for Panel A in Figure 153 below.
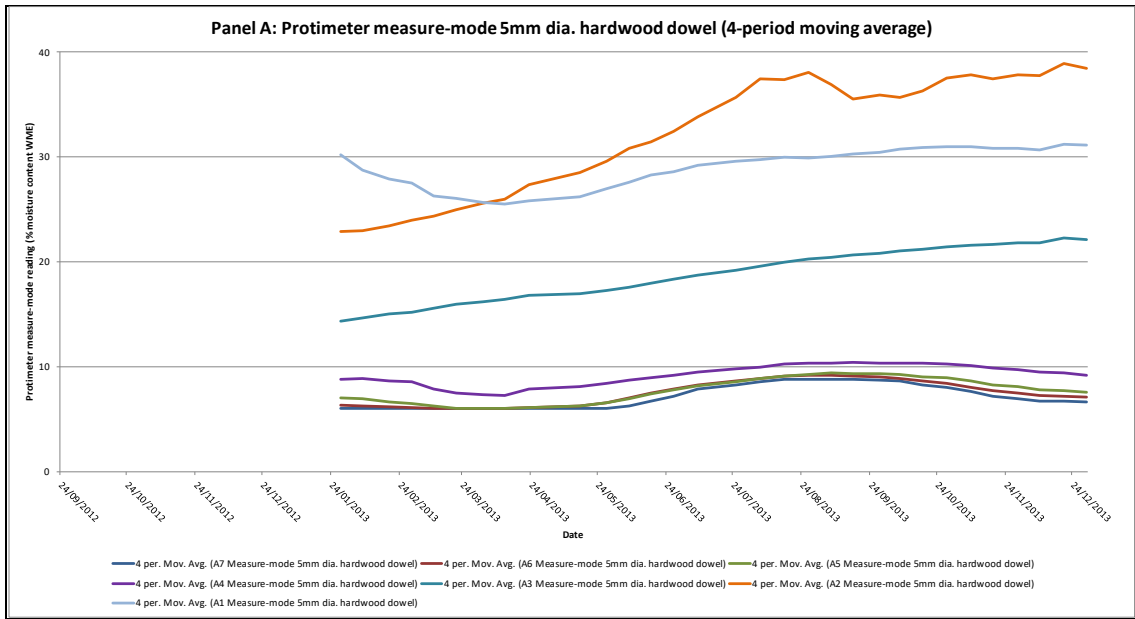
Figure 153: Panel A Protimeter measure-mode plain timber dowels (4-period moving average).

Measure-mode values obtained from the plain timber dowels in Panel A displayed a gradient inversely proportional to their row position (i.e. increasing from top to bottom). This trend was apparent on all five panels.

The distribution of readings was less pronounced but remained apparent for Panel C, as shown in Figure 154, a difference attributed to the effect of moisture loss following installation of the damp proofing cream.
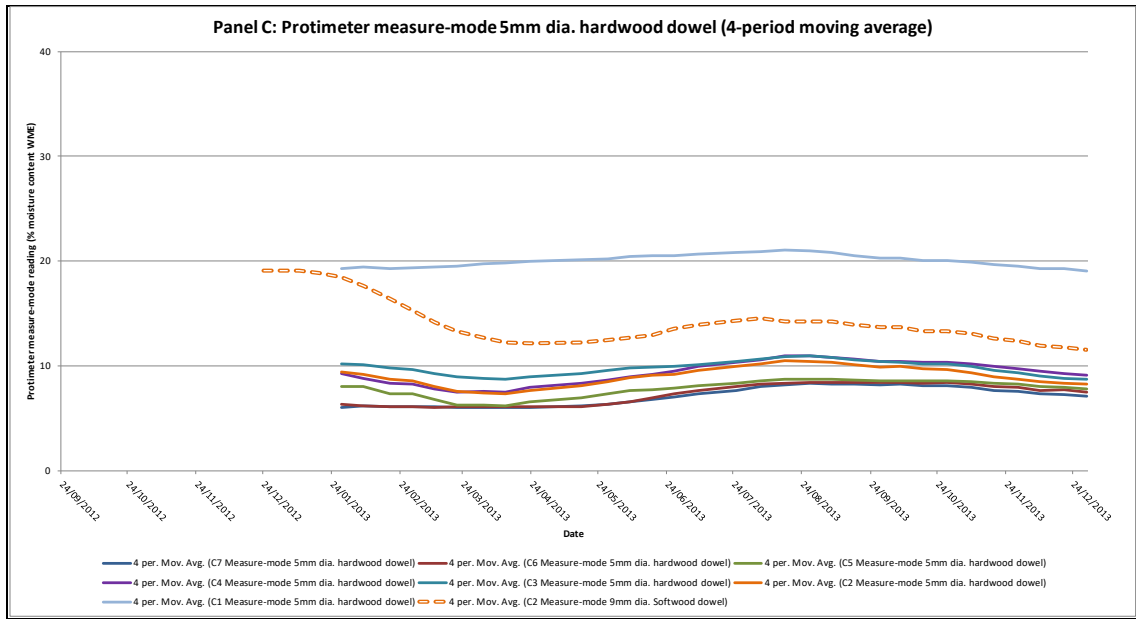
Figure 154: Panel C Protimeter measure-mode plain timber dowels (4-period moving average).

Measure-mode values obtained from the plain timber dowels in Panel C were confined to a narrow range but essentially demonstrated an increase inversely proportional to row height.

Given that the capillary moisture content of the test panels essentially reduced from bottom to top, thereby mirroring the profile of measure-mode readings, these initial results suggested that plain timber dowels may offer a useful method of tracking moisture distribution in a masonry wall.

Unfortunately, because the plain timber dowels were installed between three to four months after the damp proofing cream had been inserted into the bases of Panels A and C, their effectiveness as a method of monitoring moisture change was unquestionably compromised. Nevertheless, an evaluation using the available data and an assessment of their susceptible to hygroscopic salts, the issue that had affected the preceding moisture monitoring methods, was possible.

For Panel A, Figure 155 below compares the measure-mode readings of the plain timber dowels against the capillary moisture content of the masonry derived through Stage 2, 3, and 5 analyses for rows 1-4. The chart reveals that although the capillary moisture

content of row 1 (the brick course directly below the line of the damp proof course) remained high, it fell significantly across rows 2-4; yet, neither the high CMC in row 1 nor the changes in rows 2-4 were reflected in the measure-mode readings from the plain timber dowels, which remained both relatively low and constant.
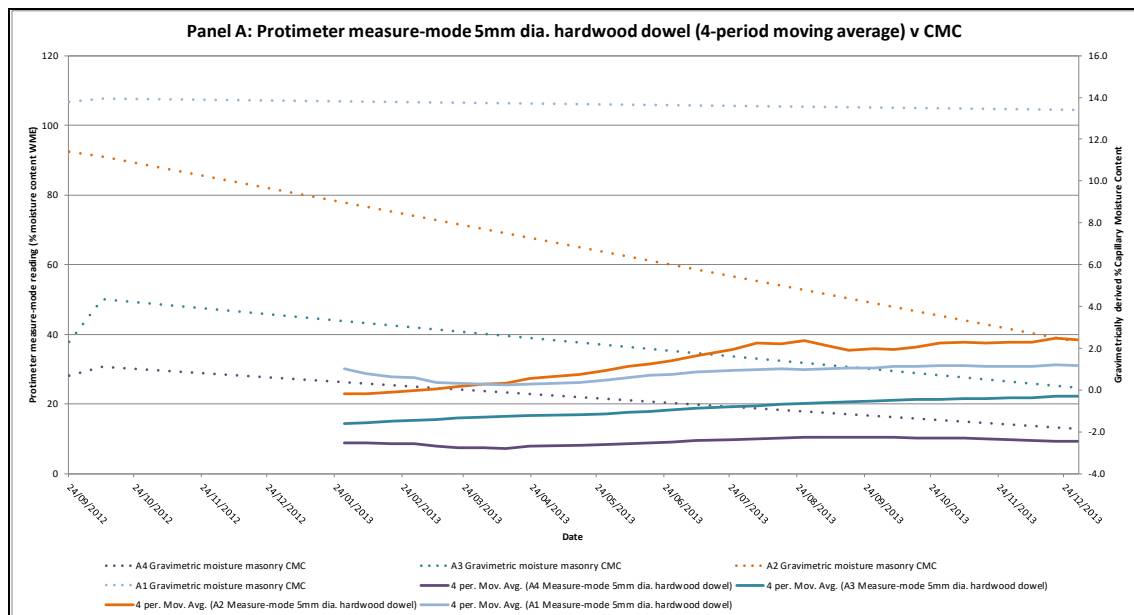
Figure 155: Panel A rows 1-4 Protimeter measure-mode readings 5 mm hardwood dowels (4-period moving average) v CMC of masonry.

Despite the CMC of Panel A row 1 averaging 13.7% and the CMC for rows 2, 3, and 4 falling from 11.4% to 2.3%, 4.4% to 0.1%, and 1.1% to -1.9%, respectively, the measure-mode readings of the plain timber dowels remained relatively low and constant.

The fact that the plain timber dowels were independent of the CMCs in rows 2-4 could be accounted for by their installation some four months after the damp proofing cream had been inserted and, therefore, after capillary moisture in the lower rows had receded; however, this delay cannot explain why the high CMC of row 1 was not reflected in the measure-mode readings obtained from the plain timber dowel or why these values were lower than those recorded from the dowel in row 2 above. Unfortunately, this is a finding of this study that could not be satisfactorily answered.

For Panel C, Figure 156 below illustrates the plain timber dowel versus capillary moisture results for rows 1-4. The CMC values effectively fell to zero between stages 3 and 5, but the Protimeter measure-mode readings recorded on the plain timber dowels were consistently low over this period.
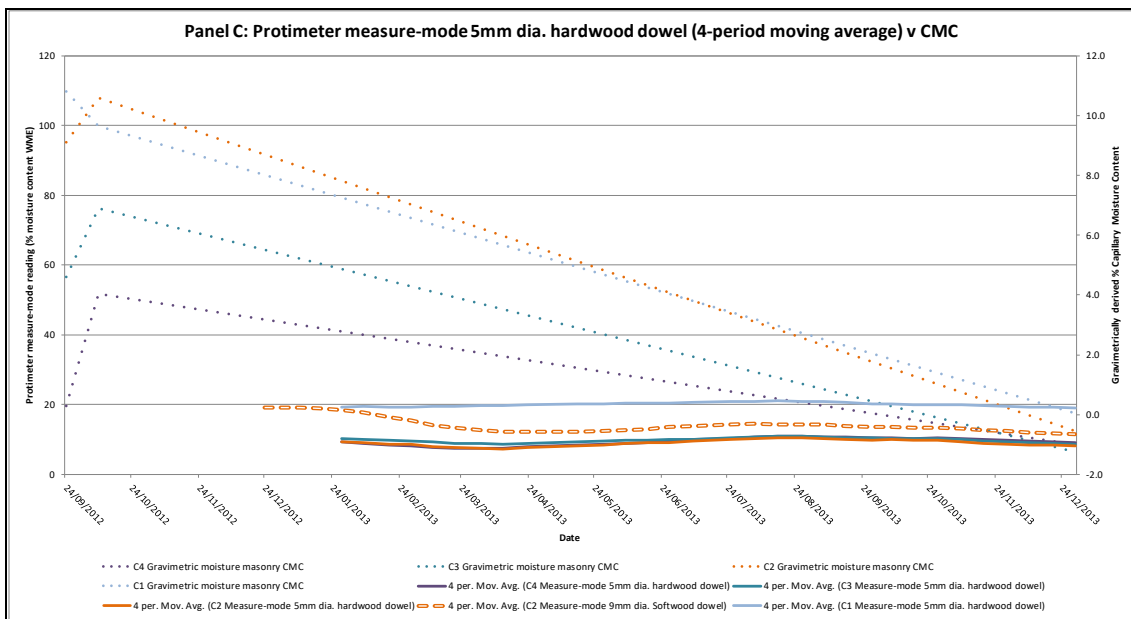
Figure 156: Panel C rows 1-4 Protimeter measure-mode readings 9 mm softwood dowel and 5 mm hardwood dowels (4-period moving average) v CMC of masonry.

The generally low and static measure-mode readings obtained from the plain timber dowels of Panel C rows 1-4 did not reflect the fall in the capillary moisture content between Stages 3 and 5.

Measure-mode readings obtained from the Timber Probes Type 1 were influenced by changes in environmental moisture; essentially, because the Type 1 probes' tendency to absorb this moisture was enhanced as their HMCs increased. To test this effect, relative humidity and vapour pressure data from the Lascar data loggers, mounted on the face of each panel, was overlaid onto the charts of their measure-mode values.

Figure 157 below illustrates the plain timber dowels' measure-mode readings against vapour pressure for Panel C. There is a clear correlation across the rows, albeit less pronounced for row 1, with the peak corresponding with mid-summer 2013. This same effect was apparent on Panels B, D, and E.
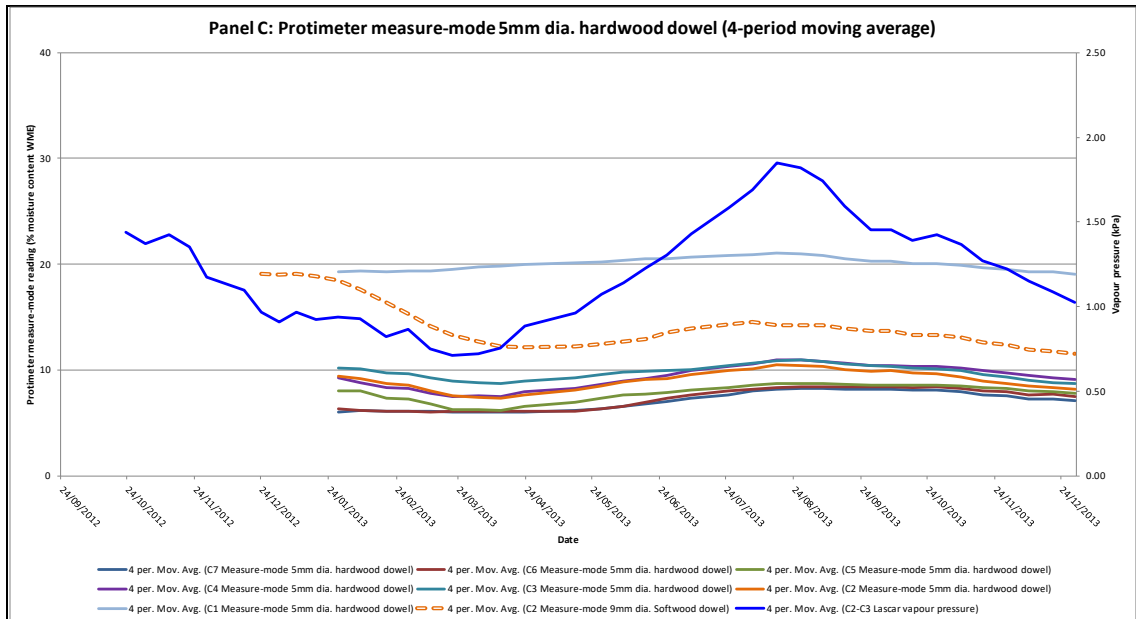
Figure 157: Panel C rows 1-7 Protimeter measure-mode readings of plain timber dowels (4-period moving average) v boundary layer vapour pressure (4-period moving average).

Panel A, shown in Figure 158 below, displayed the same correlated effect of plain timber dowel measure-mode readings against vapour pressure in its upper four rows, 4-7. An upward trend was only apparent for rows 1-3, but this is accounted for by their high total moisture content, as illustrated in the top section of Table 37 below, which essentially counteracted this effect. In practice, the influence of environmental moisture is more pronounced for plain timber dowels located in the drier parts of the walls; where capillary moisture is present, there is less of an effect.

Figure 158: Panel A rows 1-7 Protimeter measure-mode readings 5 mm hardwood dowels (4-period moving average) v boundary layer vapour pressure (4-period moving average).
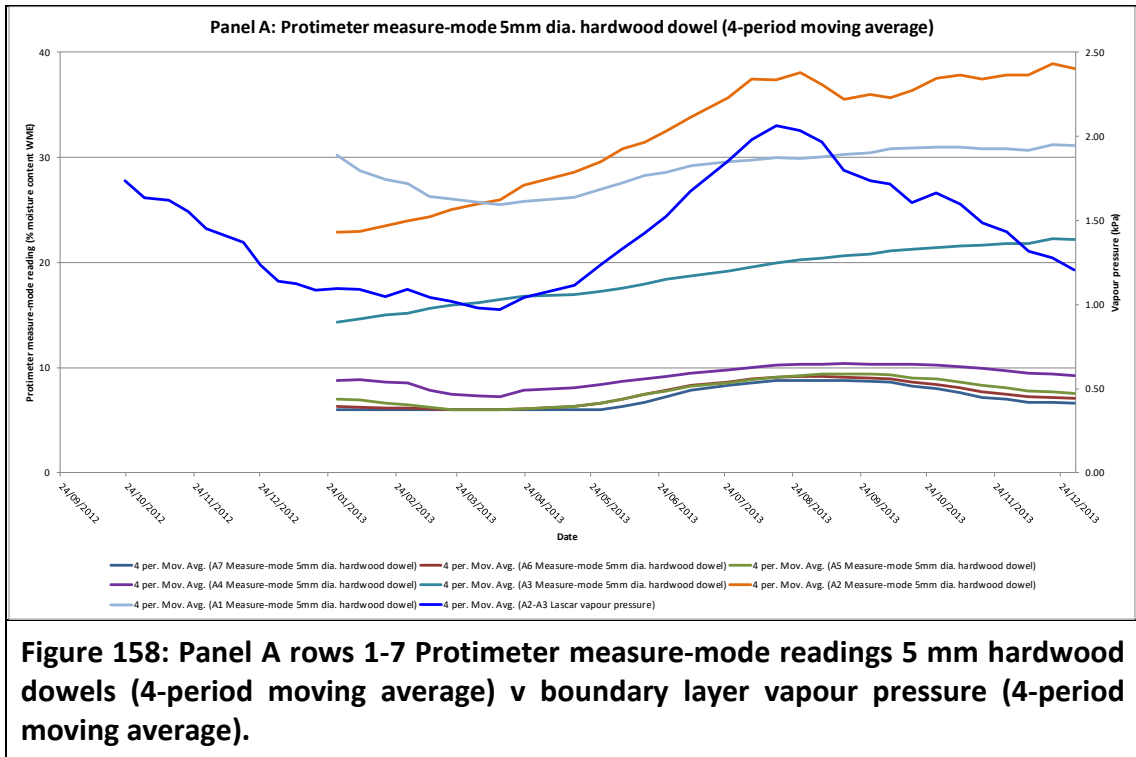
On completion of the data collection phase, the plain timber dowels were taken off-site and processed, using the procedure described in the previous section with respect to the Timber Probes Type 1, to provide their final measure-mode value and total, capillary, and hygroscopic moisture contents. Three unused lengths of 5 mm hardwood dowel were included in these analyses to provide baseline values. The results are set out in Table 37 below, essentially using the same format as Table 36 above, but rows containing 9 mm softwood dowels have been highlighted and their final on-site readings placed in an additional column to distinguish them from the majority of the 5 mm diameter hardwood dowels.

