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SHEEPISH Report for Energy Project Enabling Fund - Round 2

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Executive Summary

This report presents the findings from part of the Peacock and Verity SHEEPISH Development Stage project, which is funded by the North East and Yorkshire Net Zero Hub's Energy Project Enabling Fund. The SHEEPISH project aims to develop 15 Silver Street, Masham, North Yorkshire, using bioconstruction materials, particularly sheep's wool insulation (SWI), become a SWI training site for installers across Yorkshire and the North East, and create a stakeholder cooperative into a robust circular SWI supply chain.

Leeds Sustainability Institute has been appointed by Peacock and Verity to consult with stakeholders to find out whether there is support for a Yorkshire-based SWI supply chain, advise on how the performance of SWI at 15 Silver Street could be monitored over time, and perform hygrothermal simulations of building elements at 15 Silver Street to assess whether there are any moisture risks associated with using SWI.

Twelve stakeholder interviews were conducted in February 2024 with participants from four stakeholder groups: Yorkshire sheep farmers; general contractors; private and social housing clients; and both SWI suppliers and wool merchants. Participants talked about their current beliefs about SWI, barriers to its use, the potential of developing a Yorkshire SWI market and rationale behind it. Cost was perceived to be the main barrier to increasing use of SWI. Farmers were willing to supply their fleeces if it were financially advantageous to do so, but despite the cost of raw wool making up a fraction of overall manufacturing costs, SWI suppliers and wool merchants thought there would be little opportunity to pay farmers more for their fleeces. There is already a SWI manufacturer based in Yorkshire but for a collaboration to develop, demand for Yorkshire SWI would need to grow. This could be stimulated by promoting the low-carbon, safer-to-install and breathable credentials of SWI to a potential Yorkshire client base, such as private homeowners, prestige commercial organisations, and those with historic assets or a sustainable ethos.

Literature on SWI indicates favourable performance for improving air quality, controlling moisture levels and reducing sound transmission. However, most of this data comes from laboratory testing which does not replicate the reality of a product's performance within a construction, highlighting the value of capturing *in situ* performance data at 15 Silver Street. A range of monitoring options, together with practical considerations, are discussed. We recommend monitoring SWI moisture levels over an extended period and measuring air quality during SWI and conventional insulation installation periods for comparison.

Moisture behaviour and breathability of SWI is often considered to be a benefit; however, natural materials can be more vulnerable to decay due to moisture accumulation over time. Hygrothermal simulation models the movement of heat and moisture through materials in a representation of a building element, such as a wall or roof, in response to internal and external climate conditions. Hygrothermal simulation models were used to assess the risk of moisture accumulation over time in selected external elements at 15 Silver Street following a retrofit. Modelling was carried out using the WUFI Pro version 6.7 software for four external wall build ups and three roof build ups, where each case was simulated for a virtual 3 and 10-year period. Overall, hygrothermal simulation indicates that the proposed build ups, including those using SWI, have low moisture risk. In each of the cases modelled, total water content declined over the simulation period or reached an equilibrium state that indicates a low risk of water accumulation in the building fabric. Therefore, the use of SWI appears to be as safe as the wood fibre insulation also specified in the design at 15 Silver Street.

Contents

1 Introduction

This report presents the findings from part of the Peacock and Verity SHEEPISH Development Stage project, which is funded by the North East and Yorkshire Net Zero Hub's Energy Project Enabling Fund. The SHEEPISH project has three aims: first, to develop a heritage building at 15 Silver Street, Masham, North Yorkshire, using bioconstruction materials, particularly sheep's wool insulation (SWI). Second, to become a SWI training site for installers across Yorkshire and the North East. Third, create a stakeholder cooperative that brings together regional farmers, SWI manufacturers and end users into a robust circular supply chain.

The SHEEPISH project addresses a series of gaps that currently prevent SWI from becoming a more accessible and viable bioconstruction material across Yorkshire and the North East. These centre around understanding the performance of SWI in region-specific stone-built properties as well as 20th-century social housing with regards to moisture movement and heat loss and creating a predictable and local market stream for farmers supplying their fleeces to manufacture SWI.

