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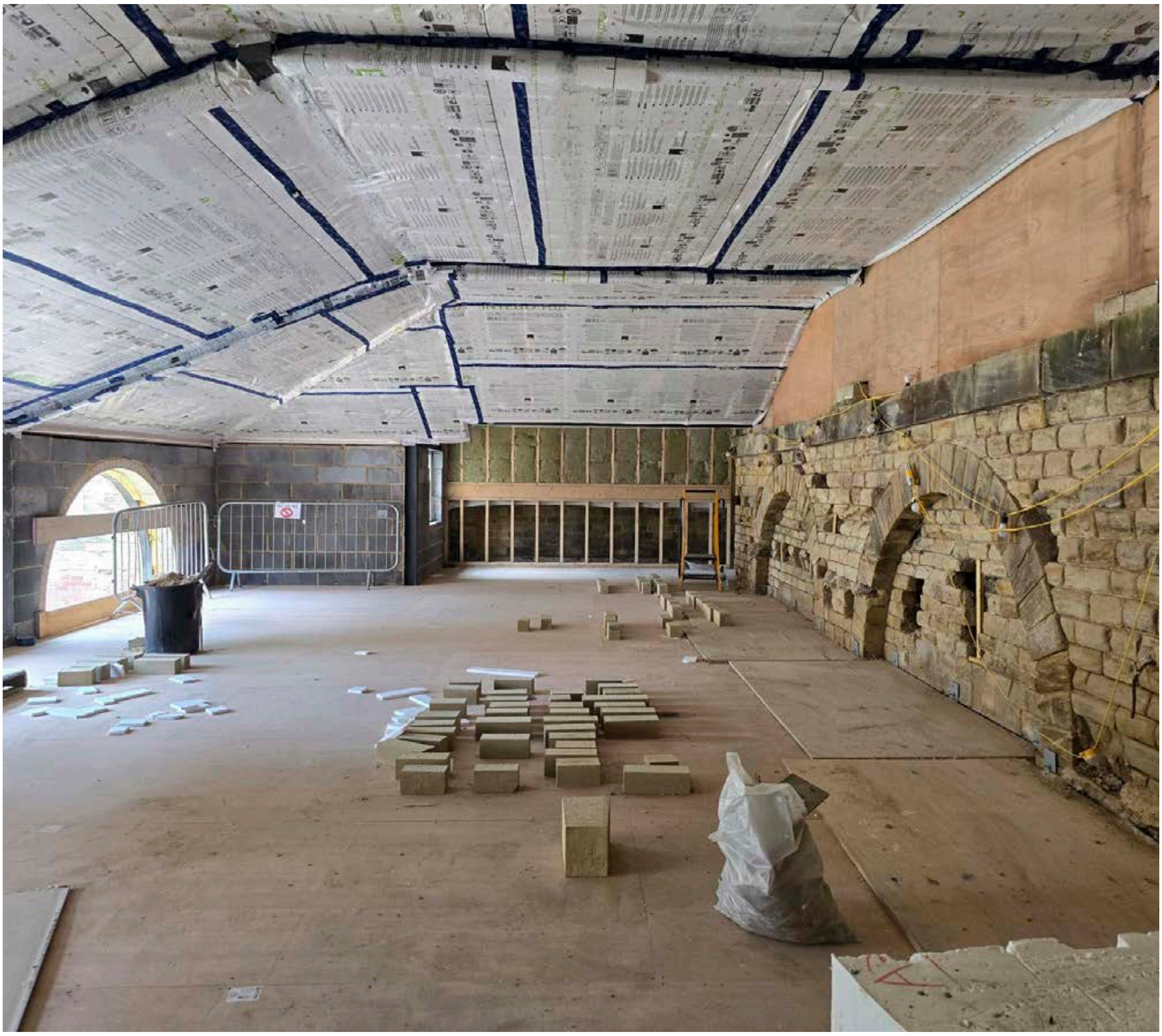
Air and Vapour Control Layers (AVCLs) in Buildings of Traditional Construction

A literature review on understanding appropriate use

Dr Valentina Marincioni, Bingyu Xu, Toby Cambray



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Air and Vapour Control Layers (AVCLs) in Buildings of Traditional Construction.

A literature review on understanding appropriate use

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Summary

This report presents the existing evidence on the functionality, performance, longevity and failure modes of air and vapour control layer (AVCL) membranes in relation to moisture movement in traditional building construction. The methodology involves a comprehensive analysis of peer-reviewed literature from databases such as Web of Science and Scopus. An initial general review, using keywords, establishes the concept and theory of AVCLs. The study then explores and summarises AVCL definitions, current products and their properties. Finally, it presents evidence on AVCL performance in building systems, focusing on internal wall insulation, timber-frame walls, insulated roofs and suspended floors, using both *in situ* measurements and hygrothermal simulations. The findings indicate that while there is some evidence on the benefits and limitations of AVCLs, further research is required to fully understand them and the impact they have on the performance of building fabric systems particularly in buildings of traditional construction.

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Front cover image: Variable diffusion AVCL secured under roofing, Wentworth, South Yorkshire. Matthew Thompson © Historic England

Date of research

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Introduction

In recent years, several new air and vapour control layer (AVCL) membrane products have entered the UK market. These are intended to prevent air leakage while allowing vapour diffusion. They can be installed as part of a set of interconnected components within the building fabric, usually coupled with vapour permeable materials. The aim is to prevent excessive moisture accumulation within the building fabric and reduce occurrences of associated interstitial mould growth, wood rot and corrosion.

The walls, floors and roofs of buildings can be considered to be systems, made up of layers that interact with respect to heat and moisture. Because of this interaction, it is essential to consider the influence of the AVCL on the behaviour of the whole system; the properties of the AVCL in isolation are insufficient. Traditional buildings are constructed from different materials and using different types of building systems to most modern buildings, and so perform differently (May and Griffiths, 2015). In traditional construction, moisture transport and storage mechanisms – such as solar-driven vapour diffusion, bulk vapour transport and capillary flow – can significantly affect the moisture balance of the building fabric. The extent of vapour control and the resulting moisture balance are the focus of this report, which aims to determine:

- The existing evidence base for the functionality, performance, longevity and failure modes of AVCL membranes and their auxiliary components;

- An evidence base for the long-term impact of AVCL membranes on moisture movement in traditional construction and the effect on both building fabric and thermal performance of insulating materials/systems;

- The suitability of AVCL membranes for inclusion in retrofitted insulation proposals for wall, floor and roof applications in buildings of traditional construction.

An introduction to AVCLs, including definitions and their role in the moisture balance of building fabric systems, is followed by a literature review covering building fabric systems where AVCLs are typically specified.

An introduction to air and vapour control layers

Definitions

An AVCL is defined as ‘a continuous layer of low permeability material to control the movement of air and water vapour’ (BS 6229:2018). The moisture balance of a building fabric system depends on the hygrothermal properties of the system as a whole, whether or not an AVCL is used. For buildings of traditional construction especially, this balance includes capillary flow as well as vapour control, airtightness, and ventilation provision. When AVCLs are incorporated into the design, assessing their influence on the moisture balance of the entire building fabric system is necessary, as their interaction with other elements can affect moisture transport and drying capacity. A breakdown of the main properties of an AVCL is found below.

A (Air)

In its role as an airtightness layer, an AVCL is designed to prevent uncontrolled air movement through the building fabric. Uncontrolled air movement can lead to the unintentional movement of heat, carried by bulk air, from the inside to the outside of a building, or vice versa, as well as within the building fabric, known as ‘thermal bypass’ (Siddall, 2022). The movement of air also leads to the bulk movement of water vapour, which is a distinct moisture transfer mechanism separate from vapour diffusion. When warm humid air moves through the building fabric, it may reach a colder spot. As a result, a condensing environment can be established due to the cooling of the air and the subsequent decrease in its capacity to retain moisture. Excess moisture can increase the risk of mould growth and condensation in the building fabric. The location of the AVCL and the quality of sealing (absence of gaps or tears during the lifetime of the building) are likely to influence the effectiveness of the AVCL in reducing moisture risks associated with air flow. It is important to note that no building can be perfectly sealed.