Panel	Row	Plain dowel type	Measure-mode reading: final on site (5 mm dowel)	Measure-mode reading: final on site (9 mm dowel)	Stage 5: measure-mode reading	Stage 5: TMC	Stage 5: HMC	Stage 5: CMC
A	7	5 mm hardwood	6.3%		7.9%	6.4%	7.4%	-1.0%
A	6	5 mm hardwood	6.9%		8.2%	6.6%	7.6%	-1.0%
A	5	5 mm hardwood	7.3%		8.4%	6.5%	7.4%	-0.9%
A	4	5 mm hardwood	8.8%		9.6%	7.1%	7.7%	-0.6%
A	3	5 mm hardwood	21.2%		20.8%	10.6%	9.8%	0.8%
A	2	5 mm hardwood	34.8%		22.7%	14.7%	10.9%	3.8%
A	1	5 mm hardwood	30.5%		26.0%	19.2%	11.7%	7.5%
B	7	5 mm hardwood	7.6%		8.8%	6.5%	7.5%	-1.0%
B	6	5 mm hardwood	7.5%		8.6%	6.2%	7.3%	-1.1%
B	5	5 mm hardwood	7.6%		8.6%	6.6%	7.2%	-0.6%
B	4	5 mm hardwood	9.2%		10.3%	6.7%	7.9%	-1.2%
B	4	9 mm softwood		13.2%	14.8%	8.5%	9.6%	-1.1%
B	3	5 mm hardwood	9.8%		11.0%	7.7%	8.4%	-0.7%
B	2	5 mm hardwood	17.5%		20.6%	11.0%	9.8%	1.2%
B	1	5 mm hardwood	29.4%		21.7%	16.1%	11.0%	5.1%
C	7	5 mm hardwood	6.7%		8.2%	6.2%	7.4%	-1.2%
C	6	5 mm hardwood	7.0%		8.2%	6.1%	7.2%	-1.1%
C	5	5 mm hardwood	7.5%		8.7%	6.1%	7.2%	-1.1%
C	4	5 mm hardwood	8.9%		10.3%	7.2%	8.2%	-1.0%
C	3	5 mm hardwood	8.6%		10.0%	7.5%	8.2%	-0.7%
C	2	5 mm hardwood	8.1%		9.5%	7.5%	8.5%	-1.0%
C	2	9 mm softwood		11.1%	12.8%	8.1%	8.9%	-0.8%
C	1	5 mm hardwood	18.7%		17.6%	10.8%	9.6%	1.2%
D	7	5 mm hardwood	7.4%		8.6%	6.1%	7.2%	-1.1%
D	6	5 mm hardwood	6.9%		8.2%	6.3%	7.1%	-0.8%
D	5	5 mm hardwood	8.5%		9.2%	6.7%	7.3%	-0.6%
D	4	5 mm hardwood	9.6%		10.2%	7.5%	8.1%	-0.6%
D	3	5 mm hardwood	11.2%		12.0%	7.9%	8.6%	-0.7%
D	3	9 mm softwood		18.4%	20.5%	9.7%	10.0%	-0.3%
D	2	5 mm hardwood	24.4%		22.9%	11.4%	9.8%	1.6%
D	1	5 mm hardwood	36.2%		23.5%	16.9%	10.9%	6.0%
E	7	5 mm hardwood	7.3%		8.5%	6.4%	7.4%	-1.0%
E	6	5 mm hardwood	7.3%		8.6%	6.5%	7.3%	-0.8%
E	5	5 mm hardwood	7.3%		8.4%	6.4%	7.3%	-0.9%
E	4	5 mm hardwood	8.1%		9.5%	6.8%	7.4%	-0.6%
E	3	5 mm hardwood	9.8%		11.5%	8.1%	8.3%	-0.2%
E	2	5 mm hardwood	15.5%		17.8%	10.2%	9.3%	0.9%
E	1	5 mm hardwood	24.4%		18.9%	14.3%	10.5%	3.8%
X	5	5 mm hardwood			8.0%	5.7%	7.1%	-1.4%
X	6	5 mm hardwood			8.0%	5.3%	7.1%	-1.8%
X	7	5 mm hardwood			8.0%	5.5%	7.1%	-1.6%

Table 37: Plain timber dowels final measure-mode and moisture values.

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The results from Table 37 demonstrate that although high measure-mode readings were obtained from plain timber dowels with high TMCs, they were also recorded on dowels with relatively low CMCs where the HMCs were elevated. Essentially, this is the same trend that was apparent for the Timber Probes Type 1.

The three hardwood control dowels, X5, X6, and X7, had the same low measure-mode value of 8%, aligning well with their hygroscopic moisture content of 7.1%. Given that the Protimeter measure-mode is calibrated for timber, it is unsurprising that the measure-mode and HMC values of the unused dowels are similar (GE Sensing, 2005, p. 17).

As was the case with the Timber Probes Type 1, the hygroscopic moisture contents of the plain timber dowels increased over the monitoring phase. However, in contrast to the HMC increase of the Type 1 probes, which tended to be concentrated around rows 3-4 therefore mirroring the distribution of hygroscopic salts typical of the rising damp model, the HMCs of the plain timber dowels displayed an increase from bottom to top row of each panel. Although, technically, there was little increase to the original HMCs of the dowels located in rows 5-7 because hygroscopic contamination did not affect this region of the panels.

Plain timber dowels respond well when inserted into masonry that is both dry and unaffected by hygroscopic salts. In this upper region of the test panels, they provided a reliable indicator with respect to the presence or more accurately the absence of moisture.

Significantly, the plain timber dowels did not reflect moisture change following the installation of the damp proofing cream in Panels A and C. Clearly, this may well be because they were inserted after drying had already occurred. However, although elevated measure-mode readings from plain timber dowels located in wetter regions of the test panels correctly reflected higher quantities of total moisture, it is not possible

to establish, without laboratory analyses, if this comprised hygroscopic or capillary moisture. Therefore, their susceptibility to hygroscopic salt contamination means they have the same disadvantages and limitations as those listed in the previous section for the Timber Probes Type 1.

Despite this criticism, plain timber dowels do offer attractive benefits over other methods of moisture monitoring: they are extremely cheap, simple to operate, and the method used to obtain measure-mode values provides built-in validity. Furthermore, the 5 mm diameter hardwood dowels tended to return lower measure-mode readings than those obtained from the 9 mm diameter softwood dowels, even where located in the same panel and row position. This difference is attributed to their lower porosity, a material property that enables the hardwood probes with a natural resistance against fungal decay and the potential to mitigate hygroscopic contamination. Their ease of removal means that plain timber dowels can be replaced periodically thus mitigating the effects of hygroscopic salts; although hysteresis could mean that replacement dowels do not achieve the same moisture content as their predecessors.

It would be both useful and interesting to repeat this experiment with plain timber dowels installed from the outset; perhaps making use of two sets per panel, one of which could employ a protocol of periodic replacement to limit hygroscopic contamination. At this stage, given the available results, it has to be concluded that as a form of moisture monitoring following damp proof course treatments, plain timber probes can only be used with caution.

8.9. Protimeter Hygrosticks

Chapter 4 provided a detailed account of the calibration drift encountered with the Protimeter Hygrosticks and explained how this problem was mitigated. This issue did not affect the evaluation of Hygrosticks as a method of moisture measurement discussed in this and the subsequent final section of this chapter.

The principal underpinning the use of Hygrosticks, shown in Figure 159 below, is that measuring changes in the moisture content of the pocket of air within the Humidity Sleeves in which they are inserted will by extension enable changes in the moisture changes of the surrounding masonry to be tracked.

Figure 159: Panel E reading a Hygrostick.

The Hygrostick is attached to a Protimeter MMS meter with a proprietary extension lead enabling the relative humidity and temperature of the pocket of air within the Humidity Sleeve to be read.

Equilibrium relative humidity is the value typically used to measure the moisture content of the pocket of air (Burkinshaw, 2010, p. 9). However, as discussed in Chapter 4, relative humidity is a function of temperature and can therefore fluctuate simply as a result of temperature change. A method to avoid this confound is to convert the Hygrostick data into vapour pressure, which, unlikely relative humidity, is a measure of the actual moisture content of the air (BSI, 2011, p. 3). Warmer air does have the capacity to hold more moisture and therefore to have higher vapour pressure but using this conversion

enables more meaningful comparisons. Thus, both relative humidity and vapour pressure were considered in this evaluation.

Initially, the relative humidity data of the Hygrosticks were plotted as charts for individual panels. These data were subsequently compared to the environmental data recorded by the Lascar data loggers and these same analyses carried out after conversion of these data to vapour pressures.

With respect to relative humidity, three trends were immediately apparent: firstly, for all five panels the relative humidity decreased in relation to row height, independently of any treatments applied; secondly, the Hygrosticks were clearly correlated with the internal Lascar data loggers sited at the boundary layer of the panels and in the living room; and, thirdly, there was no clear correlation with the external relative humidity. These trends are illustrated for Panel C in Figure 160 below.
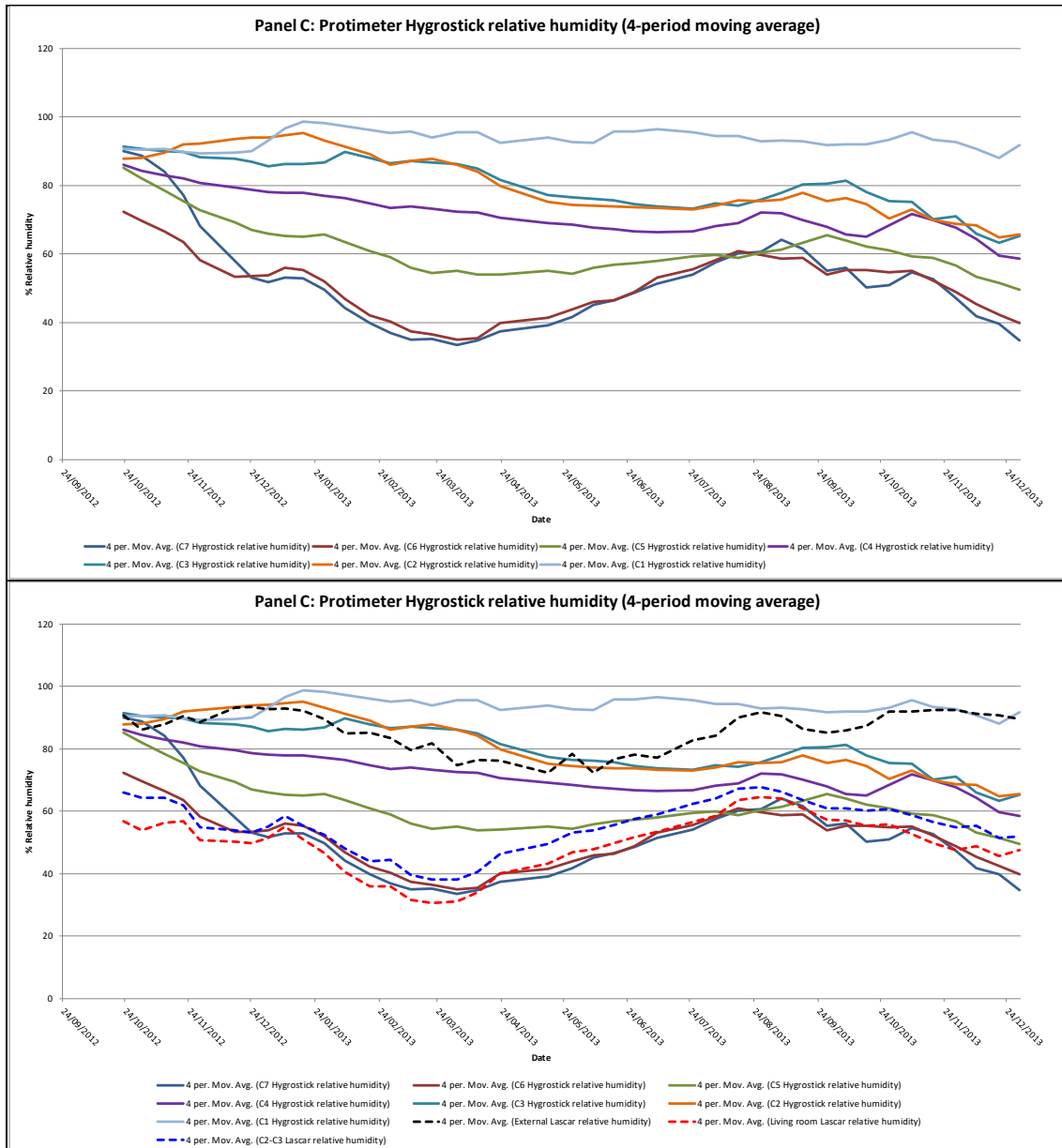
Figure 160: Panel C rows 1-7 Hygrostick relative humidities (4-period moving average) and Lascar relative humidities (4-period moving average).

The top chart shows how the Hygrostick relative humidities reduce with respect to row height. The bottom chart illustrates the correlation with the relative humidities of the living room and panel mounted Lascar data loggers. The relative humidity of the external Lascar data logger (black dashed line) was not correlated. This relative humidity trend was apparent on all five test panels independently of the applied treatments.

The apparent absence of correlation between the internal and external relative humidities can be accounted for by differences in air temperature. When the Hygrostick and Lascar data are represented as vapour pressures, thus removing the influence of

differing temperatures, a clear correlation is revealed. Furthermore, the distribution of vapour pressures across the Hygrosticks is precisely the same as that for the relative humidity: decreasing with row height. Figure 161 below illustrates these vapour pressure data for Panel C but all five test panels displayed these two trends which were again independent of the treatments applied.
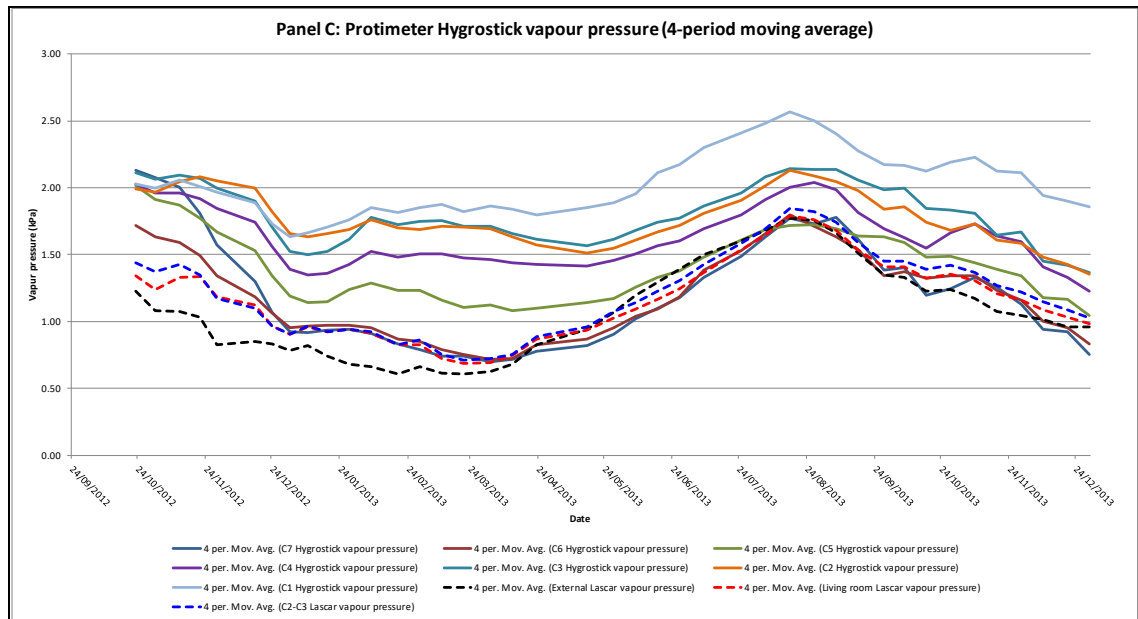
Figure 161: Panel C rows 1-7 Hygrostick vapour pressures (4-period moving average) and Lascar vapour pressures (4-period moving average).

Conversion of the relative humidity and temperature data to vapour pressures illustrates a precise correlation of the internal and external conditions. In addition, the profile of reducing values relative to row height previously applicable to relative humidity applies equally to vapour pressure. The two trends were apparent on all five test panels independently of the applied treatments.

Clearly, it is not possible for the moisture content and temperature of air inside a dwelling to influence the conditions outside and, therefore, any correlation must be driven by the external environment. Given these findings, it must be concluded that the external conditions significantly influence the environment inside the house and that this effect is not just restricted to the air within the living accommodation or at the boundary layer of the panels but affects the pocket of air within the Humidity Sleeves and thus the values returned by the Hygrosticks.

Given that the capillary moisture content of the panels, at the outset, was greater in their base than in the mid and upper rows, it would be logical to assume that the Hygrostick relative humidities and derived vapour pressures would decrease with row height and therefore align with the findings. However, it was established that the capillary moisture content of Panels A and C fell following installation of the damp proofing cream and, yet, this reduction is not reflected in the Hygrostick data.