Leeds Sustainability Institute has been appointed to support the SHEEPISH project in three ways. First, by consulting with stakeholders to find out whether there is support for a Yorkshire-based SWI supply chain, and if so, what could it look like. Second, advising on how the performance of SWI at 15 Silver Street, Masham could be monitored over time, compared with alternatives, and showcased at the premises. Third, modelling hygrothermal simulations of building elements at 15 Silver Street to assess whether there are any moisture risks associated with using SWI. Therefore, the report comprises three sections: stakeholder interviews; building monitoring advice; and hygrothermal simulations.

2 Stakeholder interviews

2.1 Background

This research explores views of SWI from four stakeholder perspectives: Yorkshire sheep farmers; general contractors; private and social housing clients; and both SWI suppliers and wool merchants. We combine these four perspectives to develop an understanding of how the UK SWI industry currently works and whether there is scope for a Yorkshire SWI industry.

This work contributes towards two questions outlined in the Energy Project Enabling Fund Round 2 application by looking at the costs and barriers of SWI as well as the economic and ethical benefits of increased SWI use, and whether there is the potential for a viable Yorkshire SWI industry. Our findings can be used to inform a business model for Yorkshire SWI.

2.2 Methods

We conducted 12 semi-structured interviews across the four SWI stakeholder groups. Participants were selected from a list of contacts provided by Peacock and Verity. All had some knowledge of SWI. They were contacted about the study and provided with information about what taking part would involve. They were given the opportunity to ask questions before the interview and they provided informed consent to take part.

Interviews were conducted in February 2024 by phone or video and lasted an average of 26 minutes. They were transcribed using MS Teams and the transcripts checked manually for accuracy. The research received Leeds Beckett University ethical approval.

Table 2-1 shows the number of participants in each stakeholder group.

Table 2-1 Breakdown of interview participants

Stakeholder group	Number of interviews
Sheep farmers	3
General contractors	2
Clients – Social Housing	2
Clients – Private landlords	2
Supplier - Wool merchant / SWI manufacturer or supplier	3
Total	**12**

For the farmers, contractors, and clients, we asked participants whether they had heard of SWI and, if so, what they had heard. We explored their views about using sheep's wool as an insulation product, and whether they would be interested in supplying or using it (depending on their role). We spoke about what others might think if they were to supply or use SWI and what would make it easier or more difficult to start supplying or using SWI.

For wool merchants and SWI suppliers, we asked them about their role in the industry, their products, whether they would be interested in growing the market and what would make it easier or more challenging to do so. We also asked them whether they would be interested in using Yorkshire wool and whether there would be any benefit of the wool coming from Yorkshire.

2.3 Results

The results are described in four sections. We first summarise current beliefs about SWI, including interest in using it. Section 2 explores barriers to its use. The third section summarises the SWI process and the potential for developing a market for Yorkshire SWI. Finally, in Section 4, we summarise views on the rationale behind Yorkshire SWI.

2.3.1 Beliefs about SWI

Since our participants had been included because of their potential role in the SWI industry, they were all aware of this form of insulation, although their level of awareness varied. Several had previously used it: one installer had used it for one specific project and is an approved supplier. Another focuses on natural products and regularly uses SWI. Others had never used it. One of the farmers had read about SWI in the farming press and another has friends in other parts of the country who supply fleece for the insulation industry. One participant had learnt about it while studying but had not actually come across it in a professional capacity. They remembered that it had the potential to be a good insulation product but wondered whether there would be sufficient availability. Another had read about it but again had never used it. All participants had positive beliefs about its thermal properties.

> *"From the limited stuff I've looked at I think it has very good thermal values and I think it's quite good with dealing with moisture content as well." (I7, Social Housing Client)*

Participants believed that, as a natural product, SWI offers a sustainable alternative to mineral wool and fibreglass and they believed there would be several benefits associated with using a sustainable product. They discussed that sustainable products are becoming more mainstream, and that there is increasing demand for them.

> *"I have noticed within the industry and going to trade shows and meeting other newer established architects, there is definitely a big push for sustainable materials. You know, teachings from recent graduates have clearly changed and the architects seem to be the ones that are behind specifying these materials, so they're aware of the environmental concerns regarding other traditional materials." (I1, Contractor)*

Participants from housing associations believed that their tenants would support the use of a more natural insulation product, although the Board would be more interested in the cost of retrofit and the need to maximise their spending on reducing fuel poverty and moving towards net zero. They assumed that SWI would be more expensive than mineral wool, and so anticipated challenges from their Board if they were to recommend its use.

They talked positively about the benefits SWI would bring. One main benefit in addition to its good thermal properties is that it is breathable, so it is less likely than mineral wool to trap moisture, which could result in timber rotting.