V (Vapour)

Water vapour is the gaseous form of water. It can move via diffusion or air movement. The previous section (Air) outlines how an AVCL may prevent uncontrolled air movement; this section describes how it helps to control vapour diffusion. Both transport mechanisms can lead to the accumulation of excess moisture within the building fabric, increasing the risk of mould growth and other problems in the building fabric. However, vapour diffusion is also a mechanism in drying. Evaporation – often influenced by meteorological phenomena such as wind flow or solar radiation – drives the flow of moisture (as vapour diffusion or capillary flow) through the building fabric (Hall and Hoff, 2012).

An AVCL is applied directly onto the warm side of the insulation, with no air gaps in-between. This method effectively controls vapour diffusion during the heating season. However, it can increase the risk of interstitial condensation on the exterior side of the AVCL in the summer (Karagiozis and Salonvaara, 1999), known as 'reverse condensation'. As a result, the approach in both construction and research has recently shifted away from the widespread use of 'vapour barriers', which provide high resistance to vapour diffusion. Instead, 'vapour retarders' and 'variable diffusion membranes' are being used, because they allow controlled vapour diffusion into the wall but also some degree of drying to the inside. This characteristic is particularly relevant for traditional and historic building elements, which rely on a balance between wetting and drying. The shift has also gained traction in some areas of new build construction, where moisture balance is a priority (such as timber structures). The vapour diffusion resistance of an AVCL – considered in relation to the other elements in the system – determines its effectiveness in reducing the moisture risks associated with outwards vapour diffusion in winter.

C (Control)

Controlling air movement means providing high resistance to air transfer. Vapour control can encompass a wide range of vapour diffusion resistances. The most appropriate resistance depends on the context.

The s_d-value is particularly useful to describe the vapour diffusion resistance of an AVCL, and it can be used to determine the overall vapour resistance of an insulation system. A high s_d-value indicates the product is more resistant to vapour diffusion (*see Physical quantities to describe the vapour diffusion properties of an AVCL*).

Membranes with high vapour resistance, such as aluminium foil (which typically has an s_d-value greater than 1500m) are referred to as 'vapour barriers'. A 'vapour retarder' has a lower vapour diffusion resistance than a vapour barrier. Membranes with a water vapour resistance lower than 0.12m, but greater than 0.05m, are often called 'breather membranes' (BSI, 2021). Breather membranes are used on the outside of a timber-frame structure to prevent liquid water transport while allowing vapour diffusion and are outside the scope of this review.

Most AVCLs are vapour retarders (*see 1.4 Product review*), but some offer high vapour diffusion resistance, with reported s_d-values ranging from as low as 2m to as high as 4000m. This broad range of vapour resistance might lend itself to AVCLs being classified as vapour permeable, semi-permeable or impermeable. However, the literature does not offer a clear distinction between low, medium and high vapour resistance, and the terminology used in literature can be contradictory.

It is important to note that the overall vapour resistance of a building fabric system is not determined by the s_d-value of the AVCL alone, but also by the s_d values of the other materials in the system. To account for this, some authors report the overall vapour resistance of the insulation system, from the indoor environment to the location of interest (for example, the interface between the insulation and the masonry in internally insulated walls). In this literature review we present the quoted terminology as used by the authors of each paper. We also report the declared vapour resistance of the AVCL – and, when relevant, of the associated insulation system.

L (Layer)

The most common application of an AVCL is in the form of a membrane, continuously sealed by compatible airtightness tape.

Products that are outside the scope of this review include spray-applied airtightness membranes, wet-applied plasters, *in situ* concrete and sheet timber materials. These materials can have similar characteristics to AVCL membranes, providing air and vapour control, but their installation is different.

Physical quantities to describe the vapour diffusion properties of an AVCL

To understand the performance of an AVCL in managing moisture within the building envelope, several quantities are used. As mentioned above, the main one that quantifies vapour diffusion properties is the s_d-value, or ‘equivalent air layer thickness’, which can be calculated as described below.

Vapour permeability (δ) is a measure of how easily water vapour can diffuse through a material. It is expressed in seconds (s), in the notation kg/(m·s·Pa), or it can also be found in g·m/(MN·s), a notation that provides more manageable values. The vapour permeability of air depends on temperature and pressure. Typically, for building applications in the UK, the vapour permeability of steady air at ambient temperature and pressure (δ_a) is around 0.2g·m/MNs. The inverse of vapour permeability is called vapour resistivity (δ^{-1}).

Knowing the vapour permeability, it is possible to determine the vapour diffusion resistance coefficient (μ), which is needed to calculate the s_d-value. The μ-value indicates the ratio of the resistance of a material to vapour diffusion compared to that of steady air (at the same temperature and pressure).[1] As the vapour permeability of a material is always lower than that of air, the lowest possible value for μ is 1. This means that the material is as

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[1] A useful resource for converting these quantities is the BuildDesk help document on vapour resistances: https://builddesk.co.uk/wp-content/uploads/2013/01/vapourResistances.pdf

resistant to vapour diffusion as steady air. It is calculated as $\mu = \delta_a / \delta$.The μ-value is the most commonly used quantity to describe the behaviour of materials in relation to vapour diffusion. It is a property of a material (independent of thickness), as opposed to a property of a layer with a particular thickness. For example, extruded polystyrene (XPS) has a μ-value of 150, while mineral wool has a μ-value close to 1.

The vapour permeability can be measured using the test method outlined in BS EN ISO 12572 (BSI, 2016). This standard provides technical information on measuring vapour permeability, including the environmental conditions under which the tests must be performed. Specimens are placed in a test chamber with controlled temperature and humidity, with one face of the specimen exposed to an environment containing either a desiccant (dry cup) or saturated salt solution (wet cup). In this set-up, a controlled vapour pressure difference is achieved to determine water vapour permeability. Dry cup tests provide information about the performance of materials at low humidity, whereas wet cup tests give guidance about the performance of materials at high humidity.

The s_d-value of an AVCL is often declared according to BS EN 1931 (BSI, 2000), which requires the water vapour permeability of membranes to be measured using the dry cup test, with boundary conditions of 0 per cent and 75 per cent relative humidity. In case of variable diffusion, the range of s_d-values is measured with several cup tests at different humidities.

Exploring the evolution of AVCLs

AVCLs have evolved over the past 25 years, from simple vapour barriers with a relatively high vapour resistance to variable diffusion membranes. Initially developed from research in cold climates, vapour barriers were designed to prevent moisture from entering insulation layers, aiming to avoid structural and thermal issues in colder regions. These barriers worked well in environments where prolonged cold created a consistent drive for moisture to move from warm interiors to colder exteriors. However, these conditions differ significantly from those in temperate climates like the UK.

Before the 2010s, research specifically on vapour control in climates similar to the UK was limited, creating gaps in understanding of how AVCLs function in buildings exposed to regular wetting and drying cycles. Under the UK’s temperate maritime climate, buildings experience evaporation of liquid moisture as part of their everyday function, driven by fluctuations in temperature and humidity. This climate requires a more balanced approach to vapour control that focuses on managing moisture movement, not entirely blocking it, supporting both reduction of vapour ingress and the drying potential within the building fabric.

Modern AVCLs allow vapour to diffuse to a certain extent, enabling buildings to dry through regular evaporation processes, while preventing excessive water vapour ingress. Recent developments include variable diffusion membranes, which adjust their permeability based on humidity conditions, allowing a controlled form of vapour diffusion within the building envelope. Also known as ‘intelligent membranes’, ‘smart vapour retarders’ or ‘smart vapour barriers’, these membranes offer added flexibility. However, they are not always essential. In many cases, a balanced AVCL strategy provides effective moisture management without need for this type of membrane, which supports drying and preserves building integrity.