This conflicting pattern is illustrated in Figure 162 and Figure 163 below, which compares the vapour pressures against the capillary moisture content of rows 1-4 for Panels A and C, respectively.
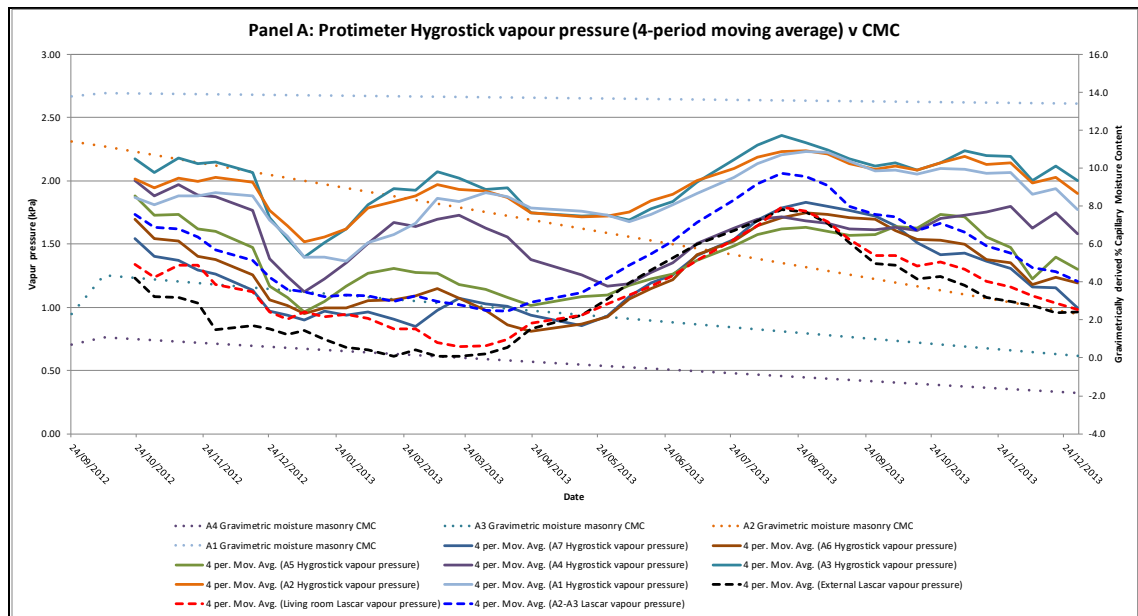
Figure 162: Panel A rows 1-7 Hygrostick vapour pressures (4-period moving average) and Lascar vapour pressures (4-period moving average) v CMC of masonry.

For Panel A, with the exception of row 1, which remained high, the capillary moisture contents of rows 2-4 displayed significant falls. The trend of the vapour pressures derived from the Hygrostick data is independent of the capillary moisture content and instead is driven by the external conditions.
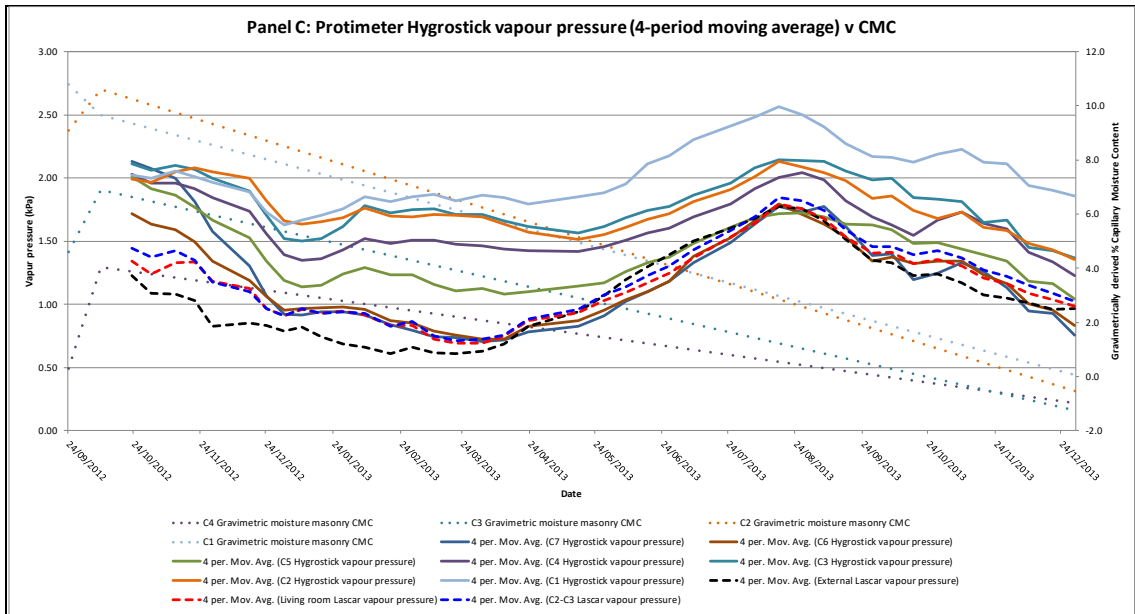
Figure 163: Panel C rows 1-7 Hygrostick vapour pressures (4-period moving average) and Lascar vapour pressures (4-period moving average) v CMC of masonry.

For Panel C, the capillary moisture contents of, rows 2-4 displayed significant falls. The trend of the vapour pressures derived from the Hygrostick data is independent of the capillary moisture content and instead is driven by the external conditions.

A further interesting discovery was that the vapour pressures were not only independent of capillary moisture but also of hygroscopic moisture, which is illustrated For Panel A in Figure 164 below but was apparent on all five test panels.
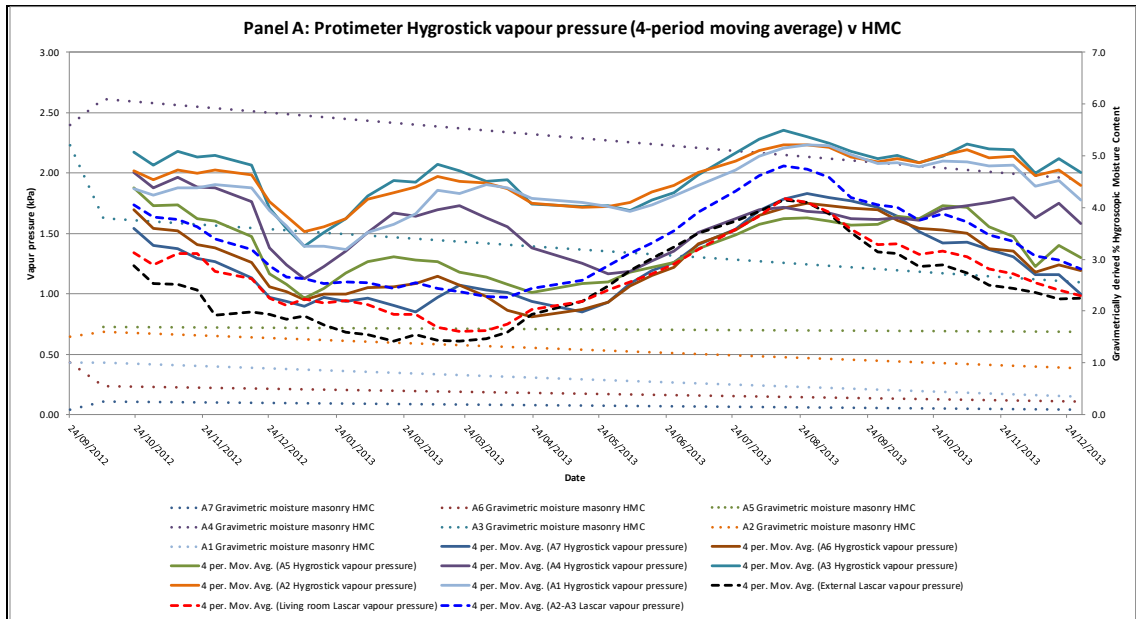
Figure 164: Panel A rows 1-7 Hygrostick vapour pressures (4-period moving average) and Lascar vapour pressures (4-period moving average) v HMC of masonry.

The vapour pressures trend, driven by the external conditions, was independent of the masonry HMCs, which, for each row, remained relatively stable between Stages 3 and 5.

The findings suggested that the external conditions strongly influenced the trend of the Hygrosticks. However, if moisture in the panels was not the reason for the Hygrosticks displaying a distinct and similar trend across the seven rows of each panel—the relative humidity and vapour pressures increasing inversely to the row number—what could be the cause of this effect? Temperature provides the answer.

The data revealed that the temperature recorded by the Hygrosticks, unsurprisingly, followed the trend of the general air temperature; however, what was unexpected was the temperature distribution, which rose incrementally with row height: the temperature at row 7 being 1.5-2.0°C higher than that in row 1. This temperature trend, which is illustrated for Panel E in Figure 165 below, was common to all five panels and consistent through the data collection phase. What is interesting is that the panels consisted of internal wall parts rather than external walls parts that would have logically seemed more prone to such temperature variations with height. Given conditions of

high vapour pressures, this temperature difference could potentially enable condensation to form on the wall bases and thus be a contributory cause of dampness.
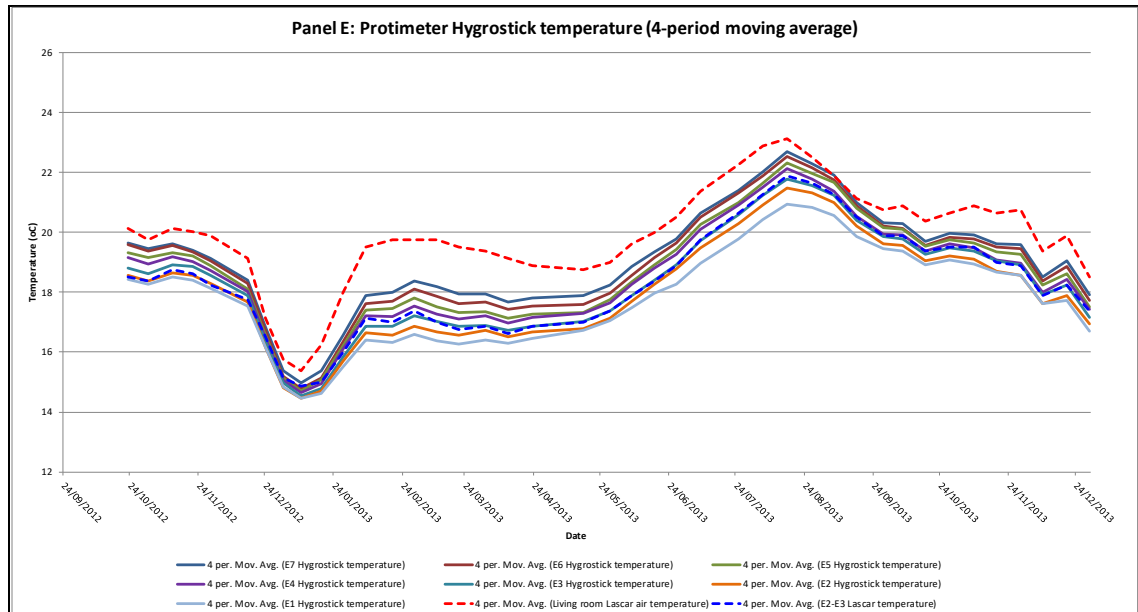
Figure 165: Panel E rows 1-7 Hygrostick temperatures (4-period moving average) and internal Lascar temperatures (4-period moving average).

All temperatures follow the general ambient trend of the internal air and rise incrementally with row height. This effect was apparent on all five panels.

Protimeter Hygrosticks and their accompanying Humidity Sleeves are simple to install, use¸ and validate using a saturated solution of sodium chloride. However, calibration drift was a significant during the data collection phase, and although this was mitigated through a protocol of checking and timely replacement, it undermined confidence in this method.

Initially, it was thought that using vapour pressure to evaluate the findings would provide better results than relative humidity by removing the potential confound of fluctuating temperatures. In practice, regardless of whether relative humidity or vapour pressure is employed to assess moisture change, the external conditions exert such a strong influence over the internal environment, including the pocket of air inside each of the Humidity Sleeves, that humidity data recorded by the Hygrosticks is largely independent of moisture present in the masonry walls. It is for this reason that

Hygrosticks are not suitable as a method to monitor the reduction of moisture in a rising damp affected wall following remedial damp proof course treatment.

8.10. Environmental and wall moisture: evaluation of correlation

This part of the study set out to determine if moisture in the environment could be correlated with moisture in a damp wall. In other words, could the evaporation of moisture from a wall affected by rising damp bring about environmental changes or, conversely, could humidity in the air increase the moisture content of a masonry wall?

The findings discussed in earlier sections of this chapter revealed a relationship between atmospheric moisture and the moisture measuring apparatus; namely, that internal vapour pressures respond to changes in external vapour pressures and that such changes are reflected in the Protimeter measure-mode readings obtained from the Timber Probes Type 1 and the plain timber dowels and the relative humidity values of the pocket of air within each of the Humidity Sleeves.

Measure-mode readings obtained from the Type 1 probes and plain timber dowels increased overtime as hygroscopic salts present in the masonry wall migrated into the wood. Essentially, their hygroscopic moisture content and therefore their ability to absorb atmospheric moisture was enhanced. Clearly, this same effect applies to the masonry: parts contaminated with hygroscopic salts will absorb greater quantities of atmospheric moisture and this hygroscopic moisture content will fluctuate in response to environmental moisture changes.

The findings suggested that environmental moisture only caused significant increases to the hygroscopic moisture content of the masonry where hygroscopic contamination had occurred. It had no significant impact on masonry that was unaffected by hygroscopic salts, nor did it alter its capillary moisture content. Of more interest is the potential for

evaporation of capillary moisture from a rising damp affected wall to bring about changes to environmental moisture.

A typical household produces 7-14 litres of water per day through living activities (Garratt & Nowak, 1991, p. 18). Evaporation from a half-brick thick wall affected by rising damp is claimed to be between 0.14-0.88 litres per day per metre length (Hall & Hoff, 2007, p. 1876; Rirsch & Zhang, 2010, p. 6). Given a house with several walls affected by rising damp, such evaporation would contribute significantly to the internal vapour pressure. If this was the case, evaporation, or more specifically changes to the vapour pressure at the boundary layer of a damp wall, should be measurable.

Lascar data loggers had been mounted on the face of each of the five test panels between rows 2 and 3. This vertical position was chosen because it corresponded with the maximum height of the damp rise and therefore the location on the panels where evaporation of moisture associated with rising damp would be greatest. The Lascar data loggers were to measure the relative humidity and temperature of the air at the boundary layer of each panel and from these data the vapour pressures would be calculated.

Logic suggested that the vapour pressures at the boundary layer should be higher in locations where capillary moisture was elevated and should reduce if capillary moisture fell or if the low-permeability render applied to Panels B and C resulted in slower surface evaporation. Thus, vapour pressures at the boundary layer of Panels D and E would be higher than those from Panels B and C and, given that their capillary moisture content reduced following installation of the damp proofing cream, the vapour pressure of Panels A and C would fall over the drying period.

There was uncertainty with respect to Panel A. The capillary moisture content in rows 2 and 3 were confirmed to have fallen following installation of the damp proofing cream. However, because plasterwork was absent, the Lascar data logger was attached directly

to the brick face. This brickwork was known to be contaminated with hygroscopic salts, and the influence of these salts with respect to boundary layer vapour pressure was undetermined.

During the data collection phase, readings were taken from the Lascar data loggers at each visit to the house, providing a total of forty-four individual data sets. In addition, all seven Lascar data loggers were programmed to record the relative humidity and temperature values at each hour, continuously throughout the fifteen-month monitoring period, thus providing seven further data sets, each containing 11,257 value pairs. These data were converted to vapour pressures during processing. For their use in charts, the forty-four and 11,257 data sets were smoothed by applying 4-period and 240-period moving averages, respectively.

The charts for these two data sets are illustrated in Figure 166 below and reveal that the vapour pressure trend across all seven Lascar data loggers is correlated; furthermore, that this trend is driven by the conditions outside the house and not those inside or at the boundary layer of any individual panel. It was also independent of any presumed effect of applying low-permeability render to Panels B and C.
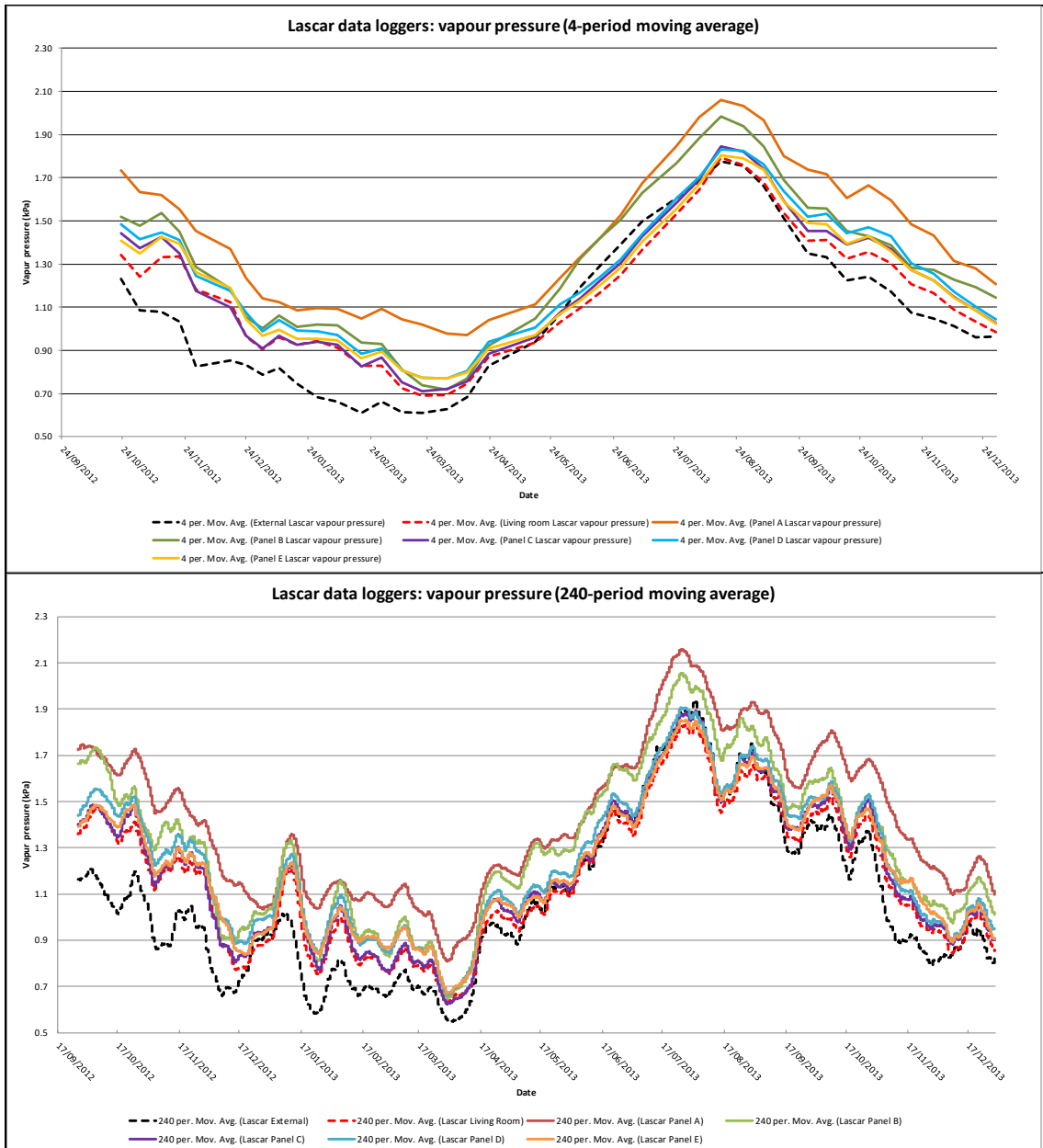
Figure 166: Lascar data loggers vapour pressure data sets.