> *"It's lovely to use, it's very suitable for the old buildings that we use because it is completely breathable, it's natural, it's assembly sourced." (I1, Contractor)*

Participants also believed that SWI is less of a health threat than mineral wool insulation or fibreglass. They talked about how mineral wool insulation has the potential to damage the lungs of people who inhale its fibres, especially when insulation is being cut during installation.

> *"Typically the mineral wools that we use are glass fibre and they the terrible for your lungs and once you start cutting into them and breaking them apart, it's impossible to clear up every trace of them." (I1, Contractor)*

> *"I imagine it would be easier to handle, less sort of, less nasty as sort of as a material to handle. So in that way it would actually be a positive change." (I6, Social Housing Client)*

As SWI was believed to be safe, participants talked about how it is more ethical to use, as it protects the health of the people who install it and the people who live or work in the buildings in which it is installed.

> *"It's a lot safer for our staff to work with. The other non-natural installations are terrible for your health and the environment." (I1, Contractor)*

Some participants were aware of other natural insulation products that are also believed to be breathable and safe, such as hemp fibre insulation. One participant talked about how there is a Scottish company in receipt of Scottish Government funding to develop hemp insulation, and they have seen significant cost reductions of this type of insulation as a consequence. Furthermore, this participant believed that hemp insulation is easier to install than SWI, and as such it is viewed as preferable to SWI.

> *"We do need to compare it to the hemp. We are very happy with the hemp fibre that we're using because it's a bit more rigid, it stands up straight within stud walls. It comes in a range of different widths and sizes which you know we try and buy it to the size we need. So we don't need to cut it and we can just install it and the sheep wool is a bit more bit more fluffy and a bit harder to deal with, which is absolutely fine when using it in attic spaces and for loft insulation, using its in between rafters and stud work and harder to reach places." (I1, Contractor)*

Participants were asked two specific questions during the interviews about the fire rating of SWI, and about the potential for infestation. Several participants were unsure about the fire rating, and how SWI compares with other insulation. Other participants described how fire rating is not an issue because the insulation is located inside the roof. The farmers were confident that SWI would be fire safe and highlighted how fleece does not burn easily.

> *"No, if you get a bit of wool and put a match to it, it will only smoulder. It doesn't burst into flames anything like that." (I4, Farmer)*

One supplier talked about how a competing brand of SWI mixed polyester in the wool, which meant that a chemical-based flame retardant had to be added to the product as a result.

In terms of infestation, one participant highlighted that this might be a perceived problem because of a “Grand Designs” television episode that featured this issue. However, they talked about how modern production methods mean that this should not be a problem for SWI. Other participants were not aware of any problems with infestations and so had not considered this issue until specifically asked.

> *“There was a Grand Designs episode where that was highlighted. That was quite a while ago though, and I believe the, but I know that the new stuff, it's ionically flashed, which supposedly changes the protein structure in the fibres, so that that is what the moths were feeding off. So that is changed now, so they shouldn't attack it and take it over.” (I1, Contractor)*

> *“The only negatives I think I've ever heard about it is that people have said about it can be prone to kind of like insects and pests. But I assume the fleeces are treated so that’s not an issue.” (I7, Social Housing Client)*

Participants talked about their beliefs about the costs of SWI. Those with no experience of using it assumed it would be much more expensive than mineral wool. Participants with experience of using it were aware of how the cost compares, and they talked about why they believe it is worth paying more for.

> *“I think it's about 30% more compared to Rockwool. But then when you factor in the health side of it and other non-financial aspects of it I think it works out better. And carbon, as well, once you start taking the carbon production side of it into it then if there was a financial equivalent of like that, that would be quite good, which I think is coming as well with all the corporate social responsibility stuff.” (I10 Private Client)*

2.3.2 Barriers to SWI use

Participants talked about several barriers that stopped them from using SWI. The most frequently mentioned barrier was cost, as SWI was reported as being between three and five times more expensive per m^2 than a conventional alternative such as mineral wool or fibreglass. One contractor participant pointed out that their clients are only interested in how well the insulation performs, and how much it costs.

> *“All people are bothered about, whether it's whether it's effective and how much it costs.” (I2 Contractor)*

For housing associations, participants described how their bottom line drove investment: higher costs for insulation across some homes meant that others missed out, which was not fair to their tenants.