While colder seasons in a climate like the UK drive outward vapour diffusion – referred to here as wetting seasons, where warm, humid indoor air moves towards cooler exterior surfaces - warmer seasons bring the opposite effect - referred to here as drying seasons. During these drying seasons, such as spring and summer, solar-driven vapour diffusion can cause vapour to move inward, reaching areas where the AVCL is typically located, on the interior side of the building fabric (Marincioni and Altamirano-Medina, 2014). This inward vapour movement results from the evaporation of liquid moisture in outer layers of the building envelope. Inward vapour diffusion occurs regardless of whether an AVCL is present; however, if a barrier to vapour movement exists, this inward vapour flux may be blocked, inhibiting effective drying and potentially leading to moisture accumulation. A balanced approach to vapour control should account for this process to prevent moisture accumulation and support effective drying.

It is not unusual for the vapour permeability of building materials to vary according to humidity, and variable diffusion membranes were developed to enhance and exploit this variation. These membranes were developed to take advantage of the seasonal changes in humidity and vapour conditions. They have a high resistance to vapour during the wetting season in autumn and winter, when the membrane itself is in relatively dry conditions. Conversely, they have a lower resistance to vapour during the drying season, when the building envelope is drying and conditions near the membrane are more humid. Originally developed for roofs and tested on unvented roofs (Künzel, 1999), variable diffusion membranes can now be found in other building fabric components, such as internally insulated walls or timber-frame walls.

Research on variable diffusion membranes has included a comparative analysis of different membrane materials. Künzel and Leimer (2001) compared a composite fabric/polyethylene membrane with a nylon-based membrane. While both materials demonstrated similar performance, the mechanisms for moisture transport in each were found to be distinct. The composite fabric/polyethylene membrane was effective only when sufficient condensation formed to initiate capillary (liquid) transport within the layered fabric. In contrast, the nylon-based membrane facilitated the drying process as soon as the vapour pressure gradient reversed.

More recently, vapour transport through variable diffusion membranes was further analysed, looking at the linearity of moisture gradients and the influence of vapour pressure gradients. Some membranes show a different behaviour based on the direction of flux (Fechner and Meißner, 2017). One such ‘directional’ membrane was found on the UK market, with different s_d-values declared based on direction (*see* 1.4 Product review). These findings call for a more in-depth characterisation of variable diffusion membranes, to ensure they are adequately represented in hygrothermal simulations. It is worth noting that simpler constant resistance AVCLs can be as effective as variable diffusion membranes in many cases, provided they are carefully specified and have an appropriate level of vapour control (s_d-value) for the insulation system, building fabric and climate.

In certain regions, the classification of AVCLs is based on their s_d-value. For example, in Norway, the recommended s_d-value range for vapour retarders is from 0.5m to 10m. In contrast, in North America, vapour retarders are defined within a range of 0.34m to 3.4m, and any material with an s_d-value greater than 3.4m is classified as a vapour barrier (Geving and Holme, 2013). However, it is important to note that such specific classifications based on s_d-values are not currently available for construction systems in the UK.

Finally, limited peer-reviewed evidence was found on the longevity of airtightness membranes and adhesives. A 2011 paper compared accelerated ageing of different adhesives and found adhesive failure in the case of polyethylene. Other substrates (such as polypropylene, polyamide and timber) were found to maintain adhesion after ageing tests (Gross and Maas, 2011). It is worth noting that adhesives designed for polyethylene substrates are now available.

Product review

The AVCL membranes available in the UK were identified via an Internet search and categorised according to their s_d-value. Figure 1 shows AVCLs with an s_d-value – declared in accordance with BS EN 1931:2000 – higher than 30m, and Figure 2 shows those with an s_d-value lower than 30m. The variable diffusion membranes are highlighted in green and they include a directional membrane.

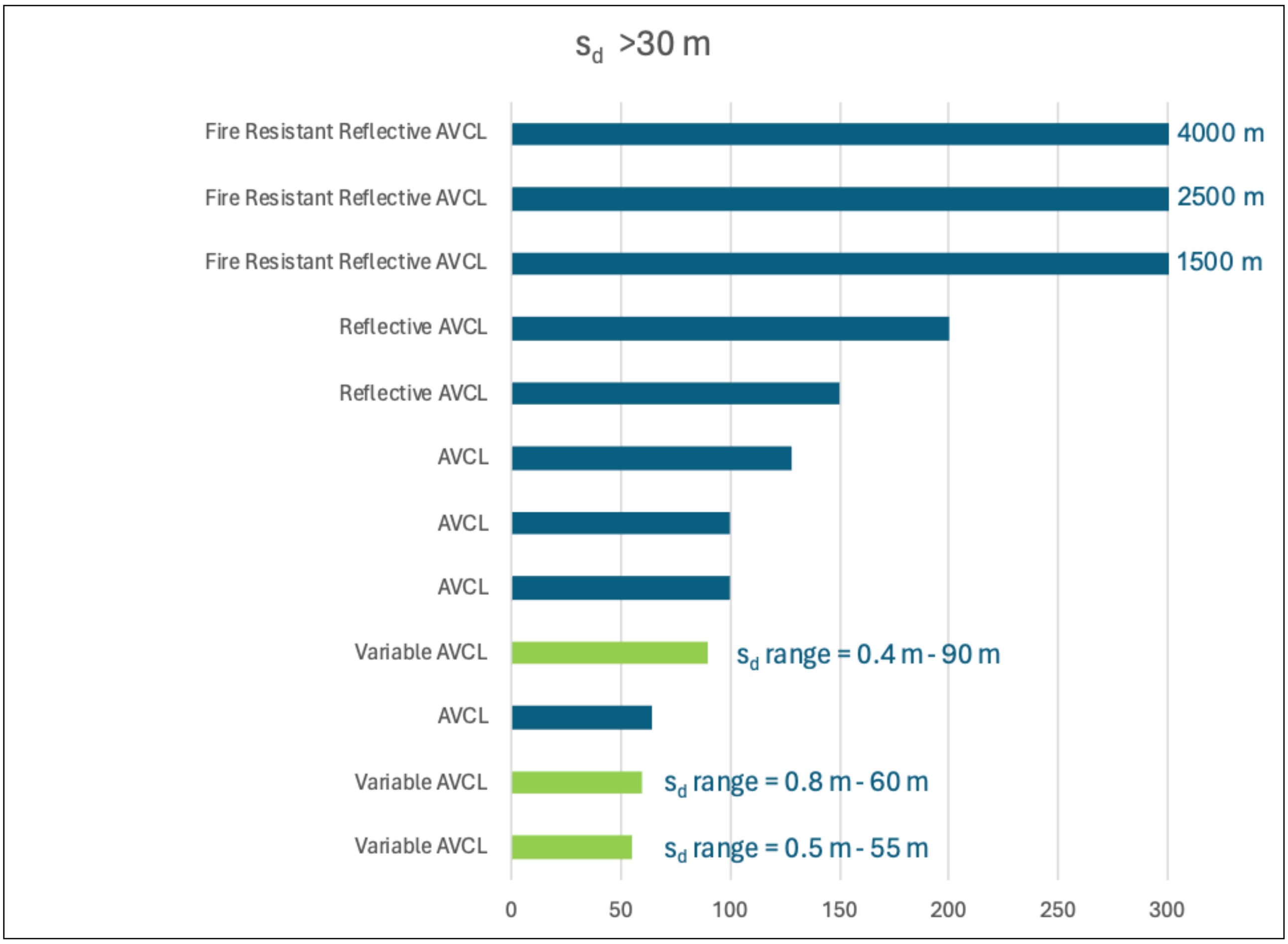

Figure 1: Classification of UK-available AVCLs, with s_d-values higher than 30m.