For all seven Lascar data loggers, the top chart represents the spot readings taken during each of the forty-four data collection visits and the bottom chart the full 11,257 data sets, smoothed by applying 4-period and 240-period moving averages, respectively. The vapour pressure trend is both similar and correlated with the external conditions.

Despite the similarity of the charts in Figure 166, the vapour pressures of the Lascar data loggers mounted on Panels C, D, and E and located in the living room are tightly constrained and contrast with the vapour pressures of the data loggers mounted on

Panels A and B which returned similar but consistently higher values. This disparity results from the panel's position. Panels C, D, and E were located on the rear wall of the living room where ambient conditions are dissimilar to those in the smaller, enclosed space of the understairs cupboard in which Panels A and B were situated. Nevertheless, the influence of the external vapour pressure is clearly evident on all five panels.

To ascertain if the internal vapour pressures are in themselves significant, each of the internal values was subtracted from the external value at the same time point to provide a vapour pressure delta. Figure 167 and Table 38 and Table 39 below provide a chart of these data and descriptive statistics respectively.
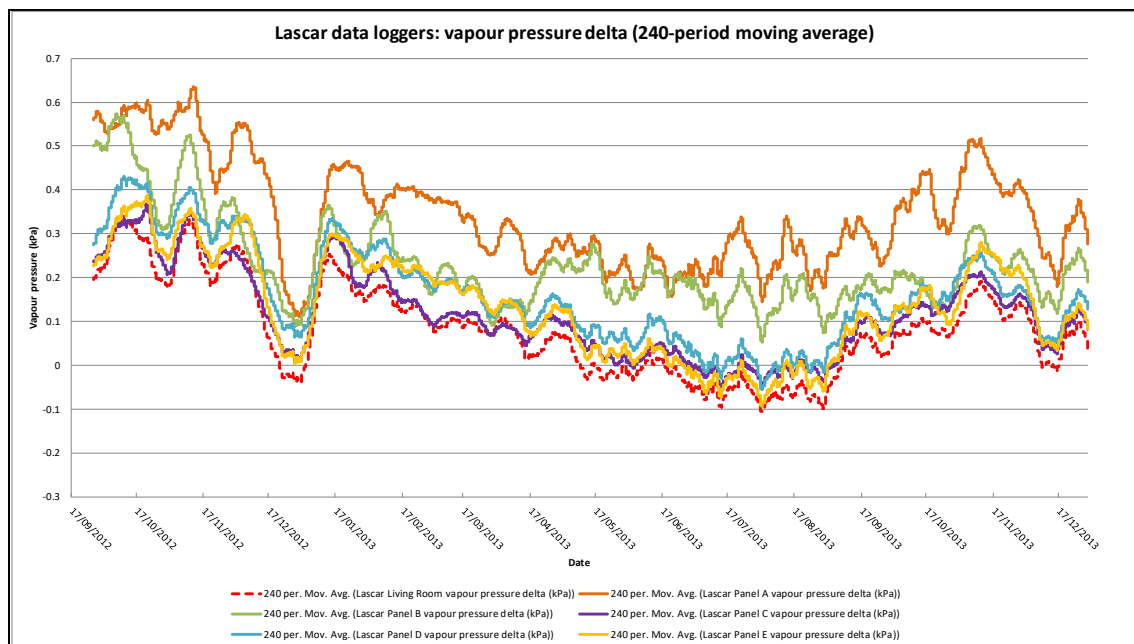
Figure 167: Lascar data loggers vapour pressure delta (240-period moving average) 11,257 point data set.

Figure 167 above illustrates that the internal vapour pressures at the boundary layer of Panels A and B were consistently higher than those of Panels C-E and of the ambient air in the living room. Note that the pronounced fall in vapour pressures that occurred at the end of December 2012 is a result of lower internal temperatures when the house was vacant over this period.

Table 38 below provides the maximum, minimum, average, and median vapour pressure and vapour pressure delta values from the forty-four and 11,257 data sets, respectively. In addition to Panels A-E, the living room and external data has been included.

Unsurprisingly, given the significant difference in the sizes of the two data sets, there are discrepancies in the maximum and minimum values; nevertheless, there is good alignment of the average and median, which for the relevant cells of the 11,257 data set have been annotated using graduated red to green fill to represent high to low values.

| | Vapour pressure 17/09/2012 - 30/12/2013 | | | | | | | | | | | | | |
| | External | | Living Room | | Panel A | | Panel B | | Panel C | | Panel D | | Panel E | |
	44 set	11257 set	44 set	11257 set	44 set	11257 set	44 set	11257 set	44 set	11257 set	44 set	11257 set	44 set	11257 set
Maximum	1.9	2.69	1.9	2.23	2.2	2.37	2.1	2.20	1.9	2.24	1.9	2.20	1.9	2.12
Average	1.1	1.08	1.2	1.16	1.4	1.42	1.3	1.31	1.2	1.19	1.2	1.24	1.2	1.21
Median	1.0	1.01	1.1	1.14	1.4	1.39	1.3	1.29	1.2	1.18	1.2	1.22	1.2	1.20
Minimum	0.5	0.41	0.5	0.46	0.9	0.55	0.6	0.48	0.5	0.48	0.6	0.53	0.6	0.51
	Vapour pressure delta 17/09/2012 - 30/12/2013													
	External		Living Room		Panel A		Panel B		Panel C		Panel D		Panel E	
	44 set	11257 set	44 set	11257 set	44 set	11257 set	44 set	11257 set	44 set	11257 set	44 set	11257 set	44 set	11257 set
Maximum	NA	NA	0.5	0.85	0.7	0.94	0.7	0.94	0.5	0.71	0.5	0.75	0.6	0.81
Average	NA	NA	0.1	0.08	0.4	0.35	0.2	0.23	0.1	0.12	0.2	0.16	0.1	0.14
Median	NA	NA	0.1	0.08	0.4	0.36	0.2	0.22	0.1	0.11	0.2	0.16	0.1	0.15
Minimum	NA	NA	-0.3	-0.74	0.0	-0.65	0.0	-0.66	-0.2	-0.68	-0.2	-0.68	-0.2	-0.76

Table 38: Lascar data loggers vapour pressure and vapour pressure delta descriptive statistics for period 17/09/2012 – 30/12/2013.

Table 38 reveals the distribution of high to low average and median vapour pressure values to be Panels A, B, D, E, C, living room, and outside. Vapour pressure delta does not apply externally but the high to low average and median deltas aligned with the distribution of vapour pressures. Essentially, the trend matches the charted data.

BSI 2520 states that the internal vapour pressure of a UK dwelling during winter is typically in the range of 1.00-1.20 kPa against an external vapour pressure of 0.5-0.60 kPa (2011, p. 14). Simple subtraction suggests that under these conditions the vapour pressure delta should be no greater than 0.5-0.6 kPa.

The average internal and external vapour pressure values in Table 38, at 1.16-1.42 kPa and 1.01-1.08 kPa, respectively, are higher than those stated in BS 2520. However, Table 38's data sets extend over a fifteen-month monitoring period, September 2012 to

December 2013, and therefore include the warmer spring and summer months. To enable evaluation against BS 2520, Table 39 below displays the data for only the winter periods: 1 October 2012 to 31 March 2013 and 1 October 2013 to 30 December 2013 when the onsite data collection phase finished.

| | Vapour pressure 01/10/2012 - 31/03/2013 & 01/10/2013 - 30/12/2013 | | | | | | | | | | | | | |
| | External | | Living Room | | Panel A | | Panel B | | Panel C | | Panel D | | Panel E | |
	44 set	11257 set	44 set	11257 set	44 set	11257 set	44 set	11257 set	44 set	11257 set	44 set	11257 set	44 set	11257 set
Maximum	1.5	1.91	1.5	1.84	1.8	1.93	1.6	2.18	1.6	1.83	1.7	1.85	1.6	1.78
Average	0.9	0.89	1.0	1.03	1.3	1.29	1.1	1.15	1.1	1.06	1.1	1.11	1.1	1.09
Median	0.9	0.85	1.0	0.97	1.2	1.21	1.1	1.10	1.0	0.99	1.0	1.05	1.0	1.03
Minimum	0.5	0.41	0.5	0.46	0.9	0.55	0.6	0.48	0.5	0.49	0.6	0.53	0.6	0.51
	Vapour pressure delta 01/10/2012 - 31/03/2013 & 01/10/2013 - 30/12/2013													
	External		Living Room		Panel A		Panel B		Panel C		Panel D		Panel E	
	44 set	11257 set	44 set	11257 set	44 set	11257 set	44 set	11257 set	44 set	11257 set	44 set	11257 set	44 set	11257 set
Maximum	NA	NA	0.5	0.85	0.7	0.94	0.7	0.94	0.5	0.71	0.5	0.75	0.6	0.81
Average	NA	NA	0.1	0.14	0.4	0.40	0.3	0.26	0.1	0.17	0.2	0.22	0.2	0.20
Median	NA	NA	0.1	0.13	0.4	0.40	0.3	0.24	0.2	0.15	0.2	0.21	0.2	0.20
Minimum	NA	NA	-0.1	-0.36	0.0	-0.24	0.0	-0.24	-0.1	-0.28	-0.1	-0.27	-0.1	-0.33

Table 39: Lascar data loggers vapour pressure and vapour pressure delta descriptive statistics for period 01/10/2012 - 31/03/2013 & 01/10/2013 - 30/12/2013.

The reconfigured data in Table 39 illustrates two differences with respect to the former average values: firstly, the vapour pressures inside the house reduce from the range of 1.16-1.42 kPa to the range of 1.03-1.29 kPa, thereby providing good alignment with the 1.00-1.20 kPa range in BSI 2520 (2011, p. 14); secondly, the external vapour pressure, at an average of 0.89 kPa, is not within the typically range of 0.50-0.6 kPa suggested in BSI 2520 (2011, p. 14).

Applying this average wintertime external vapour pressure, means that the average internal vapour pressure delta of the living room is 0.14 kPa and that of the boundary layers of Panels B-E is in the range 0.20-0.26 kPa. Panel A's average vapour pressure delta is higher, but not by a great margin, at 0.4 kPa.

Two factors that contribute to high vapour pressures in a dwelling are moisture production and inadequate heating. There were occasions when the house was unheated, but these periods were brief, and in general heating was adequate. The data revealed the vapour pressure in the living accommodation to be low. This is unsurprising because moisture production is related to occupancy and the lifestyle of the occupants;

the house had a maximum of two occupants and only one for a good proportion of the monitoring period, so moisture production was unlikely to be excessive.

Environmental moisture will cause changes in the moisture content of hygroscopic materials and to pockets of air within a masonry wall. Contamination from hygroscopic salts causes a progressive increase in the hygroscopic potential of affected materials and therefore in their hygroscopic moisture content. In other words, materials with greater hygroscopicity are those most affected by environmental moisture. However, there was no significant evidence of capillary moisture evaporation from the panels and therefore of this moisture bringing about vapour pressure changes in the internal environment. On the contrary, internal vapour pressures recorded at the boundary layer of the panels were independent of any treatments applied and, significantly, of changes in capillary moisture content that occurred in Panels A and C between Stages 3 and 5; instead, they were driven by the external conditions.

The application of low-permeability render to Panels B and C did not influence the boundary layer vapour pressures: values from these two panels were no different to those recorded on adjacent panels. Although Panel A's vapour pressures were higher than those of the other four panels, they followed the same pattern, and this anomaly is attributed to its location rather than any effect of its moisture content.

From these findings, it may be concluded that evaporation of moisture from a wall affected by rising damp does not bring about environmental changes and that such evaporation cannot be detected at the boundary layer of the wall. In this sense, moisture in a damp wall and moisture in the environment are not correlated.

However, hygroscopic materials absorb moisture from the air and their hygroscopicty, and thus their potential to absorb this moisture is enhanced as a result of contamination from hygroscopic salts. Thus the hygroscopic moisture content of any material, including masonry and plaster contaminated with hygroscopic salts as a consequence of rising

damp, will increase if moisture (i.e. vapour pressure) in the surrounding air increases. Technically, then, moisture in a wall and moisture in the environment are correlated; nevertheless, the findings of this study indicated that moisture absorbed in this manner does not impact on the capillary moisture content.

8.11. Evaluating the moisture measuring apparatus: closing comments

The purpose of the aspect of the project discussed in this chapter was to evaluate the common method of measuring moisture in masonry walls, namely an electronic moisture meter (i.e. a Protimeter), along with three other lesser used techniques, Timber Probes Type 1, plain timber dowels, and electronic thermo-hygrometers (i.e. Protimeter Hygrosticks), all of which are readily available to general building surveyors and other persons who may have an interest in assessing dampness in buildings.

The evaluation was undertaken by considering how successfully each of the chosen methods performed in measuring the change in the moisture content of the test panels, where such changes occurred following application of their respective damp proofing treatments.

From the outset it was expected that hygroscopic moisture and, in particular, enhanced hygroscopicty of masonry and plaster materials resulting from their contamination with hygroscopic soil salts as a consequence of rising damp would affect the operation of a Protimeter. The results showed this to be the case with the Protimeter measure-mode function, whether used with the Heavy Duty Probe or Deep Wall Probes, and the search-mode function producing elevated values on such contaminated parts, Irrespective of the subject materials' capillary moisture content. It was thought that the use of Timber Probes Type 1 and the plain timber dowels may offset this effect; however, hygroscopic salts present in the masonry tends to migrate into the timber parts over time, producing erroneous results. Essentially, the Protimeter functions can identify dampness (i.e. total moisture) and for this reason it is a diagnostic instrument

that is useful, and, arguably, indispensable, for practitioners who undertake dampness investigations, but it not possible to know if this moisture is comprised of capillary moisture, hygroscopic moisture, or a combination of these two forms.

That Protimeters are confounded by hygroscopic salts is not a revelation. Indeed, although it is a criticism levied at the use of this instrument when used for the diagnosis of rising damp, it is a fact that has been common knowledge in the damp proofing industry for many years. What is more surprising is the susceptibility of timber probes and dowels to this same limitation. Although the timber probe method is arguably far less frequently used with a Protimeter than the Heavy Duty or Deep Wall Probes, the research findings nevertheless provide useful guidance to inform practice and those practitioners who wish to employ this technique.

It was anticipated that the Hygrosticks, by measuring the moisture content of a pocket of air within a hole formed in the wall surface rather than through direct measurement of the masonry, would mitigate the effect of hygroscopic salt contamination. At the same time, however, it was expected that problems of accuracy would result if the equilibrium relative humidity of this pocket of air was used to compare values. This is because relative humidity, as a function of temperature, is affected by temperature changes that may not necessarily be related to variations in the moisture content of the surrounding masonry. To work around this problem, relative humidity and temperature data pair sets were to be converted to vapour pressure on the basis that this technique would effectively overcome this limitation. Surprisingly, this was not found to be the case.

An important finding of this study was for both the relative humidity and vapour pressure of the pocket of air measured by the Hygrosticks to be driven by the external conditions. Furthermore, in regions of the test panels where the capillary moisture content was low, changes in the values recorded by the Hygrosticks were solely a result

of the external environment rather than an accurate indication of the moisture content of the surrounding masonry.

Electronic thermo-hygrometers are used to measure moisture in masonry, to a lesser extent with respect to walls but more commonly in solid floors. That these instruments demonstrate a strong correlation with the external environment that may be independent of their local environment is a significant finding. Furthermore, as was described in Chapter 4, substantial problems with respect to calibration drift were found to affect the Hygrosticks used in this project. Together, these matters suggest that practitioners who make use of electronic thermo-hygrometers to assess moisture in masonry materials need to consider precisely what is being measured and ensure that they employ a robust calibration checking protocol.

This discussion concludes this chapter. Chapter 9, which follows, provides conclusions and the unique claims to knowledge arising from the research findings.

Chapter 9

Conclusions and Contributions to Knowledge

9.1. Introduction

The impetus for this research project stemmed from criticisms levied at the damp proofing industry and of the phenomenon and treatment of rising damp; criticisms that in Chapter 1 were categorised, respectively, as soft and hard. Those in the soft-domain concerning the damp proofing specialist's knowledge, skill, ability, and integrity and those in the hard-domain the mechanics of rising damp, the usefulness of the instruments used to diagnose it, and the effectiveness of chemical injection damp proofing treatments. This study has focussed on these hard-domain concerns, which are encapsulated in the project's research aim:

> To establish whether contemporary remedial damp proof course treatments are (a) necessary and (b) effective and (c) if evaporation from damp masonry affects moisture in the environment.

To inform this primary aim, the project had two operational and four research objectives:

Operational objectives:

1. Develop a research methodology.

2. Evaluate the effectiveness of common and novel methods of moisture measurement.

Research objectives:

3. Examine the history and science of rising damp.

4. Determine the existence of rising damp.

5. Determine the effect that contemporary remedial damp proof course treatment has on the moisture in a wall affected by rising damp.