> *“If we're using a product which costs more, essentially what happens is we can help fewer homes, you know, we can help fewer of our customers. So we have to then consider how equitable that is.” (I9 Social Housing Client)*

For private clients, cost was also a key driver behind insulation choice. One participant talked about how their private landowner clients were asset-rich but cash-poor, meaning that they were looking to make savings where possible.

> *"Some of my clients own like a whole village, so you have to kind of share the money, you know, fairly between the properties. So a lot of the time it comes down to cost." (I7 Private Client)*

However, for another private client, health, breathability and carbon savings were more important. They cited savings being made through having to install less mechanical ventilation as the homes were better able to breathe.

> *"The natural building materials tend to be breathable, so they're like vapour permeable. So we use them so that we don't have to put as much ventilation in." (I10 Private Client)*

For other private clients, it was a balance between cost, their property value and cash flow.

> *"They certainly want to be environmentally conscious as possible and trying to create a nice, low risk and healthy environment for their family… So they want that, but it does come at a slight premium overall, which they have to have to weigh up whether they can afford or justify it given the property's value." (I1 Contractor)*

One participant spoke about the reduced labour costs associated with installing SWI. Less time was needed to put on PPE, install the insulation and clean up afterwards.

> *"It was surprisingly quick to use… You don't have to, you know, mask up or fully protect all your skin from all these fibres, because it's just like a jumper, isn't it? You don't need PPE for a jumper." (I10 Private Client)*

However, an installer participant described the length of installation time as comparable between SWI and conventional insulation.

> *"The labour is comparable… It's a very similar type of material in terms of how you cut it up and how you use it, how you install it… It's a soft, squishy thing that you have to cut with a sharp blade. (I1 Contractor)*

Interestingly while SWI was more expensive, one supplier had noted that the cost of conventional insulation materials had risen due to increased energy costs, thus closing the cost gap.

> *"The cost of producing Rockwool and fibreglass and everything else has gone up dramatically because of energy costs. So we have found that we are much more competitive cost-wise now in the marketplace than we used to be. So the gap between us and those standard products is not as big." (I11 Supplier)*

Participants described how a lack of awareness across the industry acted as a barrier to SWI installation. This has manifested in different ways. One participant felt that a lack of understanding of natural insulation materials resulted in building professionals just specifying what they knew and were comfortable using.

> *"It's basically a lack of knowledge… I find that with everything when it comes to sustainable building practices, some people think just sticking Kingspan in something is gonna fix the problem or whatever or insulation-backed plasterboard is the norm." (I10 Private Client)*

In this instance, the participant took the opportunity to educate contractors so that they could talk more knowledgeably about natural materials to clients in future.

> *"I'm in quite a fortunate position that I know the building side of it, on this sort of information and technology side of it and the spec and scoping side of it. So I can give people the information they need to make that kind of decision, so I suppose it would be better for the builders to be better equipped with the knowledge to be able to tell their clients that it's better for their health and things like that." (I10 Private Client)*

Participants who had no experience of using SWI talked about it being somewhat niche so did not know much about the products and how they compared to conventional insulation. They asked questions, such as, "Do I need more or less SWI to reach a certain U-value? Is it easy to source? Will there be enough for the whole job? Will it fit through a loft hatch? It is more durable? Will it last longer? Will it slump over time?"

One participant with direct experience talked about how they made their clients aware of SWI and natural materials and that some take an interest as a result.

> *"If it wasn't for us informing [clients] about these materials, I don't think they'd know any better or simply give it a second thought. I think now some of our clients are more aware and are now more interested because of what we've done and then they do." (I1 Contractor)*

They also commented that SWI could be viewed as too unconventional by the public, so not trusted. They thought that a marketing campaign not focused entirely on sheep might be beneficial to the cause.

> *"I think people think it's a bit odd really. I think obviously they think of sheep wool, they think of, well, sheep obviously, and they don't really connect the dots between that and insulation… So perhaps if it wasn't branded as sheep wool, or it was just natural insulation and you didn't have the image of the sheep then, you know, people think of the smell, no doubt and shearing and all that comes with it… Potentially it sounds a bit a bit too environmentalist sometimes… People seem to have a distrust for things that seem too 'out there'… It's not seen as a wonder modern material, that is, you know, all singing, all dancing… Customers are certainly, you know, prefer those kinds of products really just because they're much better marketed." (I1 Contractor)*

One participant talked about how a lack of information about SWI in building regulations has led to uncertainty about whether or not its use would be approved and whether there could be any negative consequences. They gave an example of a university not installing SWI across its campus because of uncertainty around fire protection and building insurance.