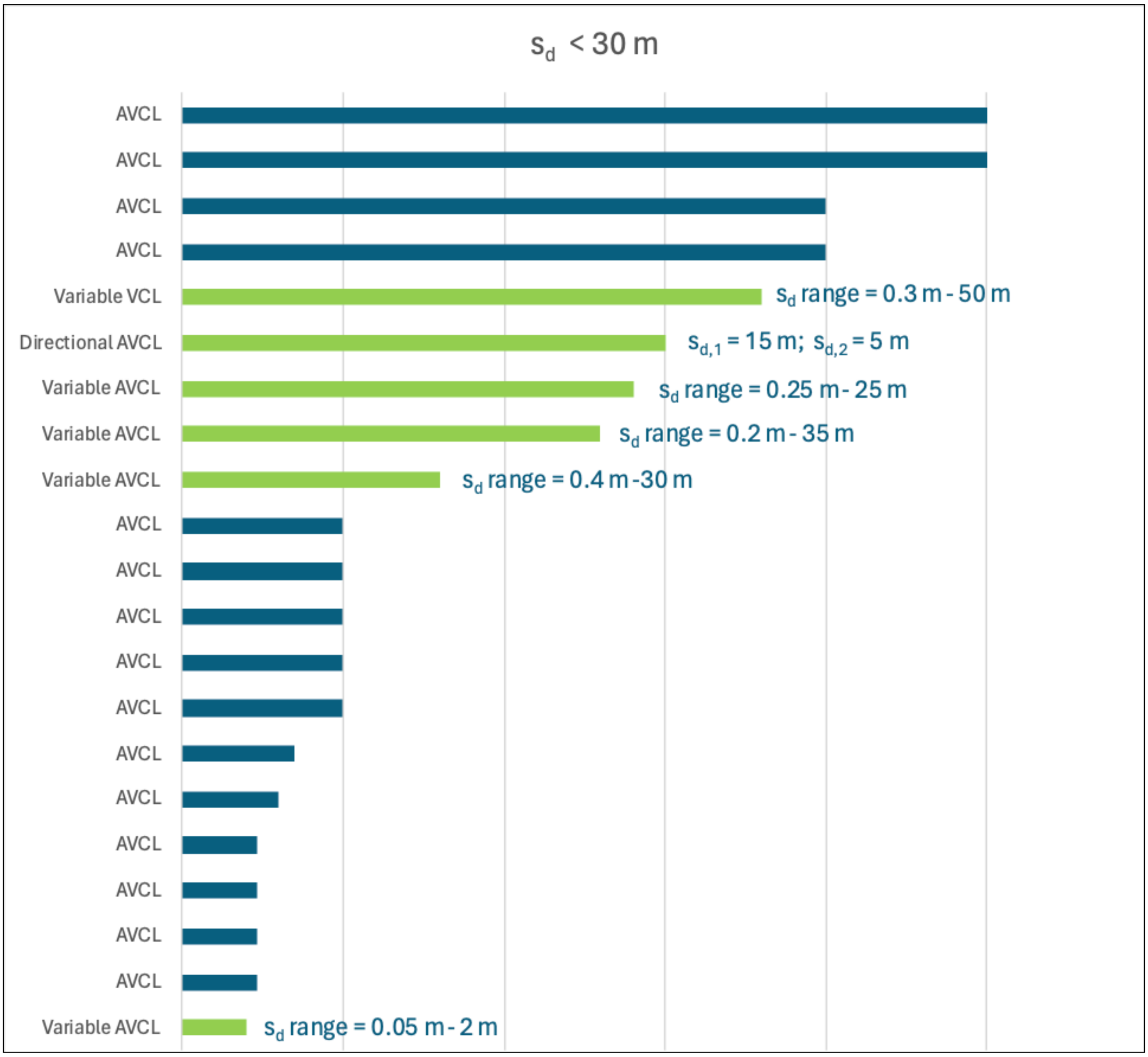

Figure 2: Classification of UK-available AVCLs, with s_d-values lower than 30m.

AVCL and moisture transfer: Summary

Conventionally, vapour barriers were used to prevent interstitial condensation within building elements by resisting vapour diffusion, in accordance with the Glaser method. This method *only* considers the effects of vapour diffusion and temperature gradients on interstitial condensation. However, evidence has shown that insulated building fabric systems, particularly in traditional buildings, are far more complex. Factors such as solar-driven vapour diffusion, hygroscopicity, bulk vapour transport and liquid moisture transport (capillary flow and gravity) play significant roles. This complexity has led to the development of AVCLs with low to medium vapour resistance, as well as intelligent membranes. These advancements are explored in the gap analysis below.

Literature review: Understanding system behaviour

As part of a low-energy retrofit of a traditional building, AVCLs might be specified in insulated roofs, suspended ground floors and/or wall insulation systems, if the system is deemed to require additional air and vapour control. Their effectiveness depends on their integration within the overall retrofit strategy.

The literature review aims to identify the function and performance of AVCLs and of the systems they are specified for, to gather evidence of the long-term impact of AVCL membranes on moisture movement in traditional construction, and the effect on both building fabric and thermal performance of insulating materials and systems. The report aims to explore the dynamics of systems (i.e. walls, floors and roofs) incorporating retrofitted AVCLs. It also looks to find evidence of failure modes and longevity in building fabric systems with AVCLs, by means of simulations, observations and monitoring. The literature review focuses on developments over the past 25 years in building fabric systems that are likely to incorporate AVCLs. While the main focus is to review literature based on retrofit interventions, the low availability of such literature led the authors to expand the research to new build systems that can offer some insights for the retrofitting of traditional buildings. As mentioned previously, the result tables (*see* Appendix) present the quoted terminology as used by the authors of each paper, and the declared vapour resistance of the AVCL – and, when relevant, of the associated insulation system.

AVCLs always form part of a system of layers that make up a construction. As with any system, its behaviour depends on the interaction of the various components. The characteristics of an AVCL must, therefore, be considered in context to draw a meaningful conclusion.

Understanding the system behaviour can be informed by different approaches, such as:

- Applying principles and simple rules of thumb (for example, in the UK climate, placing an AVCL on the warm side of insulation, and ensuring that its vapour permeability is balanced for the system in which it is placed);
- Using quantitative models, such as the Glaser method, or numerical hygrothermal simulations, to estimate likely conditions;
- Monitoring real buildings.

It is often useful to combine two or more of these approaches. Simulation tools such as WUFI and Delphin allow the behaviour of systems to be estimated quickly, including exploring how different AVCLs influence the overall performance of a particular build-up, i.e. the combination of the insulation system and the existing wall, for example.

Monitoring studies have the advantage of revealing real-world behaviour, but they take longer and require a real building to measure. Testing many different permutations (of AVCLs, for example) is often not practical.

It is recognised that oversimplification in modelling can lead to substantial error and using the steady-state Glaser method for condensation analysis has been demonstrated to be unreliable, particularly in complex retrofit cases (McLeod and Hopfe, 2013). The evidence of complex interactions in systems with AVCLs calls for moving away from the Glaser method towards more representative dynamic approaches to moisture analysis, such as using hygrothermal simulations (May and Sanders, 2017).

2.1 Internal Wall Insulation

AVCLs are usually installed on the warm side (internal side) of internal wall insulation (IWI) to control vapour diffusion and bulk air flow from the internal space into the colder regions of the wall (Saïd et al., 2003). An AVCL is often used for this purpose, but wet plaster can also be utilised in some wall insulation systems. Internally insulated walls are influenced by various moisture sources, including those originating from occupants, the ground, wind-driven rain and potential leaks. There is also evidence of non-negligible solar-driven vapour diffusion occurring in internally insulated walls in the UK (Marincioni and Altamirano-Medina, 2014). The measurement and simulation of IWI systems with AVCLs, based on existing literature, are explored in Tables 1 and 2 of the Appendix, a summary of which is given below.

Measurement (*see* Table 1): The tested IWI systems included mineral wool with AVCL, and phenolic foam insulation with aluminium foil, alongside capillary-active systems based on wood fibre, calcium silicate and other innovative systems with varying levels of vapour diffusion resistance. The types of AVCL varied from aluminium foil, polyethylene vapour barriers, to a vapour control layer of s_d = 3.5m; the analysed IWI systems without AVCLs had a total vapour resistance as low as 0.2m. All monitoring strategies included wired temperature and relative humidity sensors within the wall, although some experiments had a wider array of sensors (such as wood resistance for moisture content).