6. Determine if moisture in the environment and moisture in damp walls is correlated.

The final chapter of this thesis will comprise two parts. The first part considers each of the six objectives and, through this discussion, how they have been met and given their role with respect to the research aim how the questions posed have been answered. The second part will make explicit the unique claims to knowledge required of this doctoral level research project.

9.2. Objective 1: to develop a research methodology

The methodology employed for this research project combined case study and quasi-experimental methods. This dual methodology and the protocols adopted to assess the house, determine that rising damp was occurring, to set up each of the test panels, to apply treatments, and to measure and monitor moisture change were intended to reflect the practice-based nature of this project and in so doing to make the methods accessible to other building surveyors and therefore easy to replicate.

It is contended that this objective has been met through the techniques used. This thesis essentially comprises a manual to inform this and similar projects and thus to add to the body of academic and practice knowledge. However, this is not to imply that everything went well, that there were no issues, or that improvements could not be made.

In earlier chapters, problems encountered with respect to the Timber Probes Type 1 and the Protimeter Hygrosticks have been described and recommendations to mitigate these issues provided. For example, through the use of the plain timber dowels in preference to the more complex Type 1 probes—the dowels enabling periodic replacement to mitigate the effect of hygroscopic contamination and removing any doubt as to what is being measured—and a protocol to facilitate monitoring of the Protimeter Hygrosticks to detect calibration drift.

The fundamental concept, that of sourcing a suitable house, establishing rising damp, allocating the component parts of the damp proof course treatment to individual test panels, and determining the panels' base moisture content and ultimately their final moisture content through gravimetric analyses, achieved all that was expected of this project. There is, however, one fundamental change that could be made to simplify future studies and reduce both the time involved with data collection and the overall costs, and that is to limit the extent of the moisture measuring apparatus.

For moisture profiling carried out at Stage 2, seven rows of samples were removed from each panel's location. The lowest samples were taken from a vertical position corresponding with the bottom four brick courses and the remaining three samples from every other brick course above. The topmost sample was located at a height of 750 mm above floor level.

Subsequent, gravimetric moisture analyses revealed that capillary moisture essentially affected the bottom three brick courses. Elevated hygroscopic moisture was found to be restricted to the bottom four brick course in both the masonry and plaster, with the exception of Panels A and B where it was high in the plaster in all of the samples tested.

Taking account of the above data in designing the configuration of the moisture measuring apparatus, it was apparent that the bottom four brick courses had to be monitored; furthermore, because the application of low-permeability render to Panel B

was envisaged to test if the render caused capillary moisture present in the wall to rise upwards, measurement equipment was required in the brick courses above the fourth. At that stage it was not known how high moisture may rise; ultimately, the decision was to install monitoring equipment in the fifth, sixth, and seventh brick courses and these became the panel rows 1-7, described in earlier chapters.

What the results of the fifteen-month monitoring period determined was that capillary moisture changes in Panels A and C, into which the damp proofing cream was installed, essentially occurred in rows 1-3. In addition, there was no apparent increase, with respect to magnitude or height, in the capillary moisture content of Panel B, despite the application of low-permeability cement render to a wall part that was known to contain this form of moisture.

The data from the Protimeter Hygrosticks did show a generalised distribution of relative humidity and temperature over the full height of each of the seven rows, which was an interesting outcome, but this effect would have been apparent if, say, Hygrosticks had only been installed in the bottom five brick courses. In all other respects, data from rows 6 and 7, and arguably from row 5, were essentially redundant.

For these reasons, and particularly if costs were a concern, it would be feasible to limit the equipment used in future studies to five rows (i.e. to one or two brick courses above significant masonry capillary or hygroscopic moisture). Given the results found, this would still provide an adequate margin to identify moisture change and, if discovered to take place, to establish if the application of low-permeability cement render to a damp wall causes capillary moisture to rise upwards.

Despite these recommendations, the methodology developed essentially served its intended purpose in facilitating this study and, consequently, objective 1 has been met.

9.3. Objective 2: to evaluate the effectiveness of common and novel methods of moisture measurement

Electronic moisture meters such as the Protimeter MMS and Surveymaster meters used in this project are essentially calibrated for use on timber and therefore readings obtained from masonry, plaster, and other inorganic building materials can only be considered relatively (i.e. they do not provide quantitative values). Furthermore, this type of meter functions by measuring electrical resistance and therefore responds to any form of moisture or any electrical conducting substance that is present in the material under test. It is for these reasons that a criticism levied with respect to the diagnosis of rising damp is that far too much reliance is placed on the readings of an electronic moisture meter and that subsequent misdiagnosis results in the undertaking of unnecessary remedial damp proof course work.

Arguably, practitioner's that make use of electronic moisture meters are aware of their limitations, and in the majority of cases high readings returned from an electronic moisture meter when testing masonry materials typically indicates that dampness is present; nevertheless, precisely how accurate these meters and other methods may be in measuring moisture in masonry materials was the intention of this second objective.

Five methods of moisture measurement were evaluated to test their effectiveness in measuring the effects of the applied damp proofing treatments:

1. Protimeter measure-mode function using the Heavy Duty Probe (to obtain readings from the panels' surface).

2. Protimeter measure-mode function using the Deep Wall Probes (to obtain readings from the underlying masonry of the panels).

3. Protimeter search-mode function.

4. Timber Probes Type 1 read using the Protimeter measure-mode function.

5. Plain timber dowels read using the Protimeter measure-mode function.

6. Protimeter Hygrosticks.

9.3.1. Protimeter measure-mode and search-mode functions

This study found that both the Protimeter measure-mode function, however it is applied (i.e. directly on plaster or brickwork or the timber probes), and the Protimeter search-mode function are confounded when the materials under test have high hygroscopic moisture contents.

Given that plasterwork and masonry wall parts affected by rising damp will inevitably become contaminated with hygroscopic salts of nitrates and chlorides, technically, the electronic moisture meter cannot be reliably used to assess rising damp or moisture change following the insertion of a damp proof course: hygroscopic contamination inevitably results in high readings irrespective of the capillary moisture content of the material under test.

Removing and replacing hygroscopic salt contaminated plasterwork with low-permeability cement render, finished with a coat of plaster, effectively separated the panel's surface from the underlying masonry walls. Therefore, despite the continued presence of capillary moisture and hygroscopic moisture in the wall, this moisture was not detectable on the panel's surface using the Protimeter measure-mode function with the Heavy Duty Probes nor was it detectable in the underlying masonry wall using the Protimeter search-mode function.

What this means in practice is that low Protimeter readings, using either function, indicate that the surface of the material under test contains neither capillary moisture nor hygroscopic moisture; however, it cannot confirm that the underlying masonry wall may not be affected by such moisture. Furthermore, high readings from an electronic moisture meter do not necessarily infer that a wall is wet in the sense that it contains

capillary moisture because such high readings may simply result from hygroscopic contamination.

If it is considered that hygroscopic contamination resulting from the upward migration of soil salts will always be a consequence of rising damp, then high readings recorded by an electronic moisture meter are meaningful; they may not provide a definitive diagnosis of rising damp, but in the absence of other obvious causes, they imply that further investigation is required.

9.3.2. Timber Probes Type 1 and plain timber dowels

Because Timber Probes Type 1 and plain timber dowels are read using the Protimeter measure-mode function they are affected by the limitations of this meter outlined in the previous section and described in detail in Chapter 7; therefore, further comment is not provided in this respect. However, constructed of timber and a relatively porous material, both of these dowel methods are susceptible to fungal decay and contamination from hygroscopic salts, resulting from long term contact with damp and contaminated masonry, respectively. Yet, the plain timber dowels potentially offer a method to mitigate these concerns.

Unfortunately, the plain timber dowels were a late addition to the study, and therefore, were not fully evaluated in the sense that at least some drying following the installation of the damp proofing cream was assumed to have occurred. Nevertheless, their design offers a number of advantages over the Timber Probes Type 1: they are extremely cheap, simple to operate, and the method used to obtain measure-mode values provides built-in validity. It is, however, this ease of removal from the wall that provides the plain timber dowels with the potential to mitigate the effects of hygroscopic salts and of decay because they can, technically, be periodically replaced.

A useful and interesting exercise would see an experiment of this type repeated with plain timber dowels installed from the outset but using two sets per panel: one set to remain in place over the duration of the monitoring period and the second set to be removed and replaced periodically; subsequent, analyses would determine the viability of this technique as an effective method of measuring and monitoring moisture.

9.3.3. Protimeter Hygrosticks

Electronic thermo-hygrometers such as the Protimeter Hygrosticks have been employed as a method to monitor moisture change in masonry walls by measuring the equilibrium relative humidity of a pocket of air into which they are inserted. At the outset, concerns were raised over this method because relative humidity is a function of temperature and thus is a property that changes in response to temperature fluctuations; however, this anomaly can, technically, be mitigated by converting temperature and relative humidity data pairs to vapour pressures.

Both the equilibrium relative humidity and vapour pressure methods were used in this study. Although it had been expected that vapour pressure monitoring would be a more accurate indicator of both moisture content and the trend of moisture change, this was not found to be the case. Both techniques were flawed in that they simply responded to changes in the external environment. Furthermore, the Hygrosticks were affected by significant equipment failure; so, what seemed on paper to be an interesting and novel method of moisture measurement, ultimately proved to be unreliable.

Despite this outcome, the Hygrosticks did provide some interesting data with respect to the relative humidity, vapour pressure, and temperature distribution over the height of the panels. Perhaps, unsurprisingly, the temperatures tended to follow the trend of the air inside the house; however, the wall parts forming the bases of the test panels were consistently around 1.5-2.0°C lower than the temperature of the panels' upper parts. Similarly, relative humidity and vapour pressures were higher at the base of the panels

than they were at the top, independently of any moisture that these wall parts contained.

Given that the panels comprised of internal walls, this was a surprising find and implies that under conditions of high vapour pressure, condensation could form on the wall bases.

The effectiveness of each component of the moisture measuring apparatus was evaluated. In this sense, objective 2 has been satisfied; nevertheless, the study identified flaws, some of which were to be expected and others that were not. Ultimately, the only reliable method of diagnosing rising damp is by way of sample analyses; yet, despite their shortfalls and limitations, other, less invasive methods, may provide useful data.

9.4. Objective 3: to examine the history and science of rising damp

In Chapter 1, the criticisms with regard to the history and science of rising damp were identified; namely, that the Public Health Act 1875 did not require the mandatory installation of damp proof courses in houses; that the term rising damp was not in common usage until the mid-twentieth century; and that the explanations for and therefore the mechanism of capillary action as a cause of rising damp in buildings is unsatisfactory, particularly given the opposing effects of gravity.

Chapter 2, a literature review, approached these issues through an examination of the history and science of rising damp. Thus, in undertaking this review, objective 3 has essentially been satisfied and its findings are summarised as follows.

The Public Health Act 1875 did not make any direct mention of either rising damp or damp proof courses and, therefore, did not require the mandatory installation of the latter; instead, this was dealt with through local government by-laws.

By the mid-nineteenth century, rising damp was a mechanism known to cause dampness in buildings that could be alleviated through the installation of damp proof courses.

The theory underpinning capillary action as a mechanism that enables rising damp to occur in masonry walls is compelling. The size of individual pores in brick, stone, and mortar materials is sufficiently narrow to support significant capillary rise height. It is this pore size, typically 0.001 mm in building materials, that enables capillary forces to overcome the effects of gravity, which can largely be ignored.

The movement of moisture in masonry by capillary action is complex, however, and sorptivity, the property of a material to absorb and desorb water, is increasingly being used to describe this mechanism. The Sharp Front model, which employs the sorptivity property, aligns well with real world examples of rising damp.

Rather ironically, as well as providing answers, the literature review identified a number of additional concerns with respect to the methods used to create rising damp in laboratory research, to test chemical injection damp proof courses, and in the effects of evaporation.

Rising damp does not readily affect new construction: it is said to occur in the masonry walls of older buildings because they become more sorptive with age. Therefore, to create rising damp in a laboratory, test pillars are required to be constructed using highly sorptive mortars that are argued to mimic the aged walls of older buildings. In the UK, this method of testing is described in MOAT No. 39 (BBA, 1988); however, all rising damp research, whether based in the UK or overseas, typically employs this high sorptivity test pillar method. In addition, test pillars are inevitably placed into trays of liquid water to encourage rising damp to take place; for some research projects, this wetting process has been carried out after the damp proof course chemicals have been inserted into the test apparatus.

The concerns raised with respect to these methods is that they are not replicating the walls of actual buildings nor the conditions in which these walls become damp. Furthermore, although significant research has been carried out overseas, for example in Italy, these studies employ materials dissimilar to those used for the construction of UK houses and, more importantly, their climates differ. Evaporation is the most significant factor with respect to the height to which rising damp can climb and, because climatic conditions strongly influence evaporation, warmer climates do not match conditions to which UK buildings are exposed.

Opinions regarding evaporation and the effect that moisture evaporating from a wall affected by rising damp may have on the environment differs among researchers: some argue it is significant and others that it is not. In fact, it was this opposing view and the desire to learn more about the process of evaporation from damp masonry that prompted the inclusion of a specific research objective to investigate the correlation between moisture in the environment and moisture in a damp wall.

But perhaps one of the most pressing concerns is the type of damp proof course chemicals that have been tested and the methods employed for this purpose. Since the beginning of the twenty-first century, fluid-based chemical injection damp proof course methods have essentially been replaced with damp proofing creams. Little research has been undertaken on the effectiveness of these creams. In addition, the MOAT 39 testing procedure was designed for damp proofing fluids and doubts have been expressed with respect to its appropriateness for the evaluation of contemporary damp proofing creams.

9.5. Objective 4: to determine the existence of rising damp

Determining the existence of rising damp or, more specifically, establishing beyond reasonable doubt that rising damp affected the wall parts that had been used for the five test panels was an essential objective of this research. If rising damp was proven to

be occurring then damp proofing treatments would be justified and therefore a necessary intervention, thus fulfilling the first part of the research aim. And only if rising damp was occurring in each of the five test panels could the results of applying treatments be confidently accepted. Thus this objective was an essential pre-requisite in the evaluation of treatments.

The visible appearance of dampness affecting the ground floor walls of the house and the pattern of Protimeter measure-mode readings recorded on them was consistent of rising damp and the Sharp Front model. Yet, for the reasons outlined in earlier chapters, neither the visible appearance of dampness nor high Protimeter readings can be relied upon as definitive proof of rising damp. To confirm this form of moisture, several distinct stages of investigation were implemented.

Firstly, a thorough survey of the house was undertaken to systematically eliminate all sources of moisture other than 'true' rising damp; that is, the rise of moisture from the ground by capillary action into the bases of the ground floor walls. This first step was essential because it was entirely possible that symptoms of rising damp, even if confirmed, could be caused by other factors; for example, through water leaking from plumbing services or specific site conditions such as bridging, as described in Chapter 4. In practice, the survey found that the dampness could not easily be accounted for other than as a result of rising damp.

The second step was to undertake initial moisture analysis using the gravimetric method described in BRE Digest 245 to confirm that excessive capillary moisture was present in the bases of the ground floor walls. At this juncture, even though dampness was present, it was possible that it could be comprised solely of hygroscopic moisture. This Stage 1 moisture analysis confirmed that capillary moisture (i.e. moisture affecting the wall parts in excess of their hygroscopic moisture contest) was indeed present.

Step three, the Stage 2 analyses, involved more comprehensive moisture profiling, whereby a column of masonry and plaster samples were removed from each of the five test panels and processed using the gravimetric analysis method to determine their hygroscopic and capillary moisture contents and to determine if the distribution of these two forms of moisture over the height of the sample column aligned with the rising damp model. For all five panels, this was confirmed to be true.

Principally, there seemed little doubt that rising damp was the cause of the dampness; however, a further test was carried out to support this diagnosis. Hygroscopic salts of nitrates or chlorides present in the ground would be expected to affect walls that have been subject to long term rising damp; indeed, these salts typically account for the elevated hygroscopicity of affected plaster and masonry parts. Thus, a simple salts test was undertaken using Quantofix test strips to determine if nitrates were present in the row four samples of each of the five test panels; the position of this fourth row corresponding with the highest point of the damp rise and therefore the region with the highest concentration of hygroscopic salts. All five salts tests were positive for nitrate contamination and because nitrates are not typically found in construction materials, rising damp provided a reason for their presence.

Given these results, there was no explanation other than rising damp as the source of moisture affecting the ground floor walls and therefore those parts of these walls that were used for the five test panels in this study. However, if further proof were needed, subsequent Stage 3 gravimetric analyses, undertaken when the moisture measuring apparatus was installed in the test panels, provided the same profile of capillary moisture versus hygroscopic moisture, and thus alignment with the rising damp model, as that determined at Stage 2.

It is concluded that if rising damp affects the test panels and thus the ground floor walls of the house, by extension, it must be a phenomenon that actually occurs in buildings, and, therefore, objective 4 has been satisfied.

9.6. Objective 5: to determine the effect that contemporary remedial damp proof course treatment has on the moisture in a wall affected by rising damp

Satisfying the research aim involved two distinct operations: firstly, to establish as far as practicable that the walls of the project's house, or more specifically those walls forming five individual test panels, were affected by rising damp and, secondly, to apply and evaluate the effect of contemporary remedial damp proof course treatments. The former operation was met through objective 4, discussed in the previous section, the latter operation is described in this section.

Evaluation of the damp proofing treatments involved accurately measuring the moisture content of the masonry component of each of the five test panels at the start and end of the fifteen-month monitoring phase, using the gravimetric method. The monitoring period was of sufficient length to enable the effect of treatments, and therefore any changes to the panels' moisture contents, to be identified.

Contemporary remedial damp proof course treatment is not a single process; instead, there are two distinct parts involved: one is the installation of a damp proofing cream that is intended to control rising damp; the second is the removal of plaster and its replacement using a low-permeability cement render and finishing coat of plaster, a procedure required to control residual moisture and hygroscopic salts that remain present in the underlying masonry walls.

A criticism levied at this two-part treatment method is that it is the low-permeability render rather than the damp proof course itself that provides the damp proofing effect. In other words, that a dry surface can be achieved through the application of the render despite significant moisture remaining in the underlying masonry wall. Furthermore, by inhibiting evaporation through the application of low-permeability render, a material

that can resist the passage of moisture under positive pressure, that water present in the underlying masonry wall is forced to rise higher.