> *"A reason for not going forward with the sheep's wool in their campus building was due to the fire safety concern… But I don't believe from a building control point of view that is a reason to not use it and then it becomes a bit of a grey area with building insurance I believe." (I1 Contractor)*

2.3.3 The SWI industry and its potential in Yorkshire

Our participants provided information about how the SWI industry works, and how raw wool is transformed into SWI to be installed in a building. Starting at the beginning of the process, the farmer shears the sheep, which can be done by the farmer and their family, or they can pay others to shear the sheep for them. It is wrapped and packed into sheets for haulage. It can take around an hour to pack a sheet which can weigh around 80 to 90kg.

It is customary for farmers to sell their wool to the British Wool Marketing Board, which is an organisation that works on behalf of the UK's 35,000 sheep farmers. The Wool Marketing Board is based in Bradford and has depots across England, Scotland and Wales. The wool is either collected from the farm by the Wool Marketing Board for a fee or farmers drop their fleeces off at a depot.

Once there, the wool is graded into between 100 and 200 different classes and farmers are given a value for it. Higher-grade wools are used for carpets, bedding or upholstery. Wool from commercial sheep, which are bred for their meat, such as the Texel or Swaledale is a lower-grade product. This wool is better suited to SWI. The raw, or greasy, wool is divided into classes of 8-tonne lots and sold over the 22 annual Wool Marketing Board auctions, equating to approximately 1.2 million kg of wool a year. Farmers are paid for their wool later in the year.

However, some farmers have become unhappy about being forced to sell their wool solely to the Wool Marketing Board and sell theirs to private firms in Ireland instead. One participant explained that this was because they often got a better price and were paid more swiftly than if they were to sell to the Wool Marketing Board.

> *"They paid more than the wool marketing board and you could just… and they had a local place. We could just take it there. And they'd pay there and then…within a few days of taking it. Whereas the wool board don't pay for a year." (I4, Farmer)*

Once the wool is sold it is usually washed and cleaned, which is referred to as scouring. There are only two scouring plants in the UK and one is in West Yorkshire. For SWI, the scoured wool needs to be treated against moth infestation by the SWI manufacturer before being turned into the final product.

There are two main suppliers of SWI in the UK; one is based in the UK and the other is based in Ireland. Both source their wool from different countries, treat their wool in different ways and manufacture insulation using different processes. The Irish company supplies rather than manufactures their SWI. It imports the insulation from a manufacturer in Austria. The wool is sourced from mainland Europe and treated for moths using a patented ionic system without harming moths.

> *"It's just based on a theory that you know moths won't eat cotton, they won't eat silk, they won't eat linen. And it's because of the structure of the fibre. So, what the Ionic Protect does is, it changes the structure of the fibre." (I11 Supplier)*

Nothing else is added to the wool, making it a 100 per cent pure wool product, which is then turned into SWI rolls and sold over the UK and Ireland by mainstream insulation distributors.