Recent studies in UK and Denmark showed that effective moisture management in IWI systems requires balancing vapour control. Current literature doesn’t identify a “best” insulation system, as performance varies depending on test conditions and factors such as wall orientation (Jensen et al., 2020a; Marincioni and Altamirano-Medina, 2023), exposure to wind-driven rain (Jensen et al., 2020a; Pagoni et al., 2024) solar radiation (Marincioni and Altamirano-Medina, 2023), wall thickness (Pagoni et al., 2024) and pH levels (Jensen et al., 2020a). Research has shown that while capillary-active, vapour-open systems allow drying (Rode, 2020; Marincioni and Altamirano-Medina, 2023), too little vapour resistance can make them sensitive to indoor conditions (Pagoni et al., 2024).

Studies on capillary active insulation, which incorporate AVCLs with low-to-medium vapour resistance (from 3.5m to 36m), highlight the effectiveness of capillary active systems when combined with some vapour control in the systems investigated (Marincioni and Altamirano-Medina, 2023; Rode et al. 2020). Such an AVCL limits vapour ingress during the wetting season while still permitting inward drying under favourable conditions. To identify the level of vapour control required in an IWI system, it is important to consider the wall interaction with the outdoor moisture sources, such as rainwater (Worch, 2009) or solar radiation (Marincioni and Altamirano-Medina, 2023).

Simulation (*see* Table 2): The modelling studies aimed to compare the hygrothermal performance of IWI systems and AVCLs. In agreement with the findings from in-situ measurements, the studies showed that capillary-active and 'diffusion-tight' (or vapour-closed) systems lead to different moisture behaviour, with capillary-active systems influenced by wall orientation (Soulios et al., 2019) and indoor moisture load (Jensen et al., 2020b). The capillary-active systems assessed in these Danish studies were found to be a more robust solution than the vapour-closed systems; however, both types of systems may be applicable depending on specific circumstances. In absence of clearer guidelines for the UK climate and traditional construction, these systems need to be evaluated on a case-by-case basis, as the specific details of their applicability have not yet been clarified.

Variable diffusion membranes can also be considered in some types of IWI assemblies (Price et al., 2021) and could be particularly useful in buildings where vapour pressure varies significantly. A study compared the behaviour of different AVCLs, including no AVCL, conventional vapour barriers (s_d = 100m), and variable diffusion AVCLs (Knarud et al., 2023). The study found that, while there is little difference in moisture risk among the AVCLs in the wetting season, in the drying season the variable diffusion AVCL allowed improved drying compared to the vapour barrier. However, more could be done to compare the hygrothermal performance of insulation systems with different levels of vapour control, under a wider range of realistic boundary conditions. The effectiveness of an insulated wall with an AVCL can be influenced by phenomena such as solar-driven vapour diffusion, hygroscopicity, liquid moisture transport (capillary flow and gravity) and breaches in the airtightness layers. Capillary active systems are promising and combining them with some additional vapour control could lead to improved performance. However, further evidence is needed on the impact of AVCLs on moisture movement in walls in the UK, particularly those of traditional construction and the effect of this on the longevity of the building fabric.

2.2 Timber-frame walls

The analysis of timber-frame walls is mostly related to new build constructions. However, some findings on the performance of AVCLs as part of an insulated building fabric system offer insights that may be relevant to other systems. In timber-frame walls, the AVCL is typically on the warm side of the insulation, although some studies evaluate the effectiveness of exterior airtightness membranes.

The existing literature on timber-frame walls is explored in Table 3 of the Appendix, which presents the modelling and experimental studies on the performance of timber-frame wall systems with AVCLs. Armstrong et al. (2009) found that sealing and properly installing AVCLs is essential in cold climates such as central Canada, where flaws in the barrier led to air leaks and moisture build up. In climates closer to the UK's, Desta et al. (2011) emphasises the role of AVCLs in reducing moisture accumulation within timber-frame walls insulated with mineral wool; in the monitoring study, the amount of absorbed moisture in the wall was found to be directly proportional to the vapour permeability of the interior finishing. Langmans et al. (2013) found that exterior air barriers could increase moisture loads due to natural convection of indoor air, while Geving and Holme (2013) suggests that timber-frame walls with variable diffusion AVCLs might have better drying potential than those with constant diffusion resistance membranes. Zhao et al. (2023) further emphasises the importance of vapour control layers, with an appropriate s_d-value for the construction to ensure moisture safety, especially when using very vapour-open insulation materials such as mineral wool, recommending their placement on the interior side of the insulation. These studies highlight the importance of properly specifying and installing AVCLs in timber-frame wall systems to manage moisture levels. They also suggest that the characteristics of an AVCL, such as its vapour diffusion resistance and location within the building envelope system build up, can significantly impact the moisture dynamics within the wall system. However, most of these studies focus on conventional timber frame construction, with mineral wool insulation and with no additional insulation outside the studs. Capillary-active insulation could be considered to provide more robustness in timber-frame construction (Langmans and Roles, 2014). Also, these studies focus on the risks associated with exfiltration of indoor air, but evidence is limited on the impact of rainwater penetration and liquid moisture in timber-framed walls, and the subsequent influence of AVCLs on drying, as well as the effect of this on the longevity of building fabric.

2.3 Insulated roofs

By far the most common type of insulated roof in the UK is a ventilated loft insulated at ceiling level. It rarely includes an AVCL, and moisture control relies on ventilating away water vapour via diffusion and bulk air movement. In a sloped roof insulated at rafter level, air and vapour control should be provided on the warm side of the insulation. An AVCL is often used for this purpose, but wet plaster can also be utilised in some roof insulation systems. The effectiveness of an insulated roof with an AVCL can be influenced by phenomena such as solar-driven vapour diffusion, night-time clear sky radiation and breaches in the airtightness layer. In some cases, insulated flat roofs can be particularly at risk of excess moisture accumulation within the structure because they lack the additional drying mechanism provided by the ventilation gap in a pitched roof (Künzel et al., 2012). Without this ventilation, the balance between wetting and drying is not always ensured, particularly if air leakage from the indoor environment is considered; Künzel et al. found that using ‘vapour retarders’ rather than ‘vapour barriers’ could enhance drying in such situations by allowing greater vapour permeability when drying is needed.

The existing literature on insulated roofs is explored in Table 4 of the Appendix. Although limited, it uses monitoring and dynamic hygrothermal simulations for insulated roofs and explores the effectiveness of intelligent membranes. A monitoring study on loft insulation (and an AVCL located under the insulation) found that AVCLs can play a crucial role in maintaining optimal moisture levels and preventing issues such as mould growth in loft spaces, particularly where there are reduced ventilation rates (Morelli et al., 2020). A monitoring study of a cold zinc flat roof shows that while AVCL systems effectively manage moisture in timber components, they struggle to prevent severe condensation on roofing materials such as zinc sheeting (Zheng et al., 2004). A simulation study showed the ability of variable diffusion AVCLs to enhance drying potential in highly insulated low-pitched roofs, emphasising the importance of proper AVCL selection and the value of hygrothermal simulations in supporting product specification (Buxbaum et al., 2010). Finally, a literature review (Roels and Langmans, 2016) on highly insulated pitched roofs identified the characteristics of a robust pitched roof: a compact roof, with a continuous air (and vapour) barrier system separate from the interior finish, an airtight wind barrier and appropriate sealing techniques.

Like timber-frame walls, there is limited evidence on the impact of rainwater penetration and liquid moisture in insulated roofs and the subsequent influence of AVCL on drying, as well as the effect of this on the longevity of building fabric.

2.4 Suspended ground floors

The performance of an insulated floor with an AVCL can be influenced by factors such as moisture migration from the ground, temperature fluctuations and breaches in the airtightness layer. In the retrofit of suspended ground floors, AVCLs are typically installed on the warm side of the insulation and combined with breather membranes on the cold side and vapour-open insulation. This set-up allows flexible insulation to stay in place, and vapour to escape from the insulated ground floor system. Other systems with closed-cell insulation (and without AVCL) are available on the market.