Testing the effects of these two processes at the same time had the prospect of causing confusion as to what precisely had provided any damp proofing effect. Although, in practice, a reduction of capillary moisture in the underlying masonry wall would suggest that rising damp had been controlled and therefore that the damp proofing cream had been effective; conversely, despite the low-permeability render providing a dry surface, were rising damp not controlled, capillary moisture in the masonry wall would remain high.

Nevertheless, to determine the effect of the remedial damp proof course treatment while at the same time providing clarity, not only was this method tested as its intended two-part system, but each of the two components parts was evaluated independently through the allocation of treatments that were both complimentary but differed for each of the five test panels:

1. Panel A was drilled and the damp proofing cream installed but its plaster was not replaced.

2. Panel B was stripped of its existing plaster and reinstated with the low-permeability cement render and plaster finish coat but the damp proofing cream was not installed nor were holes drilled to facilitate installation.

3. Panel C had both the damp proofing cream installed and its plaster removed and reinstated with the low-permeability cement render and plaster finish coat.

4. Panel D was drilled using the pattern necessary to install the damp proofing cream but the cream was not installed and its existing plaster was not replaced.

5. Panel E received no treatments.

Thus Panel E was the control against which the other panels were compared; Panel D tested the effects on rising damp of the drilling pattern of an injected damp proof course without the installation of the cream; Panel A tested the effects on rising damp of installing the damp proofing cream without the second, low-permeability render part of the process; Panel B tested the effect of simply applying the low-permeability render without any attempt to control rising damp; and Panel C tested the effect of the full two-part system: damp proofing cream and low-permeability render.

The study found as follows:

1. Panel A: the installation of the damp proofing cream reduced capillary moisture in the wall base, thereby providing control of rising damp; however, damp associated with hygroscopic moisture continued to affect the panel, essentially because the existing, contaminated plasterwork was not removed and replaced.

2. Panel B: following evaporation of construction moisture, the surface of the new plaster finish coat that had been applied to the underlying low-permeability render became dry (i.e. it contained no significant quantities of capillary or hygroscopic moisture) and remained dry for the remainder of the monitoring period; however, capillary and hygroscopic moisture present in the underlying masonry wall was unchanged. Thus, the application of low-permeability render to a wall affected by rising damp did provide excellent control, in the sense that the wall surface was apparently free of moisture, and over the fifteen-month monitoring period the height attained by rising damp (i.e. its capillary moisture) in the masonry wall did not increase.

3. Panel C: the installation of the damp proofing cream reduced capillary moisture in the wall base, thereby providing control of rising damp; in addition, following

evaporation of construction moisture, the surface of the new plaster finish coat that had been applied to the underlying low-permeability render, became dry (i.e. contained no significant quantities of capillary or hygroscopic moisture) and remained dry for the remainder of the monitoring period. In effect, Panel C achieved precisely the result claimed by the manufacturers' of the damp proofing systems: the low-permeability render providing an early damp proofing effect (i.e. the wall surface was to all intents and purposes free of damp once construction moisture had evaporated) and, overtime, the capillary moisture in the underlying masonry wall (rising damp) reduced; furthermore, the low-permeability render effectively controlled residual capillary moisture during the drying phase and hygroscopic moisture present in the underlying masonry wall over the fifteen-month monitoring period.

4. Panel D: the capillary and hygroscopic moisture content remained unchanged over the monitoring period; the drilling pattern required for the installation of the damp proofing cream, in isolation, had no controlling effect over rising damp.

5. Panel E: the capillary and hygroscopic moisture content remained unchanged over the monitoring period. This was to be expected of an untreated panel used for the control.

Thus, the foregoing satisfies objective 5.

9.7. Objective 6: to determine if moisture in the environment and moisture in damp walls is correlated

To test for correlation of environmental and atmospheric moisture, Lascar data loggers were mounted on the face of each of the five test panels between rows 2 and 3 of the moisture measuring apparatus, a vertical position corresponding with the damp region at the base of the walls.

The theory was that moisture evaporating from the panels' bases would be reflected by an increase in the vapour pressure of the air at their boundary layer and therefore detectable by the Lascar data loggers. Furthermore, that the low-permeability cement render applied to Panels B and C would restrict evaporation and that the effect of the damp proofing cream installed in Panels A and C, and which had been found to lower the capillary moisture content, would cause their boundary layer vapour pressures to differ from those recorded by the Lascar data loggers on Panels D and E.

In actuality, neither the application of low-permeability render nor the installation of the damp proofing cream made any difference to the boundary layer vapour pressures. Instead, not only were these vapour pressures well correlated across all five test panels but along with the vapour pressure of the air in the houses' living room, measured by the sixth Lascar data logger, they simply followed the trend of the external environment. In other words, the external vapour pressure dictated the movement of the internal vapour pressures independently of moisture evaporating from the test panels; in practice, such evaporation, if occurring at all, could not be measured by the equipment used in this study.

Environmental moisture is absorbed by porous materials and given that the original plasterwork and the masonry parts comprising the test panels were known to be contaminated with hygroscopic salts, this environmental moisture (i.e. its vapour pressure) had the potential to increase the hygroscopic moisture content of the panels.

Indeed, this effect was apparent through Protimeter measure-mode readings obtained from the Timber Probes Type 1 and the plain timber dowels that increased over time. On removal from the panels and following subsequent analyses, these probes and dowels were found to have elevated hygroscopicity caused by migration of hygroscopic salts present in the masonry into which they had been inserted. Thus, there is, technically, the capacity for environmental moisture to increase the moisture content of a masonry wall. Nevertheless, this change only affects the hygroscopic moisture

content; the data did not indicate that environmental moisture had any effect on the capillary moisture content of the test panels.

As noted in the previous section, data from the Protimeter Hygrosticks showed that moisture changes they detected simply reflected changes to the external vapour pressures. And although it was concluded that the air temperature, which had been determined by the Hygrosticks to be consistently up to 2.0°C higher at the top in comparison to the bottom of the test panels, could theoretically enable condensation to affect their bases, there were no indications that condensate had actually formed on these parts.

Therefore, this study found no correlation between environmental moisture and capillary moisture and, specifically, that evaporation of moisture from a damp wall causes changes to the vapour pressure of the surrounding air. It did, however, find a correlation between environmental moisture and hygroscopic moisture, and although, technically, the vapour pressure of the air in the living room is correlated with the vapour pressure of the test panels, in practice, both are driven by the external environment. In arriving at this conclusion, objective 6 has been met.

9.8. Meeting the research aims

This study established that rising damp did indeed affect the ground floor walls of an actual house. Given that rising damp is known to cause damage and lead to fungal decay and deterioration, it therefore warrants treatment. For this reason, it can be concluded that damp proofing treatments are necessary.

The study subsequently found that installing a damp proofing cream into a wall affected by rising damp without removing plaster contaminated with hygroscopic salts did not achieve a practical damp proofing effect; conversely, it determined that removing contaminated plaster and replacing it with a low-permeability cement render and a

finish coat of plaster provided an apparently dry wall surface, despite rising damp continuing to affect the underlying masonry wall. However, installing a damp proofing cream and removing contaminated plasterwork and replacing it with low-permeability cement render and a finish coat of plaster (i.e. undertaking the two-part process that comprises contemporary chemical injection damp proof course treatment) both effectively controlled rising damp and, following evaporation of construction moisture, delivered a dry wall surface despite residual moisture persisting in the underlying masonry wall until completion of the drying phase and the continued presence in this masonry of hygroscopic salts. Thus the two-part system of contemporary damp proofing treatment provided optimum results.

Finally, the study found that evaporation from a wall affected by rising damp cannot be measured and although there is correlation between environmental moisture and hygroscopic moisture, capillary moisture present in a damp affected masonry wall has no perceivable effect on moisture in the adjacent environment.

This project had three connected research aims:

> To establish whether contemporary remedial damp proof course treatments are (a) necessary (b) effective and (c) if evaporation from damp masonry affects moisture in the environment.

With respect to these aims, and given the findings, the following conclusions are drawn:

> (a) Rising damp exists and therefore damp proof course treatments are necessary;

> (b) Contemporary remedial damp proof course treatments provide satisfactory control of rising damp and thus are an effective method of treatment;

(c)   Evaporation from masonry affected by rising damp does not impact on the moisture content of the adjacent environment.

9.9. Unique claims to knowledge

At the start of this project, the shortfalls of prior research were identified; namely, that they inevitably make use of test pillars constructed of highly porous mortars that are placed in tanks of water to replicate the conditions of rising damp; furthermore, that not only are contemporary damp proofing creams under-researched but the testing method, MOAT 39, is currently under review with respect to its appropriateness, having being designed for the now outdated fluid-based damp proof course systems.

It is the practical aspect of this project that sets it apart from prior research and in so doing makes it unique and enables it to make a meaningful contribution to both existing academic literature and practice.

Fundamentally, this study has achieved its primary aim: firstly, to show that rising damp did indeed affect the walls of an actual house and, secondly, to test the effectiveness of the contemporary method of remedial damp proof course treatment, not on meticulously constructed highly sorptive test walls but on the actual aged walls of a house with their inherent variability, nuances of construction, and in a real world setting.

The study found that evaporation at the boundary layer of walls affected by rising damp, which the literature suggests is a significant factor with respect to the height that it attains, is not significant. In practice, evaporation from the wall surface, whether comprised of exposed brick, original contaminated plasterwork, or newly applied low-permeability render, could neither be measured nor did this moisture contribute to the moisture content of the surrounding air.

On a related matter, although environmental moisture was determined to be correlated with the hygroscopic moisture content of the panels, a fact that is not surprising given the nature of hygroscopic materials to absorb moisture directly from the air, capillary moisture associated with rising damp was found not to be correlated with moisture in the environment. Given the importance of evaporation, that it is reported to be under-researched, and of the magnitude of potential evaporation rates claimed in prior studies, these are important findings.

An additional discovery with respect to environmental moisture was for the vapour pressure, and by extension the relative humidity, of pockets of air in a masonry wall, and changes that take place to those properties of that air, to be driven by the vapour pressure of the wider, external environment. Given that equilibrium relative humidity is a method used to measure moisture in solid floors and has been adopted to measure moisture in masonry walls, this finding, which at worst suggests that caution is required when considering the data recorded by hygrometers and, at worst that the method is flawed, is significant.

The uniqueness of the study extends beyond its novelty, because uniqueness also applies to the findings. This was a case study undertaken in a traditional Victorian terrace house of brick construction. There are many hundreds of thousands of such houses located throughout the United Kingdom; however, it is not possible to know that its construction, specific site conditions, and localised environmental factors will be representative of these conditions in other properties. Furthermore, the limitations of a field study are acknowledged, particularly with respect to controls that can applied in a laboratory setting but are far more difficult to achieve in the real world. It is for these reasons that no generalizable claims are made. Instead, it is only contended that the results found, conclusions drawn, and claims made are valid for this research project.

Despite this apparent non-generalisability, the unique quasi-experimental case study methodology, the techniques used to configure the test panels and to allocate

treatment methods, and the moisture measuring techniques employed have been shown to be successful and may be easily replicated by other researchers. It is this methodology and the research design that is the final claim to knowledge. Additionally, in evaluating and validating the contemporary remedial damp proof course method, the project makes a contribution to practice by providing valuable reassurance to property professionals, home owners, and other stakeholders with respect to the phenomenon and treatment of rising damp in houses.

9.10. Closing comments

Although the idea for this project arose from criticisms levied at the damp proofing industry, its methodology and methods were informed through perceived shortfalls in laboratory research, and, after identifying this knowledge gap, by undertaking a quasi-experimental case study in a field setting to provide answers to the research questions posed.

The quasi-experiment was carefully constructed to not only assess the contemporary method of remedial damp proof course treatment but also the component parts of this system, common and novel methods of moisture measurement, and correlation of moisture in the damp walls and in the environment. In keeping with its practical aspect, this field work was undertaken in the setting of an actual house and only employed methods that were purposely intended to be readily available to general building surveyors and other researchers who may wish to replicate this or a similar study.

During the course of the project a number of problems were encountered that included unexpected failures of the Protimeter Hygrosticks, certain issues with respect to the functioning of the Protimeter and timber probes, and unintended occurrences such as the malfunction of the house's central heating system and periods when it was vacant. However, in all of these situations a solution consistent with the practical nature of this

study was found. On reflection, I have no regrets with respect to the project's design, implementation and, importantly, its outcomes.

If I am critical, however, I do recognise the limitations of this study: it was, after all restricted to a single house of a particular type and occupation. Nevertheless, this is not to imply that the findings are not useful to practice in a wider sense. Indeed, that rising damp was proven to exist in an actual house and is effectively remedied using the contemporary method of damp proof course treatment provides credibility to both the phenomenon and treatment of rising damp under real world conditions. In addition, the study yielded interesting findings and, perhaps more importantly, shortfalls in the use of timber probes, plain timber dowels, and electronic thermo-hygrometers (e.g. Protimeter Hygrosticks) as methods for measuring moisture in masonry materials.

Ultimately, the findings of this project provide both valuable feedback and useful reassurance to the damp proofing industry, the wider surveying profession, and other who have an interest in dampness in buildings. Despite this, it is does not provide all the answers. Rising damp was confirmed to be occurring in the walls of the case study house, but how prevalent this form of dampness may be across the wider housing stock remains unanswered. Furthermore, although the applied damp proofing treatment was effective in alleviating rising damp, only one type of damp proofing cream, installed in a brick wall, was tested; how would other manufacturers' creams perform and how effective are these creams in other forms of masonry construction such as stone?

Logical action is to recommend the replication of this study in other houses of both similar and differing construction and to undertake tests using a variety of damp proofing creams. Clearly, care is needed with this strategy because variable house types (i.e. that differ in construction and age) and differences in occupation—a family produces far more environmental moisture than a single occupant—introduces potential confounds. These conditions would have to be accounted for if valid comparisons are to be made. Yet, the idea of repeating this study is appealing and

experience gained from this project suggests that it could arguably have a simplified design.

For example, the findings suggest that treatment type 2—simply drilling holes in a horizontal mortar bed joint without installing the damp proofing cream—and, indeed, treatment type 3—installing the damp proofing cream without replacing the plaster may be omitted; therefore, a more concise design using test panels for control (treatment type 1), low-permeability render only (treatment type 4), and damp proofing cream installation and low-permeability render (treatment type 5) would simplify future studies. In addition, omitting rows of moisture measuring equipment in the panels' upper rows, where they are essentially redundant, would further help to provide a less complex set up while maintaining the robustness inherent in the original design. Thus, by applying moderate changes, there is excellent potential to further add to the existing body of knowledge with respect to the phenomenon and treatment of rising damp in houses.

This project has endeavoured to adopt the 'epistemology of practice' (Schön, 1991, p. 287) to create what is hoped is a noteworthy and interesting piece of work. Schön (1991, p. 68) suggests that "in each instance, the practitioner allows himself to experience surprise, puzzlement, or confusion in a situation which he finds uncertain or unique. He reflects on the phenomena before him, and on the prior understandings which have been implicit in his behaviour. He carries out an experiment which serves to generate both a new understanding of the phenomena and a change in the situation." It is through exemplars that unfamiliar situations may be informed (Schön, 1991, p. 138).

Earlier, in Chapter 3, it was suggested that by closely examining all significant factors, using appropriate and robust evidence, and considering alternatives explanations that this project would produce an exemplar. Given the methodology employed, the results achieved, and in satisfying all six research objectives and the project's research aims, it is hoped that this goal has been met.

References

Alasuutari, P., Bickman, L., & Brannen, J. (2008). *The SAGE handbook of social research methods*. Los Angeles, Calif. ; London: SAGE.

Alfano, G., Chiancarella, C., Cirillo, E., et al. (2006). Long-term performance of chemical damp-proof courses: Twelve years of laboratory testing. *Building and Environment, 41* (8), 1060-1069.

Amphenol Advanced Sensors. (2014). Protimeter Speedy user instructions: Amphenol Advanced Sensors.

Ashurst, N. (1990). Understanding dampness in historic buildings. *Structural Survey, 8* (3), 268 - 277.

Bagg, J. (2006). Rising damp in historic buildings, *Context* (Vol. 95, pp. 48). Kent: Institution of Historic Building Conservation. Retrieved. Available from http://www.ihbconline.co.uk/context/95/#/22/
http://www.ihbc.org.uk/context_archive/95/bagg/julian.htm

BBA. (1988). Method of assessment and testing. MOAT 39: 1988. Assessment of damp-proof course systems for existing buildings (pp. 13). Watford: British Board of Agrement.

BBA. (2014, 20 October 2014). BBA Statement On Chemical Damp-Proofing Creams: 4 April 2014.   Retrieved, 12 March 2017, from http://www.bbacerts.co.uk/wpfb-file/bba-statement-on-chemical-damp-proofing-creams-pdf/

BBC. (1999a). Raising the roof: rising damp 1. London: British Broadcasting Corporation.

BBC. (1999b). Raising the roof: rising damp 2. London: British Broadcasting Corporation.

BBC. (2011). QI : The rising damp myth. London: British Broadcasting Corporation.

Beck, K., Al-Mukhtar, M., Rozenbaum, O., et al. (2003). Characterization, water transfer properties and deterioration in tuffeau: building material in the Loire valley--France. *Building and Environment, 38* (9-10), 1151-1162.

BRE. (1997). *Diagnosing the cause of dampness. Good Repair Guide 5*. Watford: Construction Research Communications Ltd.

BRE Housing Defects Action Unit. (1986). Defect Action Sheet 86: Brick walls: replastering following dpc injection. Watford: Building Research Establishment.

British Medical Journal. (1872). Damp houses. *The British Medical Journal* (25 May 1872), 558-559.

British Medical Journal. (1875). Forty-Third Annual Meeting of the British Medical Association. *The British Medical Journal* (28 August 1875), 257-279.

British Medical Journal. (1878). Important Metropolitan By-laws. *The British Medical Journal* (23 November 1878), 772-783.

British Medical Journal. (1895). Local Government (Scotland) Bill. *The British Medical Journal* (25 May 1895), 1161-1162.