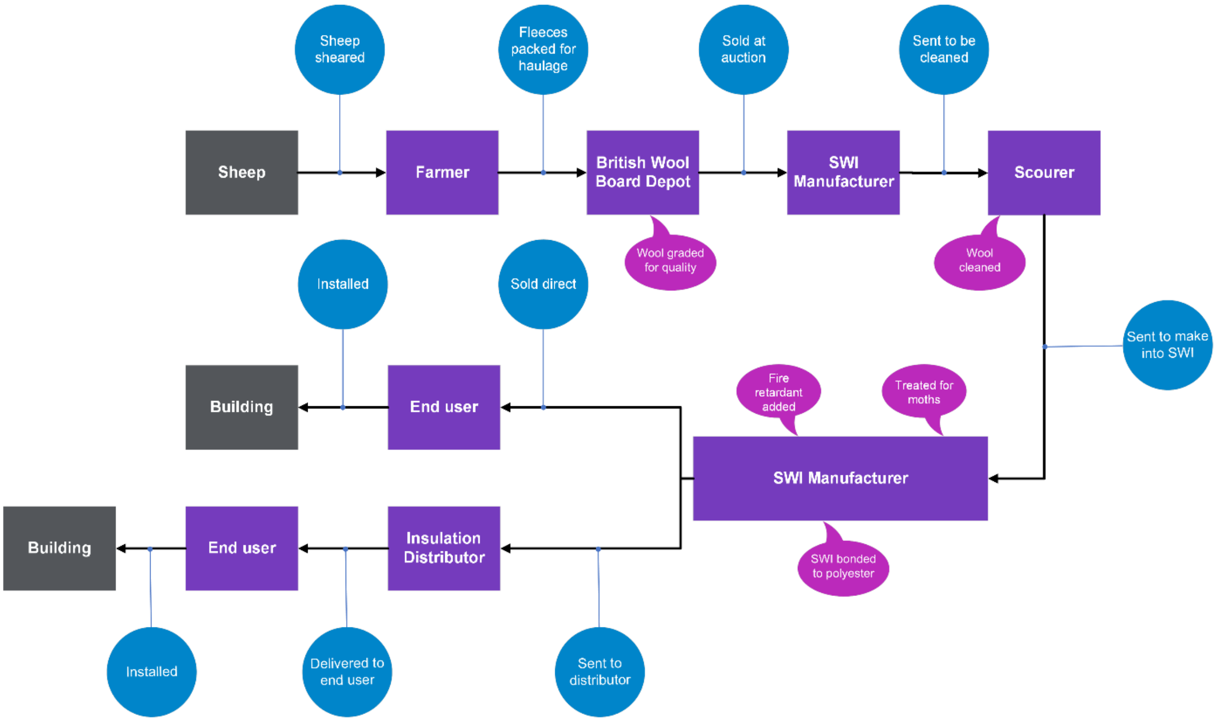

Figure 2-1 Illustration of SWI manufacturing process for UK-made SWI

The manufacturing process for the UK company is different (see Figure 2-1). The company buys low-grade wool at auction from the Wool Marketing Board. It is sent to be scoured in Yorkshire, and once clean, it is treated with a borate fire retardant which also acts as an insecticide against moths. The SWI is a mix of 75% pure wool and 25% polyester. The polyester is bonded to the wool to increase product durability and compressibility as it is turned into SWI rolls. This takes place in the company's factory in West Yorkshire. The SWI is then packed and sold either directly to an end-user or to mainstream distributors who sell it to the general public and contractors.

With an understanding of how the SWI manufacturing process works, it is then possible to explore the potential for a Yorkshire SWI industry. SWI as a product has been available in the UK for around 25 years, so it is not a new industry. As one participant pointed out, it is important to build on what has already been done than start over from scratch.

> *"It's sort of important… just to make people aware of what exactly is currently in place, so they're not reinventing the wheel in that we're actually moving the market forward and trying to appeal to a need or a demand that exists, and I guess in the case of this project, you're looking at sort of very much a regional or a local agenda and seeing how things can tie into that." (I12 Supplier)*

However, the natural fibre insulation market makes up only one per cent of the UK insulation market. This is lower than France or Germany where it is around 10 to 15 per cent. This may account for participants perceiving it as a niche material, even though SWI products can be purchased from mainstream distributors.

There are three possible approaches available to a Yorkshire-based farming co-operative looking to supply and manufacture SWI.

- Invest in their own operation;

- Collaborate with the Irish SWI supplier;
- Collaborate with the UK-based SWI supplier.

These are explored below.

Invest in their own operation

Participants from both client and supplier perspectives talked about their views on starting a SWI manufacturing facility in Yorkshire. One client talked about how they had looked into it but decided against going down this route because of the scale of the commitment it would involve.

> *"We have 30 farms, and they all have sheep farmers on them. I've already looked into can we make our own sheep's wool insulation and it's the amount of equipment you need and the processing of it. It's just beyond us really to sort of set up an operation like that on our own." (I10 Private Client)*

It is possible to send batches of greasy wool to the scouring plant for cleaning, as a participant described how a scouring plant would be open to that possibility:

> *"If a group of farmers came together and they were part of a company, formed their own company or something and said, 'Right, we have five tonnes of wool that we have collected, can you give us a price of how much it will cost us to scour per kilo?' We could then give them a price. They would already own the wool, so it would just be the price of the scouring that would be added on to the price of their wool." (I8 Supplier)*

However, the manufacturing process itself appears to be more complicated and involves substantial knowledge and financial investment as it is important to treat the fleeces correctly before manufacturing SWI:

> *"The difficulty you've got not protecting wool properly in a building is that wool could be built into the fabric. So, if you get an infestation with insects, then that can be costly to rectify. So, it's very important that if anyone's involved with wool insulation that they do things properly. It's not a hobby kind of thing. It's, you know, it requires a lot of that knowledge and diligence about what you do…. To manufacture insulation requires an investment in capital between, if you want to do it properly, between £10 and 15 million." (I12 Supplier)*

Overall, while it is possible for a Yorkshire-based farming co-operative to get their wool washed, setting up a small-scale SWI manufacturing facility appears challenging due to the level of investment and specialist skills required to make the product.