Suspended ground floors with AVCLs have been examined primarily from an energy perspective, focusing on aspects such as thermal transmittance (Pelsmakers and Elwell, 2017). However, the durability and specific role of AVCLs in suspended ground floors remain under-researched. While there is some evidence on the airtightness of insulated suspended ground floors, these studies (Glew et al., 2020) do not specifically investigate systems incorporating AVCLs. Similarly, research on moisture levels in floor voids exists (Pelsmakers et al., 2019), but does not sufficiently address the role of AVCLs. Evidence is also limited on the impact of rainwater penetration and escape of water in suspended floors and the subsequent impact of AVCLs on moisture balance (during both wetting and drying), as well as the effect of this on the longevity of building fabric. Further research is, therefore, needed to fully understand the implications and benefits of AVCLs in suspended ground floors.

Discussion

In the field of insulated building envelopes, the focus has been shifting from individual materials to the entire system. This holistic approach considers the interplay of all building components and their collective impact on the hygrothermal performance of a building and the internal environment. An AVCL is one such component, and it can play a crucial role in managing vapour and air movement within the building envelope.

The characteristics of an AVCL, such as its resistance and position within the building fabric, can significantly impact the moisture dynamics and drying potential of the building. Various phenomena can affect the moisture balance of building fabric components, including rainwater ingress, solar-driven vapour diffusion and night-time clear sky radiation. When selecting a type of AVCL (including materials other than synthetic membranes), it is important to consider the characteristics and behaviour of the entire system, in order to achieve safe moisture levels. Failure to do so carries the risk of moisture imbalance, potentially leading to issues such as mould growth, fabric decay and structural damage.

In some situations, variable vapour diffusion can be a useful feature of an AVCL, especially when drying to the inside is necessary but would not be achievable with an AVCL of constant vapour resistance. However, aside from such cases, it is often possible to manage moisture effectively either by using AVCLs with constant vapour diffusion resistance, traditional materials – which have an intrinsic level of resistance to vapour diffusion – or, in some instances, even without a dedicated layer.

The literature shows that the effectiveness of an AVCL in an insulation system can be evaluated using hygrothermal simulations. These simulations can predict the performance of an AVCL under various conditions, providing valuable insights for the design and selection of the insulation system. When it comes to *in situ* measurements for an AVCL, temperature and relative humidity are critical parameters to monitor. They can be combined with other measurements, depending on the scope of the research. It is important to use sensors that are calibrated for high relative humidity, and to measure the boundary conditions.

It is beneficial to evaluate the performance of the building fabric after construction and when the building is occupied (May and Sanders, 2017), rather than relying solely on its designed behaviour. For components with an AVCL, breaches and gaps in the AVCL are likely to affect the overall performance of the component. The longevity of the AVCL is also a key consideration. Accelerated ageing has been used to test and further develop membranes and adhesives. However, literature on *in situ* testing of the longevity of AVCLs is limited. The Retrofit Revisit project led by CIBSE and Studio PDP (Godefroy and Baeli, 2024) addressed the topic of AVCL longevity in its airtightness measurements and found similar levels of airtightness 10 years after installation. The buildability (ease of proper installation) of an AVCL or of a system requiring one, is another important factor to consider, especially at junctions and in existing buildings of traditional construction.

When applying AVCLs in the retrofit of traditional buildings, there are several things to consider:

- Alternative materials: The function of an AVCL can be achieved using materials other than membranes, such as plaster or timber sheet materials (plywood, OSB). These alternatives can be connected to AVCLs in other building elements. They may also be simpler to install be considered more sympathetic and offer comparable performance.

- Heritage significance: The type of construction to which the AVCL is applied is important. While an AVCL might be technically practicable to accommodate, with varying degrees of ease which relate to construction type, feasibility of application may be influenced by considerations of heritage values and impact on significance.

- Reversibility: If the building needs to be modified or the insulation system requires updating, the ease of removing and replacing an AVCL is an important factor. An AVCL might be technically practicable to remove, along with its associated system, if placed on the inner or outer face of the existing structure. However, this is achieved with varying degrees of destruction, disruption, and expense.

- Detectability of Moisture: Trapped moisture hidden from view can cause undetected damage over time. The easier it is to identify a leak (e.g., from rainwater penetration or internal escape of water), the easier it is to address the issue and restore the moisture balance of the building. Although AVCLs may influence the ability to detect moisture, this aspect has not been fully explored and is necessary for the long-term durability of systems in real-world applications.

Despite the advancements in AVCL technology and application, there are still some knowledge gaps that need to be addressed. The role of constant and variable diffusion AVCLs depends on the specific performance of the building system, making it difficult to establish simple guidelines. It is necessary to understand and apply fundamental principles and, in some cases, simulate or model behaviour to determine the potential benefits and applications of AVCLs. Additionally, understanding the characteristics of traditional materials within the building system is necessary to model their behaviour with insulation and AVCLs. With regard to the long-term impact of AVCLs on moisture movement in traditional construction, including liquid and vapour transport, the evidence was particularly limited. There are some *in situ* studies that focus on internally insulated solid masonry walls (*see* Appendix: Table 1) and one study on a traditional zinc roof. More *in situ* analysis of a wider range of systems, considering a wider range of failure modes, is necessary.

Conclusions

This report explores the role and impact of AVCLs in insulated building fabric systems, with a particular focus on their use in retrofit solutions for traditional buildings. The study highlights the increasing prevalence of new AVCL products on the market and introduces the main properties used to express the water vapour resistance of AVCLs.

The review conducted in this report aimed to establish the existing evidence base for the functionality, performance, longevity, and failure modes of AVCLs, particularly in buildings of traditional construction. It also sought to understand the long-term impact of AVCLs on moisture movement in traditional and new build construction and the effect of AVCLs on the performance of insulating building fabric systems.

Regarding the evidence base on the functionality and performance of AVCL membranes, the review found few comprehensive studies on the performance of AVCL membranes in building fabric components. This highlights the need for a detailed analysis to determine the most suitable application of AVCLs under different construction types and climates. Classifications of AVCLs for the climate and construction systems in the UK are not currently available. Simulation studies could be used to develop these classifications. Also, there is insufficient long-term *in situ* evidence on the durability and longevity of AVCL membranes and their adhesives or jointing compounds. Accelerated aging tests exist, but real-world longevity studies have not been published to date.

The published studies suggest that moisture balance is influenced by the choice of AVCL. An inappropriate specification can, therefore, lead to moisture imbalance, potentially causing issues such as condensation, mould growth and structural damage. In internally insulated walls, the presence of an AVCL with low-to-medium vapour diffusion resistance was found to be beneficial for managing moisture, particularly when used in combination with other system characteristics, such as in capillary-active, fully bonded systems (Rode et al, 2020; Marincioni and Altamirano-Medina, 2023; Pagoni et al., 2024). In other examples, such as the study of a well-insulated flat zinc roof, the AVCL-based insulation system analysed could not prevent condensation at the critical area. For these situations, variable diffusion AVCLs could be advantageous (Buxbaum et al., 2010; Knarud et al., 2023), although there is limited evidence of their *in-situ* performance in traditional buildings. Additionally, evidence was particularly limited on the long-term impact of AVCLs on the drying of liquid moisture in traditional construction. Thus, more research is needed to establish the suitability of AVCLs in insulation proposals for traditional buildings. To this end, collecting evidence on the performance of existing applications can help identify common issues in systems with AVCLs.

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Appendix: Tables

The following tables present a summary of the main papers reviewed in this study, specifically reporting the AVCL-related terminology as used by the authors. These tables aim to provide clarity on how each study approached AVCLs within their respective methodologies and highlight key findings. For each study that focused on Internal Wall Insulation (IWI) systems, the table also details monitoring equipment and materials used in the wall and insulation.

Table 1: Measurement of IWI systems with AVCLs.