British Standards Institution. (1985). British Standard Code of practice for Installation of chemical damp-proof courses, *BS 6576 : 1985* (pp. 12). London: British Standard Institution.

British Standards Institution. (1991). Code of practice for design and installation of damp-proof courses in masonry construction, *BS 8215:1991* (pp. 20). London: BSI.

British Standards Institution. (2005). Code of practice for diagnosis of rising damp in walls of buildings and installation of chemical damp-proof courses, *BS 6576:2005* (pp. 18). London: BSI.

BSI. (1984). BS 6515:1984 Specification for polyethylene damp-proof courses for masonry, *BS 6515:1984* (pp. 12). London: BSI.

BSI. (1991). BS 8215:1991 Code of practice for design and installation of damp-proof courses in masonry construction, *BS 8215:1991* (pp. 20). London: BSI.

BSI. (2002). BS 5250:2002 Code of practice for control of condensation in buildings, *BS 5250:2002* (pp. 90). London: BSI.

BSI. (2011). BS 5250:2011 Code of practice for control of condensation in buildings, *BS 5250:2011* (pp. 92). London: BSI.

BSI. (2013a). Hygrothermal performance of building materials and products - Determination of hygroscopic sorption properties, *BS EN ISO 12571:2013* (pp. 28). London: BSI.

BSI. (2013b). Hygrothermal performance of building materials and products - Determination of moisture content by drying at elevated temperature, *BS EN ISO 12570:2000+A1:2013* (pp. 16). London: BSI.

Building Research Establishment. (1974). *Drying out buildings.* [S.l.]: Building Research Establishment : H.M.S.O.

Burkinshaw, R. (2002). What is the moisture meter trying to tell us? *Structural Survey, 20* (5), 162 - 172.

Burkinshaw, R. (2009). *Remedying damp*. Coventry: Royal Institution of Chartered Surveyors.

Burkinshaw, R. (2010). The rising damp tests of Camberwell Pier: Potential height of moisture rise in brickwork and the effectiveness of a modern chemical injection cream damp coursing application. *J Build Apprais, 6* (1), 5-19.

Burkinshaw, R., & Parrett, M. (2003). *Diagnosing damp*. Coventry: RICS Books.

Campbell, D. T., & Stanley, J. C. (1963). *Experimental and quasi-experimental designs for research*. Boston: Houghton Mifflin Company.

Chadwick, E. (1842). Report on the sanitary condition of the labouring population of Great Britain and on the means of improvement. Retrieved from http://www.deltaomega.org/ChadwickClassic.pdf

Charlton Scientific Ltd. (2017). Quantofix Nitrate/Nitrite. Retrieved, 29 January 2017, from http://www.charltonsci.co.uk/catalog/quantofix-nitratenitrite-p-29.html

Chudley, R., & Greeno, R. (2006). *Building construction handbook* (6th ed. ed.). Amsterdam ; London: Butterworth-Heinemann.

Clay, H. H., & Davis, F. G. (1977). *Clay's Handbook of Environmental Health* (14th rev. edn. ed.). [S.l.]: H. K. Lewis.

Cohen, L., Manion, L., & Morrison, K. (2007). *Research methods in education* (6th ed. ed.). London: Routledge.

Coleman, G. R. (1990). *Guide to identification of dampness in buildings*. Sherbourne: Remedial Technical Services Ltd.

Coleman, G. R. (1993). Dampness following the insertion of a remedial damp-proof course. *Structural Survey, 11* (1), 3 - 9.

Cook, T. D., & Campbell, D. T. j. a. (1979). *Quasi-experimentation : design & analysis issues for field settings*. Chicago: Rand McNally College Pub. Co.

Cox, D. R., & Reid, N. (2000). *The theory of the design of experiments*. Boca Raton, Fla. ; London: Chapman & Hall/CRC.

Creswell, J. W. (2003). *Research design : qualitative, quantitative, and mixed methods approaches* (2nd ed. ed.). Thousand Oaks, Calif. ; London: Sage.

Culligan, P. J., Ivanov, V., & Germaine, J. T. (2005). Sorptivity and liquid infiltration into dry soil. *Advances in Water Resources, 28* (10), 1010-1020.

D'Agostino, D. (2013). Moisture dynamics in an historical masonry structure: The Cathedral of Lecce (South Italy). *Building and Environment, 63* (0), 122-133.

Dampbuster.com. (2008). About Us : Mike Parrett.   Retrieved, 17 March 2017, 2017, from http://www.dampbuster.com/about_us.html

De Freitas, V. P., Abrantes, V., & Crausse, P. (1996). Moisture migration in building walls - Analysis of the interface phenomena. *Building and Environment, 31* (2), 99-108.

Department for Communities and Local Government. (2016). English housing survey : Headline Report 2014-15 (Vol. 2016, pp. 54). Available from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/501065/EHS_Headline_report_2014-15.pdf

DePoy, E., & Gitlin, L. N. (1998). *Introduction to research : understanding and applying multiple strategies* (2nd ed. ed.). St. Louis ; London: Mosby.

Dill, M. J. (2000). *A review of testing for moisture in building elements*: Construction Industry Research and Information Association.

Douglas, J. (1998). The development of ground floor constructions: part IV (damp proofing methods). *Structural Survey, 16* (2), 76 - 80.

Douglas, J., & Noy, E. A. (2011). *Building surveys and reports* (4th ed. ed.). Oxford: Wiley-Blackwell.

Eassie, W. (1873). Reports on sanitary engineering in houses, hospitals, and public institutions. *The British Medical Journal* (20 December 1873), 734-736.

EMERISDA. (2015). EMERISDA Newsletter 1. In Cultural Heritage (Eds.)pp. 4). Available from http://www.emerisda.eu/wp-content/uploads/2014/07/English.pdf

EMERISDA. (n.d.-a). EMERISDA : Project website.   Retrieved, 17 March 2017, from http://www.emerisda.eu/

EMERISDA. (n.d.-b). Factsheet #4: JPICH/JHEP: Effectiveness of methods against rising damp in buildings. 2. Retrieved from http://heritageportal.eu/Browse-Topics/BUILT-HERITAGE/Factsheet-4-Effectiveness-of-Methods-Against-Rising-Damp-in-Buildings.pdf

Emmitt, S. (2002). *Architectural technology*. Oxford: Blackwell Science.

Everitt, B. (2006). *The Cambridge dictionary of statistics* (3rd ed. ed.). Cambridge: Cambridge University Press.

Feilden, B. M. (2003). *Conservation of historic buildings* (3rd ed. ed.). Amsterdam ; London: Architectural.

Ferluq. (2010). Churches of Rome Wiki. San Bernardo alle Terme (last udated 16 March 2010). Retrieved, 23 August 2010, from http://romanchurches.wikia.com/index.php?title=San_Bernardo_alle_Terme&oldid=4919

Field, A. P., & Hole, G. (2003). *How to design and report experiments*. London ; Thousand Oaks, Calif.: Sage publications Ltd.

Fischer, K. (2009). Rising dampness - everywhere well known or a hoax and fake? What is true? : The Fraud of the Rising Damp - Part One.   Retrieved, 17 March 2017, from http://www.konrad-fischer-info.de/2auffen.htm

Fischer, K. (n.d.). Healing 'Rising Damp' in Masonry Walls and Cellars of Old Buildings - Part Two : How to heal moistured houses, wet cellars & soaked walls : A Helpful Guide Against Wet Walls.   Retrieved, 17 March 2017, from http://www.konrad-fischer-info.de/2auffe2.htm

Flyvbjerg, B. (2001). *Making social science matter : why social inquiry fails and how it can succeed again*. Cambridge: Cambridge University Press.

Français Wikipedia. (2010). Dictionnaires et Encyclopédies sur 'Academic'. Thermes de Dioclétien. Église San Bernardo alle.   Retrieved, 23 August 2010, from http://fr.academic.ru/dic.nsf/frwiki/1626766

Garratt, J., & Nowak, F. (1991). *Tackling condensation : a guide to the causes of, and remedies for, surface condensation and mould in traditional housing*: Building Research Establishment.

Garson, G. D. (2002). *Guide to writing empirical papers, theses, and dissertations*. New York: Marcel Dekker.

GE Sensing. (2005). Protimeter MMS : Moisture Measurement System : Instruction Manual. Available from http://www.ge-mcs.com/download/sensing-manuals/MMS-Instruction.pdf

GE Sensing. (2009). Surveymaster: Protimeter Dual-Function Moisture Meter: Instruction Manual. (INS5360, Rev. B August 2009 ed.): GE Sensing.

Gerring, J. (2007). *Case study research : principles and practices*. Cambridge: Cambridge University Press.

Gill, J., & Johnson, P. (2010). *Research methods for managers* (4th ed. / John Gill, Phil Johnson, with Murray Clark. ed.). London: SAGE.

Golding, A. M. B. (2006). Sir Edwin Chadwick and inequalities. *Public Health, 120* (5), 474-476.

Griffiths, R. (2004). Knowledge production and the research-teaching nexus: the case of the built environment disciplines. *Studies in Higher Education, 29* (6), pp. 709-726.

Guimaraes, A. S., & de Freitas, V. P. (2009). Wall base ventilation system as a new technique to treat rising damp in existent buildings. *Journal of Building Appraisal, 5* (2), 187-195.

Hall, C. (1977). Water movement in porous building materials - I. Unsaturated flow theory and its applications. *Building and Environment, 12* (2), 117-125.

Hall, C., Hamilton, A., Hoff, W. D., et al. (2010). Moisture dynamics in walls: response to micro-environment and climate change. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Science*.

Hall, C., & Hoff, W. D. (2007). Rising damp: capillary rise dynamics in walls. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Science, 463* (2084), 1871-1884.

Hall, C., & Hoff, W. D. (2012). *Water transport in brick, stone and concrete* (2nd ed. ed.). London: Spon.

Hall, C., Hoff, W. D., & Nixon, M. R. (1984). Water movement in porous building materials - VI. Evaporation and drying in brick and block materials. *Building and Environment, 19* (1), 13-20.

Hanzic, L., Kosec, L., & Anzel, I. (2010). Capillary absorption in concrete and the Lucas-Washburn equation. *Cement and Concrete Composites, 32* (1), 84-91.

Heritage House Building and Restoration. (2017a). Damp and Condensation : Peter Cox damp proofing. Retrieved, 17 March 2017, from http://www.heritage-house.org/peter-cox-damp-proofing.html

Heritage House Building and Restoration. (2017b). Damp and Condensation : Property Care Association - Rising Damp and Facebook. Retrieved, 17 March 2017, from http://www.heritage-house.org/property-care-association-rising-damp-and-facebook.html

Heritage House Building and Restoration. (2017c). Damp and Condensation : The Fraud of Rising Damp. Retrieved, 17 March 2017, from http://www.heritage-house.org/the-fraud-of-rising-damp.html

Heritage House Building and Restoration. (n.d.). Managing Damp in Old Buildings. Retrieved, 31 March 2017, from http://www.heritage-house.org/managing-damp-in-old-buildings.html

Hollis, M., & Gibson, C. (2005). *Surveying Buildings* (5th ed. ed.). Coventry: RICS Books.

Howell, J. (2008). *The rising damp myth*. Woodbridge: Nosecone Publications.

Hunt, M., Geoff. (2006). Mike Parrett's Guide to Building Pathology. [journal article]. *Journal of Building Appraisal, 2* (3), 264-265.

I'Anson, S. J., & Hoff, W. D. (1986). Water movement in porous building materials - VIII. Effects of evaporative drying on height of capillary rise equilibrium in walls. *Building and Environment, 21* (3-4), 195-200.

isurv. (2017). Building surveying : Pathology : Damp : Exploring dampness : Rising damp – myth or fact? Retrieved, 14 March 2017, from http://www.isurv.com.salford.idm.oclc.org/site/scripts/documents_info.aspx?documentID=4612&categoryID=1155&pageNumber=6

Jarvis, P. (1999). *The practitioner-researcher : developing theory from practice*. San Francisco, Calif.: Jossey-Bass.

Karoglou, M., Moropoulou, A., Giakoumaki, A., et al. (2005). Capillary rise kinetics of some building materials. *Journal of Colloid and Interface Science, 284* (1), 260-264.

Knight, A., & Ruddock, L. (2008). *Advanced research methods in the built environment*. Oxford: Wiley-Blackwell.

Kropp, J., & Hilsdorf, H. K. (1995). *Performance criteria for concrete durability : state-of-the-art report prepared by RILEM Technical Committee TC 116-PCD, Performance of Concrete as a Criterion of its Durability*. London: E & FN Spon.

Kyte, C. T. (1987). The treatment of rising dampness. *Structural Survey, 5* (4), 312 - 315.

Kyte, C. T. (Ed.). (1997). *Laboratory analysis as an aid to the diagnosis of rising damp*. Ascot: The Chartered Institute of Building.

Lascar Electronics Ltd. (2015). Products : Data Loggers : EL-USB-2+. Retrieved, 26 November 2015, from http://www.lascarelectronics.com/temperaturedatalogger.php?datalogger=386#

Leedy, P. D., & Ormrod, J. E. (2005). *Practical research : planning and design* (8th ed. / Paul D. Leedy and Jeanne Ellis Ormrod. ed.). Upper Saddle River, N.J.: [Great Britain] : Prentice Hall.

LinkedIn. (2017a). Building Pathology Forum. Retrieved, 17 March 2017, from https://www.linkedin.com/groups/4141773

LinkedIn. (2017b). Diagnosis of dampness defects. Retrieved, 17 March 2017, from https://www.linkedin.com/groups/4141773

Locke, L. F., Silverman, S. J., & Spirduso, W. W. (2010). *Reading and understanding research* (3rd ed. ed.). Los Angeles ; London: SAGE.

Lockington, D. A., & Parlange, J. Y. (2003). Anomalous water absorption in porous materials. *Journal of Physics D: Applied Physics, 36* (6), 760.

Lockington, D. A., & Parlange, J. Y. (2004). A new equation for macroscopic description of capillary rise in porous media. *Journal of Colloid and Interface Science, 278* (2), 404-409.

Machery-Nagel. (2015a). Detection of nitrate in potatoes, vegetables and fruits with Quantofix Nitrate / Nitrite test strips Available from ftp://ftp.mn-net.com/english/customer%20information/Nitrate_in_food.pdf

Machery-Nagel. (2015b). Quantofix® Chloride. Retrieved, 20 March 2015, from http://www.mn-net.com/tabid/10327/tabid/4928/tabid/10309/tabid/4928/tabid/10309/default.aspx

Machery-Nagel. (2015c). Quantofix® Nitrate / Nitrite test strips. Retrieved, 20 March 2015, from http://www.mn-net.com/tabid/10327/default.aspx

Marshall, D., Worthing, D., & Heath, R. (2003). *Understanding housing defects* (2nd ed. ed.). London: Estates Gazette.

Mason, G. (1974). Rising damp. *Building Science, 9* (3), 227-231.

Massari, G., & Massari, I. (1993). *Damp buildings, old and new*. Rome: ICCROM.

Mills, E. D. (1994). *Building maintenance and preservation : a guide for design and management* (2nd ed. ed.). Oxford: Butterworth-Heinemann.

Montgomery, D. C. (2001). *Design and analysis of experiments* (5th ed. ed.). New York ; Chichester: Wiley.

Mujumdar, A. S. (2015). *Handbook of industrial drying* (Fourth edition. ed.). Boca Raton: CRC Press, Taylor & Francis Group.

NBS. (2011). Knowledge : Rising damp? London: RIBA Enterprises Ltd.

Newton, W. (1846). A General Index to the Repertory of Patent Inventions and other discoveries and improvements in Arts, Manufactures and Agriculture, from 1815 to 1845, inclusive (Vol. 27, Available from https://books.google.co.uk/books?id=xNI_AQAAMAAJ&pg=PA218&lpg=PA218

&dq=The+London+Journal+of+arts+sciences+and+manufactures+1842&source=bl&ots=e43bro5xV6&sig=uk--eEx2kaPj80fd413zZj1aoIs&hl=en&sa=X&ved=0ahUKEwi_xMqd0v7SAhWElCwKHVLQAsQQ6AEILTAE#v=onepage&q&f=false

Noy, E. A., & Douglas, J. (2005). *Building surveys and reports* (3rd ed. / rev. by James Douglas. ed.). Oxford: Blackwell.

Oliver, A. C. (1984). *Woodworm dry rot and rising damp*: Sovereign Chemical Industries.

Oliver, A. C., Douglas, J., & Stirling, J. S. (1997). *Dampness in buildings* (2nd ed. / revised by James Douglas and J. Stewart Stirling. ed.). Oxford: Blackwell Science.

Oxford English Dictionary. (2010). "scientific method".   Retrieved, 2 December 2010, from http://www.oed.com/view/Entry/172685?redirectedFrom=scientific%20method

Oxley, T. A., & Gobert, E. G. (1983). *Dampness in buildings : diagnosis, treatment, instruments*. London: Butterworths.

Panoramic Earth. (2010). San Bernardo alle Terme.   Retrieved, 23 August 2010, from http://www.panoramicearth.com/503/Rome/San_Bernardo_alle_Terme

Parnham, P., & Rispin, C. (2001). *Residential property appraisal*. London: Spon Press.

Parrett, M. (2009). Stop the rot. *The Journal, RICS Building Surveying, January-February 09*, 16-17.

Parrett, M. (n.d.). Mike Parrette's Guide to Building Pathology : Peer Reviews. Retrieved, 17 March 2017, from http://www.buildingpathology.net/testimonials.asp

Philip, J. R. (1957). The Theory of Infiltration: 4. Sorptivity and Algebraic Infiltration Equations. *Soil Science, 84* (3), 257-264.

Phillips, E., & Pugh, D. S. (2005). *How to get a PhD : a handbook for students and their supervisors* (4th ed. ed.). Maidenhead: Open University Press.

Phillipson, M. C. (1996). *Effects of moisture in porous masonry : overview of the literature*: Construction Research Communications.

Platten, A. (1989). Building performance and maintenance: moisture ingress. *Property Management, 7* (4), 357 - 362.

Property Care Association. (2007). Plastering in association with the installation of a remedial damp proof course (Vol. DP2/1107). Huntingdon: Property Care Association.

Property Care Association. (2009). Chemical Damp-Proof Course Insertion - the attendant problems (Vol. DP5/0909). Huntingdon: Property Care Association.