Reference	Method and insulation system	Key findings	Monitoring equipment
(Saïd et al., 2003)	A four-storey 330 mm solid brick wall in central Canada was retrofitted with insulation and vapour and air barriers installed on the interior side of the wall. The building was subject to continuous monitoring for over two years to analyse its hygrothermal performance.	The air and vapour barriers in the retrofit did not significantly change the drying rate of the brick wall in summer, but the wall drying potential was reduced during winter, likely due to the presence of the insulation (and not the AVCL). Additionally, the freeze-thaw cycles and moisture levels in the brick were found to be higher after the retrofit.	This study focused on a brick wall insulated with mineral wool. Moisture monitoring was facilitated using various sensors: ceramic (resistance) sensors, moisture pin (resistance) sensors and time-of-wetness moisture sensors (Sereda et al., 1982). The experiment also incorporated heat flux sensors, pressure transducers, relative humidity (RH) sensors and thermocouples.
(Jensen et al., 2020a)	The study involved an experiment with 16 solid masonry walls (358 mm thick) in Denmark, monitoring different IWI systems for two years to assess the hygrothermal performance and mould growth risk. The IWI systems consisted of mineral wool with a vapour barrier (sd = 140m), phenolic foam with aluminium foil (sd = 10,000m), and lime-cork insulating plaster (sd = 0.266m).	Phenolic foam systems with higher vapour resistance showed lower levels of RH between the wall and insulation, although mould growth was predicted to be high in most cases. However, within embedded wooden elements, the mineral wool system showed the highest RH, close to condensation, while the phenolic foam and plaster systems showed comparable results, similar to the uninsulated wall. Mould level quantification was more influenced by the pH levels than by RH, with lower mould levels at higher pH under similar RH levels.	Temperature and RH were monitored and recorded at 10-minute intervals using digital HYT221 sensors positioned in nine distinct locations within each test wall, including the wall-insulation interface and wooden elements (i.e. wall plates and joist ends), as well as indoor and outdoor environments. Mould level quantification and pH measurements were also performed and compared with mould prediction from T and RH measurements.

(Rode et al., 2020)	The study used laboratory experiments and field measurements in Denmark for three years to evaluate the performance of three capillary-active IWI systems: (i) calcium silicate (CaSi, sd = 0.3m), (ii) closed-cell PU foam combined with capillary-active strips (sd =2.16m) and (iii) a newly developed system with mineral wool, an AVCL and a capillary-active layer. (sd = 36m).	Although RH trends were similar, differences in RH levels were observed at the wall-insulation interface among the three capillary-active systems tested, with systems (i) and (ii) showing higher interstitial RH levels than system (iii). However, at the joist ends, more similar RH levels observed across the systems.	Wired Sensirion SHT75 sensors were installed in 7 locations to measure temperature and relative humidity; the locations included the interface between the wall and the insulation, two locations within the masonry, the joist ends and another location within the joist.
(Marincioni and Altamirano-Medina, 2023)	Two case studies of capillary-active wood fibre insulation systems were monitored in solid wall buildings in England (330mm solid brick wall, and 400-450mm stone wall) for over one year. The IWI systems analysed were: (i) composite dense wood fibre board with lime plaster as adhesive and interior finish (total sd = 0.83–1.03m) and (ii) a system made of a clay-wood board bonded to the wall, lightweight wood fibre and a low-resistance AVCL (total sd = 3.77m).	The study emphasised the importance of wall orientation and outdoor climate, especially wind-driven rain and solar radiation, on the performance of internally insulated solid walls in the UK. Similar to Rode et al, (2020), this paper showed that not all capillary-active wood fibre insulation systems perform the same; while all tested systems showed effective inward drying, the system with a low-resistance AVCL showed lower RH in the wetting season.	Relative humidity and temperature sensors, specifically HOBO H08-003-02 units, were installed at the wall-insulation interface and within the layers of the IWI, to measure interstitial conditions. Indoor and outdoor conditions were also measured.
(Pagoni et al., 2024)	The study conducted hygrothermal measurements on two case studies with solid brick walls (228-360 mm thick) and two with cavity walls, in Denmark. The solid walls were internally insulated with different insulation systems: phenolic foam with aluminium foil (sd = 6,000m) in case study 1, and autoclaved lightweight AAC (sd = 0.2m) in case study 2.	Although the systems performed differently, the risk of mould growth was generally low for both IWI systems in most areas of the 350-360mm walls. In contrast, the risk was higher in the thinner 228mm wall (only the AAC system was tested). Additionally, for the system with sd = 0.2m, excessive indoor moisture led to high RH in the construction in colder months, making it necessary to maintain moderate indoor humidity.	Temperature and relative humidity sensors of the type Rotronic HygroClip2 and Rotronic HL-RC-B were installed in the building system, at various depths.

Table 2: Simulation of IWI systems with AVCLs.

Reference	Method	Key findings
(Soulios et al., 2019)	Different insulation systems were tested, including ‘vapour-tight’ systems such as XPS (s_d = 36m), and mineral wool (MW) with a vapour barrier (MW+VB, s_d = 70m), and capillary active systems such as calcium silicate (s_d = 3.68m), and PU foam with capillary-active strips (s_d =3.83m) . Simulations were performed with Delphin, using a Danish weather file, to assess heat loss, moisture content levels and potential moisture-related damage.	Introducing internal insulation raised moisture levels in the original wall, increasing the risk of problems like mould and condensation. During winter, the moisture content of XPS and MW+VB was higher than the capillary active systems, with calcium silicate showing notably lower moisture risk. Wall orientation did not notably affect the heat loss of XPS and MW+VB, although it had an impact on the heat loss of capillary active systems, calcium silicate in particular.
(Jensen et al., 2020b)	The hygrothermal performance of four solid wall insulation systems (PU foam with capillary-active stripes, s_d = 2.56m ; CaSi, s_d = 0.55m; phenolic foam with aluminium foil, s_d = 10,000m; AAC, s_d = 0.5m) were investigated using calibrated numerical simulations based on two to four years of experimental data. The simulations, through Delphin, tested different design options for the Danish climate by changing the thickness of the walls and insulation, the types of bricks and mortar used, the indoor moisture load and the potential future weather patterns.	Regarding the vapour barrier, the paper suggests that the modern diffusion-open capillary-active systems and the diffusion-tight (Phenolic foam) system manage indoor moisture differently. The vapour barrier’s role, as delineated by the diffusion-tight system, underscores its effectiveness in protecting the structure from moisture ingress. However, the adaptability of capillary-active systems to manage indoor moisture without a traditional vapour barrier suggests a nuanced approach to vapour management.
(Knarud et al., 2023)	The study conducted hygrothermal simulations of a solid brick wall, internally insulated with mineral wool, in wetting and drying conditions in Norway to investigate the uncertainty in hygrothermal simulation and the impact of modelling choices or simplifications. Vapour barrier effects were specifically explored by comparing the performance of a smart vapour barrier ($s_{d,\,dry}$ = 15.6m) with no vapour barrier and conventional polyethylene barriers (s_d = 100m) under varying conditions.	While simulations showed little difference in relative humidity and moisture risk among the AVCL scenarios during the wetting season, in the drying season the smart vapour barrier demonstrated improved drying compared to the polyethylene vapour barrier. The drying rate was highly dependent on the vapour resistance of the smart vapour barrier, with lower vapour resistance during drying proving more beneficial. However, the simulations indicated that the vapour resistance of smart vapour barrier had an almost insignificant influence on the drying of the joist ends under the studied conditions.

Table 3: Performance of timber-frame wall system with AVCLs.

Reference	**Method**	**Key findings**
(Wilkinson et al., 2007)	Ten wall assemblies with and without polyethylene vapour barriers, were tested in central Canada, considering above-grade timber-frame walls and below-grade concrete walls. Monitoring included variables such as temperature, humidity, wood moisture content and other factors for analysis.	The presence of polyethylene vapour barriers affected wintertime and summertime condensation risks differently: in winter, the risks were reduced, but in summer, they increased. Additionally, below-grade walls without polyethylene and with XPS sheathing maintained safe moisture levels throughout the year, staying below the threshold for mould growth.
(Armstrong et al., 2009)	A monitoring study was conducted in central Canada to examine interstitial condensation in wood-frame walls by analysing three identical test specimens of a conventional timber-frame wall. The test specimens were exposed to different levels of indoor relative humidity and air leakage to assess the condensation potential in different wall layers. Specific deficiencies, such as openings in the air/vapour barriers using polyethylene, were introduced to see how the walls responded to air leakage in terms of condensation and moisture levels.	When the air/vapour barriers were intact and sealed, the interior remained well protected, preventing moisture from the chamber seeping into the wall, even in external conditions conducive to condensation. However, when flaws were introduced in the air barriers, they caused air to leak out and humid indoor chamber air to enter the stud cavity. This led to condensation on the inner surface of the sheathing board. The study emphasised the importance of maintaining airtightness and ensuring proper installation of air/vapour barriers to avoid air leaks and reduce interstitial condensation in timber-frame walls in cold climates.
(Desta et al., 2011)	The experiment involved a timber-frame test wall insulated with mineral wool and divided into three sections, each designed for distinct air and vapour movement characteristics, and exposed to the Belgian climate. These sections included a reference part with a polyethylene foil air and vapour barrier (sd = 20m), a section with a wooden finish and a part with uncoated gypsum board. Sensors were positioned within the wall to track temperature, humidity, heat flux and pressure variations.	The study examined of air and vapour barriers in a timber-frame wall on moisture accumulation and transportation. Results showed that the vapour-open sections led to higher moisture accumulation compared with the reference section with the vapour barrier. The amount of absorbed moisture was found to be directly proportional to the vapour permeability of the interior finishing.

(Langmans et al., 2013)	Laboratory tests and numerical simulations were conducted to study the hygrothermal consequences of using an exterior air barrier in a lightweight timber-frame wall insulated with mineral wool, considering the Belgian climate.	Exterior air barriers can lead to increased moisture loads due to natural convection. They are useful in excluding forced air exfiltration but the lack of an interior air barrier may result in increased moisture due to vapour diffusion through the interior finish towards the exterior of the wall.
(Geving and Holme, 2013)	Hygrothermal simulations were conducted using WUFI to analyse the impact of installing permeable vapour retarders in timber-frame walls in Norway. The simulations included different configurations of timber-frame walls with variations in vapour retarder properties and moisture content scenarios.	The study found that vapour retarders with constant vapour resistance have limited usefulness in regard to increasing the drying speed in wood frame walls with vapour-open wind barriers, due to the higher influence of outward drying. To achieve substantial inward drying in timber-frame walls with very vapour-open wind barriers (sd<0.02m), the vapour resistance on the warm side needed to be relatively low, typically below sd = 1–2m, which may lead to higher moisture accumulation in the wetting season. The study suggested that intelligent vapour barriers with adaptable resistance might be more useful in increasing drying potential while reducing wetting.
(Zhao et al., 2023)	This study used WUFI to test different ways of insulating traditional timber walls in China. The analysis considered the position of the vapor barrier/ retarder in relation to the mineral wool insulation layer (installed either on the internal or external side) and its sd-value (sd = 2m, sd = 1500m).	The study found that a vapour control layer was needed to ensure moisture safety. Without it, cases showed high moisture content in the traditional timber layer. Cases that used a moisture-adaptive vapour retarder did not fare well when it was applied on the external side in combination with mineral wool, suggesting that it should be installed on the internal side of the insulation. A vapour barrier with an adequate sd-value (not less than 2m) was suggested on the interior side of insulated systems with vapour-open materials. The use of vapour-tight insulation materials like XPS did not require additional vapour control layers.

Table 4: Performance of roof system with AVCLs.

Reference	Method	Key findings
(Zheng et al., 2004)	This study assessed hygrothermal performance of well-insulated cold zinc roofs in a test building in Belgium. Four roofs were constructed with a pitch of 5^{o} and high levels of insulation and were exposed to 28-month monitoring of temperature, humidity, moisture content and heat flux. The study considered mineral wool insulation and polyethylene vapour barrier.	The study highlighted that the air vapour barrier system was effective in maintaining moisture levels in wood components but did not prevent severe condensation on the underside of zinc sheeting. Controlling air exfiltration from the indoor environment significantly reduced condensation risk, although this risk remained high on zinc sheeting undersides.
(Buxbaum et al., 2010)	The study investigated the hygrothermal behaviour of non-ventilated, highly insulated timber-framed low-sloped roofs in the climate of Central Europe. Various roof assemblies with different vapour retarders were analysed, focusing on the drying potential in shaded and unshaded conditions. WUFI was used to conduct transient hygrothermal calculations over a five-year period.	The use of 'humidity-adaptive vapour retarders' significantly influenced the remaining moisture in the analysed roof constructions, promoting faster and more effective drying. Proper vapour retarder selection was crucial for managing moisture levels and avoiding issues like mould growth and wood decay. Also, the study highlighted the non-negligible impact of shading on the effectiveness of low-sloped roofs.
(Roels and Langmans, 2016)	This paper provided practical recommendations, based on a literature review, for highly insulated pitched roofs. The analysis considered the effects of undesired air movement, which is caused by in/exfiltration, natural convection and wind-washing.	The air barrier system ensured a tight contact between insulation and interior/exterior surfaces, minimising the risk of air circulation. Interior air (and vapour) barrier systems should be separate from interior finishes to avoid potential damage and maintain airtightness. A robust pitched roof can enhance thermal performance and mitigate the impacts of undesired air movement. Recommendations include a continuous air (and vapour) barrier system at the inside of the insulation layer, high-density insulation, airtight wind barriers and appropriate sealing techniques.
(Morelli et al., 2020)	The study conducted measurements of temperature, relative humidity and ventilation rates in attics with different ceiling constructions to assess hygrothermal conditions. Tracer gas measurements were employed to validate reduced ventilation rates and investigate the role of vapour barriers in controlling moisture levels within the attic space.	The presence of vapour barriers under the loft insulation was found to be essential in maintaining balanced humidity levels in lofts, especially in case of poor ventilation in the loft.

Glossary

Bulk vapour transport - Bulk vapour transport describes the movement of vapour with air flow, for example through leaks or openings, as vapour moves along with air across pressure gradients.

Capillary flow - Capillary flow is the movement of liquid water through open and interconnected pores in materials, driven by the attraction between the liquid molecules and the surface of the material (capillary action).

Drying season - Time period, typically during warmer months, when environmental conditions favour evaporation and drying of building materials and overall reduction of moisture content in the fabric.

Equivalent air layer thickness (sd) - The sd-value represents the vapour diffusion resistance of a layer, expressed in relation to the vapour diffusion resistance of still air. This is a common quantity to describe the vapour diffusion resistance of AVCLs and membranes. Units: m.

Solar-driven vapour diffusion - Refers to the inward movement of moisture driven by increased vapour pressure when solar radiation heats the building exterior. The rise in surface temperature accelerates the evaporation of liquid water within the masonry, increasing the vapour pressure at the outer layers of the building fabric and promoting inward vapour movement.

Vapour barriers - Materials with very high vapour diffusion resistance. Vapour barriers are designed to prevent almost all vapour movement.

Vapour diffusion resistance coefficient (μ) - The ratio of the resistance of a material to water vapour diffusion compared to that of still air at the same temperature and pressure. A higher μ-value indicates greater resistance to vapour diffusion. This property is material-specific and independent of thickness. Units: dimensionless (no units).

Vapour permeability (δ) - A measure of the ease with which water vapour diffuses through a material. Units: g·m/(MN·s).

Vapour resistivity ($^1/_\delta$) - The inverse of vapour permeability, describing the resistance of a unit thickness of material to water vapour diffusion at unit vapour pressure difference. Higher vapour resistivity indicates greater resistance to vapour diffusion. Units: MN·s/(g·m).

Vapour retarders - Materials with moderate resistance to water vapour diffusion. They are designed to allow some vapour diffusion through.

Wetting season - Time period, typically during colder months, when environmental conditions favour moisture ingress into the building fabric and increase of overall moisture content.

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