Property Care Association. (2015). Annual Report 2015 (2015 ed.): The Property Care Association.

Property Care Association. (2017a). About Us : PCA Mission Statement : History. Retrieved, 12 March 2017, from http://www.property-care.org/us/

Property Care Association. (2017b). Membership : How do I join the PCA? Retrieved, 13 March 2017, from http://www.property-care.org/membership/

Property Care Association. (2017c). PCA Qualified Technician (PCAQT) – Damp & Timber. Retrieved, 13 March 2017, from http://www.property-care.org/training-qualifications/pca-technician-training/technician-damp-timber/

Property Care Association. (2017d). Surveying Timber & Dampness in Buildings. Retrieved, 13 March 2017, from http://www.property-care.org/training-qualifications/pca-surveyor-training/surveyor-remedial-treatments-training-course/

Property Care Association. (2017e). Surveyor in Structural Waterproofing Training. Retrieved, 13 March 2017, from http://www.property-care.org/training-qualifications/pca-surveyor-training/structural-waterproofing-training-course/

Property Care Association. (2017f). Surveyor Training for Property Professionals. Retrieved, 13 March 2017, from http://www.property-care.org/training-qualifications/pca-surveyor-training/

The Public Health Act, 1875 (38 & 39 Vict., ch. 55). (1897).pp. 180). Available from http://www.opsi.gov.uk/acts/acts1875/pdf/ukpga_18750055_en.pdf

Quite Interesting Ltd. (2011). The Qibble Blog : Qibbles : A Guide to QI. Series I, Episode 6 'Inventive'. Retrieved, 17 March 2017, from http://old.qi.com/qi_quibble_blog/2011/10/a-guide-to-qi-series-i-episode-6-inventive.html

Remedial Technical Services. (2010). Equilibrium Relative Humidity (ERH) - the pitfalls. Retrieved, 18 December 2010, from http://www.buildingpreservation.com/index.php?option=com_content&view=article&id=19%3Aequilibrium-relative-humidity-the-pitfalls&catid=3%3Adampness&Itemid=26

Richardson, B. A. (1995). *Remedial treatment of buildings* (2nd ed. ed.). Oxford: Butterworth-Heinemann.

Richardson, M. (2008). Advice on rising damp treatment. A report for Safeguard Europe Ltd. Retrieved from http://www.safeguardeurope.com/pdf_datasheets/dryzone-dpc-cream-test-report.pdf

RICS. (n.d.). Dampness Factsheet 04 Available from www.periodproperty.co.uk/pdf/RICS_Dampness_Factsheet_V3.pdf

Ridout, B. (2000). *Timber decay in buildings : the conservation approach to treatment*. London: E. & F. N. Spon.

Ridout, B. (2001). Taking the rise out of damp. *The Architects' Journal*, p. 51-52.

Rirsch, E., MacMullen, J., & Zhang, Z. (2011). Evaluation of mortar samples obtained from UK houses treated for rising damp. *Construction and Building Materials, 25* (6), 2845-2850.

Rirsch, E., & Zhang, Z. (2010). Rising damp in masonry walls and the importance of mortar properties. *Construction and Building Materials, 24* (10), 1815-1820.

Robson, C. (2002). *Real world research : a resource for social scientists and practitioner-researchers* (2nd ed. ed.). Madden, Mass. ; Oxford: Blackwell Publishers.

Rose, D. A. (1963). Water movement in porous materials: Part 1 - Isothermal vapour transfer. *British Journal of Applied Physics, 14* (5), 256.

Rose, D. A. (1968). Water movement in porous materials III. Evaporation of water from soil. *Journal of Physics D: Applied Physics, 1* (12), 1779.

Safeguard Europe Ltd. (2005). Renderguard Gold. Salt retardant and waterproofer for use in re-plastering applications Available from http://static.safeguardeurope.com/pdfs/renderguard_gold.pdf

Safeguard Europe Ltd. (2007). *Rising damp & its control*. Sussex: Safeguard Europe Ltd.,.

Safeguard Europe Ltd. (2015). Dryzone Application Guidelines. Retrieved, 2 January 2017, from http://static.safeguardeurope.com/downloads/application-guidelines/dryzone-system/dryzone-damp-proofing-cream-application-guidelines.pdf

Safeguard Europe Ltd. (n.d.). Safeguard : Product Information : Dryzone Damp-Proofing Cream. Retrieved, 12 April 2017, from http://www.safeguardeurope.com/products/dryzone-system/dryzone-damp-proofing-cream

Saunders, M., Lewis, P., & Thornhill, A. (2009). *Research methods for business students* (5th ed. ed.). Harlow: Financial Times Prentice Hall.

Schön, D. A. (1991). *The reflective practitioner: how professionals think in action*. Aldershot: Avebury.

Sereda, P. J., & Feldman, R. F. (1970). Wetting and Drying of Porous Materials. *Canadian Building Digest, CBD 130, October 1970*.

Shadish, W. R., Cook, T. D., & Campbell, D. T. (2001). *Experimental and quasi-experimental designs for generalized causal inference*. Boston: Houghton Mifflin.

Sharpe, R. W. (1978). A mortar for rising damp studies. *Building and Environment, 13* (4), 261-265.

Simpson, D. (2005). *Moisture in concrete floors. Concrete Advice No. 22*. Camberley: The Concrete Society.

Somsim, S., Zsembery, S., & Ferguson, J. A. (1985). *A study of pore size distributions in fired clay bricks in relation to salt attack resistance*. Paper presented at the Proceedings of the 7th International Brick Masonry Conference. Retrieved from http://www.thinkbrick.com.au/shadomx/apps/fms/fmsdownload.cfm?file_uuid=DFCE574D-936E-B09F-8517-C11C074D8757

Stationery Office. (2013). *The Building Regulations 2010. Site preparation and resistance to contaminants and moisture. Approved document C.* (2010 ed. incorporating 2010 and 2013 amendments. ed.). London: NBS, part of RIBA Enterprises Ltd.

Summersgill, I. (2013). The Yorkshire Times : Rising Damp in Old Houses - It's just a myth! Retrieved, 17 March 2017, from http://yorkshiretimes.co.uk/article/Rising-Damp-in-Old-Houses-Its-just-a-myth

Survey Express Services. (2015a). Protimeter : Accessories: Hygrosticks and Humidity Sleeves. Retrieved, 26 November 2015, from http://www.damp-meter-direct.co.uk/protimeter-accessories.htm

Survey Express Services. (2015b). Protimeter: Product Range: Protimeter Hygromaster. Retrieved, 26 November 2015, from http://www.damp-meter-direct.co.uk/protimeter-hygromaster.htm

Survey Express Services. (2015c). Protimeter: Product Range: Protimeter MMS. Retrieved, 26 November 2015, from http://www.damp-meter-direct.co.uk/protimeter-mms.htm

Survey Express Services. (2015d). Protimeter: Product Range: Protimeter Speedy. Retrieved, 26 November 2015, from http://www.damp-meter-direct.co.uk/protimeter-speedy.htm

Survey Express Services. (2017). Protimeter: Product Range: Protimeter Salt Analysis. Retrieved, 29 January 2017, from http://www.damp-meter-direct.co.uk/protimeter-salt-analysis.htm#.VRkSavzF9Zg

Taylor, J. (1863). *Sundry Sanitary Building Appliances*. Paper presented at the The Royal Institute of British Architects: Session 1862-63. Retrieved from https://books.google.co.uk/books?id=McGgAAAAMAAJ&pg=PA77&dq=Transactions+of+the+Royal+Institute+of+British+Architects+rising+damp&hl=en&sa=X&ved=0ahUKEwjM9YHnq4DTAhUBFiwKHcQQAQwQ6AEIHjAB#v=onepage&q&f=false

Tharenou, P., Donohue, R., & Cooper, B. (2007). *Management research methods*. Port Melbourne, Vic. ; Cambridge: Cambridge University Press.

The Architects' Journal. (2009). Rising damp is a myth, says former RICS chief. Retrieved, 14 March 2017, from http://www.architectsjournal.co.uk/news/daily-news/-rising-damp-is-a-myth-says-former-rics-chief/5204095.article

The Lancaster Gazette and General Advertiser. (1832). For the Lancaster Gazette. Hints on light, ventilation, and rendering houses healthful. *The Lancaster Gazette and General Advertiser. Saturday, 22 September 1832*.

Thunder Scientific Corporation. (2015). Humidity Equipment: Model 2500 Benchtop/Mobile. Retrieved, 22 September 2015, from http://www.thunderscientific.com/humidity_equipment/model_2500.html

Triton Chemical Manufacturing Co. Ltd. (2011). Triton Systems Damp Proofing & Replastering Data Pack Available from http://www.triton-chemicals.co.uk/pdf/Damproofing_&_Replastering_Data_Pack.pdf

Trotman, P. M. (2007). *Rising damp in walls: Diagnosis and treatment*. Watford: IHS BRE Press.

Trotman, P. M., Sanders, C., & Harrison, H. W. (2004). *Understanding dampness: effects, causes, diagnosis and remedies*. Watford: BRE Bookshop.

UK Parliament. (n.d.). The 1848 Public Health Act. Retrieved, 26 March 2017, from http://www.parliament.uk/about/living-heritage/transformingsociety/towncountry/towns/tyne-and-wear-case-study/about-the-group/public-administration/the-1848-public-health-act/

Unesco. (1969). *Water in the unsaturated zone : Proceedings of the Wageningen symposium*, Paris.

Vanhellemont, Y., De Clercq, H., & Pien, A. (2006). *A proposal for test procedure for injection products against rising damp*. Paper presented at the 7th European Conference "Sauveur" Safeguarded Cultural Heritage: Understanding & Viability

for the Enlarged Europe 31 May - 3 June 2006. Retrieved from http://www.arcchip.cz/ec-conference/download/A-1_182.pdf

Veiga, M. d. R., Fragata, A., Tavares, M. L., et al. (2009). Inglesinhos convent: Compatible renders and other measures to mitigate water capillary rising problems. *Journal of Building Appraisal, 5* (2), 171-185.

Visqueen Building Products. (2017). Polythene DPC. Retrieved, 12 March 2017, from http://www.visqueenbuilding.co.uk/datasheet/109?ck=1489323626

Vos, B. H. (1971). Suction of Groundwater. *Studies in Conservation, 16* (4), 129-144.

Waite, R. (2009). Rising damp is a myth, says RICS. *The Architects' Journal, 229* (23), 5.

Ward, P. (2014a, 21 August 2014). Busting the damp myth - an incompetent rics surveyor, and peter cox. Retrieved, 17 March 2017, from https://www.youtube.com/watch?v=Poj9mSjtfUU

Ward, P. (2014b, 15 November 2014). The Damp Industry Con. Retrieved, 17 March 2017, from https://www.youtube.com/watch?v=Poj9mSjtfUU

Watkin, B. (1975). *Documents on health and social services 1834 to the present day. [Selected and with introductory essays by] Brian Watkin*: London: Methuen.

Which! (2012, January 2012). Don't be misled over damp. *Which?, January 2012,* 3.

Wickes. (2017). Products : Building Materials : Water & Damp Proofing : Damp Proof Course : Dryzone Damp Proof Course Cream 310ml. Retrieved, 12 March 2017, from http://www.wickes.co.uk/Dryzone-Damp-Proof-Course-Cream-310ml/p/134011

Wilson, M. A., Hoff, W. D., & Hall, C. (1995). Water movement in porous building materials - XIII. Absorption into a two-layer composite. *Building and Environment, 30* (2), 209-219.

World Health Organization. (2009a). Damp and Mould: health risks, prevention and remedial actions Available from http://www.euro.who.int/__data/assets/pdf_file/0003/78636/Damp_Mould_Brochure.pdf

World Health Organization. (2009b). WHO guidelines for indoor air quality : dampness and mould. In E. Heseltine & J. Rosen (Eds.)pp. xvi, 328 p.).

World Weather Online. (2017a). Bari, Puigli, Italy : Monthly Climate Average. Retrieved, 13 April 2017, from https://www.worldweatheronline.com/bari-weather-averages/puglia/it.aspx

World Weather Online. (2017b). York, North Yorkshire, United Kingdom : Monthly Climate Average. Retrieved, 13 April 2017, from https://www.worldweatheronline.com/york-weather-averages/north-yorkshire/gb.aspx

Wykamol Group. (2009). Ultracure damp proof-injection cream Available from http://www.wykamol.com/images/pictures/damproofing/product-guide-and-msds/1a-ultracure-product-guide-january-2009.pdf

Wykamol Group. (2013). Brunopel IWP: Integral Waterproofing Additive Available from http://www.wykamol.com/images/pictures/datasheets/brunopel-iwp-data-sheet-2.pdf?v=8bfd8ca589094b7d0103d96d26a9c696

Yin, R. K. (2012). *Applications of case study research* (3rd ed. ed.). London: SAGE.

Yin, R. K. (2014). *Case study research : design and methods* (Fifth edition. ed.).

Young, D. (1997). Rising damp and salt attack: The South Australian perspective Available from http://www.environment.sa.gov.au/heritage/pdfs/rising_damp.pdf

Young, D. (2008). *Salt attack and rising damp [electronic resource] : a guide to salt damp in historic and older buildings*. Parramatta, N.S.W. : NSW Heritage Office.

Zhang, Z. (2010). A Review of Rising Damp in Masonry Buildings Available from http://www.property-care.org/images/stories/A_Review_of_Rising_Damp_in_Masonry_Buildings.pdf

Appendix 1

Data collection sheet V1

Date

Panel A	Lascar Temp	Lascar RH	Hygrostick Ref	Hygrostick RH	Hygrostick Temp	Surface MM	Deepwall MM	Surface SM	Timber probe -100	Timber probe
545										
460										
375										
290										
205										
115										
50										

Panel B	Lascar Temp	Lascar RH	Hygrostick -100 Ref	Hygrostick -100 RH	Hygrostick -100 Temp	Hygrostick Ref	Hygrostick RH	Hygrostick Temp	Surface MM	Deepwall MM	Surface SM	Timber probe
545												
460												
375												
290												
205												
115												
50												

Panel C	Lascar Temp	Lascar RH	Hygrostick Ref	Hygrostick RH	Hygrostick Temp	Surface MM	Deepwall MM	Surface SM	Timber probe
545									
460									
375									
290									
205									
115									
50									

Panel D	Lascar Temp	Lascar RH	Hygrostick Ref	Hygrostick RH	Hygrostick Temp	Surface MM	Deepwall MM	Surface SM	Timber probe
545									
460									
375									
290									
205									
115									
50									

Panel E	Lascar Temp	Lascar RH	Hygrostick Ref	Hygrostick RH	Hygrostick Temp	Surface MM	Deepwall MM	Surface SM	Timber probe
545									
460									
375									
290									
205									
115									
50									

Enviro	External Lascar RH	External Lascar Temp	Room Lascar RH	Room Lascar Temp

Appendix 2

Data collection sheet V2

Date			
Calibration	Protimeter MMS POL5800JC09T0005		Protimeter Surveymaster BLD536022T0506

Panel A	Lascar RH	Lascar Temp	Hygrostick Ref	Hygrostick RH	Hygrostick Temp	Surface MM	Deepwall MM	Surface SM	Timber probe -100	Timber probe	Timber probe +25
545											
460											
375											
290											
205											
115											
50											

Panel B	Lascar RH	Lascar Temp	Hygrostick -100 Ref	Hygrostick -100 RH	Hygrostick -100 Temp	Hygrostick Ref	Hygrostick RH	Hygrostick Temp	Surface MM	Deepwall MM	Surface SM	Timber probe	Timber probe +25	Timber dowel
545														
460														
375														
290														
205														
115														
50														

Panel C	Lascar RH	Lascar Temp	Hygrostick Ref	Hygrostick RH	Hygrostick Temp	Surface MM	Deepwall MM	Surface SM	Timber probe	Timber probe -25	Timber dowel
545											
460											
375											
290											
205											
115											
50											

Panel D	Lascar RH	Lascar Temp	Hygrostick Ref	Hygrostick RH	Hygrostick Temp	Surface MM	Deepwall MM	Surface SM	Timber probe	Timber probe -25	Timber dowel
545											
460											
375											
290											
205											
115											
50											

Panel E	Lascar RH	Lascar Temp	Hygrostick Ref	Hygrostick RH	Hygrostick Temp	Surface MM	Deepwall MM	Surface SM	Timber probe
545									
460									
375									
290									
205									
115									
50									

Enviro	External Lascar RH	External Lascar Temp	Room Lascar RH	Room Lascar Temp

Appendix 3

Data collection sheet V3

Date	
Calibration	Protimeter MMS POL5800JC09T0005	Protimeter Surveymaster BLD536022T0506	

Panel A	Lascar RH	Lascar Temp	Hygrostick Ref	Hygrostick RH	Hygrostick Temp	Surface MM	Deepwall MM	Surface SM	Timber probe -100	Timber probe	Timber probe +25	5mm dowel
545												
460												
375												
290												
205												
115												
50												

Panel B	Lascar RH	Lascar Temp	Hygrostick -100 Ref	Hygrostick -100 RH	Hygrostick -100 Temp	Hygrostick Ref	Hygrostick RH	Hygrostick Temp	Surface MM	Deepwall MM	Surface SM	Timber probe	Timber probe +25	9mm dowel	5mm dowel
545															
460															
375															
290															
205															
115															
50															

Panel C	Lascar RH	Lascar Temp	Hygrostick Ref	Hygrostick RH	Hygrostick Temp	Surface MM	Deepwall MM	Surface SM	Timber probe	Timber probe -25	9mm dowel	5mm dowel
545												
460												
375												
290												
205												
115												
50												

Panel D	Lascar RH	Lascar Temp	Hygrostick Ref	Hygrostick RH	Hygrostick Temp	Surface MM	Deepwall MM	Surface SM	Timber probe	Timber probe -25	9mm dowel	5mm dowel
545												
460												
375												
290												
205												
115												
50												

Panel E	Lascar RH	Lascar Temp	Hygrostick Ref	Hygrostick RH	Hygrostick Temp	Surface MM	Deepwall MM	Surface SM	9mm dowel	5mm dowel
545										
460										
375										
290										
205										
115										
50										

Enviro	External Lascar RH	External Lascar Temp	Room Lascar RH	Room Lascar Temp