Collaborate with the Irish SWI supplier

The second option is to collaborate with the Irish SWI supplier. This would involve sending scoured Yorkshire fleeces to a factory in Austria to be treated and turned into SWI. A participant described how in the past they had sent British and Irish fleeces over to Austria to do this but that it wasn't a straightforward process, as all the machinery settings had to be changed to accommodate the coarser nature of British and Irish wool compared to the softer European wools the factory normally uses.

"It meant stopping the factory floor, changing all the configuration, making our insulation from our washed wool, and then changing all the configuration back and then making the wool for Germany or for Spain... So basically, they said, 'Look, we don't have time for that. We're too busy. So, we'll try and look at it as a project moving forward.'" (I11 Supplier)

This suggests that there may be scope for collaboration in future but not until the Austrian company, that has the patent on the ionic treatment system, which one participant described as a "safely guarded secret", is prepared to make SWI from British wool. One participant mentioned how the Austrian manufacturer is currently unwilling to commit to this.

"I believe that that manufacturer particular didn't see the market share was quite there in this country to warrant UK manufacturing." (I1 Contractor)

Collaborate with the UK-based SWI supplier

The third option is to collaborate with the UK-based SWI manufacturer. The manufacturer already segregates Welsh wool to produce Welsh SWI for the Welsh market.

"In Wales where they like us to use Welsh wool, but the rest of the UK doesn't seem at the minute seem to be that partisan. But because I think in Wales it's more about buying Welsh stuff rather than having an eco-agenda about buying local." (I12 Supplier)

It therefore seems possible that they would be willing to do the same for Yorkshire SWI providing there is a sufficient market for it. An additional benefit of this option is that it reduces the travel distance between the raw materials, production process and end user.

"We make insulation in Yorkshire, the wool's cleaned in Yorkshire, so there's a genuine proper rationale there for sourcing local materials and selling them local because you don't have the movements." (I12 Supplier)

Therefore, if there is a way to segregate the Yorkshire wool, which could come at an additional cost, and there is enough of it, it appears possible to supply this manufacturer with Yorkshire wool to make Yorkshire SWI, as the manufacturer outlines:

"It just depends on the quantities… Typically we run between 30 and 50 tonnes greasy… you would need to accumulate at least 30 to 50 tonnes…Probably 25,000 [sheep], so doable." (I12 Supplier)

However, whilst the mechanics of SWI supply appear feasible, the demand side is yet to be explored. Supplier participants raised questions about who would buy Yorkshire SWI, how big the market would be, and whether potential customers would be willing to pay more for the product particularly considering the stereotypically assigned frugal nature of Yorkshire folk.

"It's a question of working out where that balance of supply and demand is and whether there's a premium. There's not a premium in manufacture for us manufacturing wool from Yorkshire. There's probably a premium in terms of the collection, specific collection, auditing of it… if there is a premium is someone from Yorkshire willing to pay a premium for Yorkshire wool, given it's Yorkshire?" (I12 Supplier)

One participant suggested starting at the end of the process and assuming how much SWI would be needed for the market and working backwards.

> *"You'd want to start from the end, I suppose, wouldn't you and say, well, the market that we're going to be supplying would demand blah, blah blah, amount of insulation. And then how much do we need to get to source, to wash, to clean, to card and weave, and to treat it against being eaten by moths?" (I11 Supplier)*

It also led to conversations about how to market Yorkshire SWI given the price difference between SWI and more conventional insulation products. One contractor participant described how clients approached their company based on their previous work rather than wanting a contractor that uses natural materials. They have a conversation about using natural materials and if clients refuse to pay the premium, they would not accept the work. However, they found that if customers could afford to, they would often pay the extra.

> *"If our customers, you know, don't want to pay the premium for a natural material, we won't do the work. So we pull them up or find somebody else that wants to do it, but nine times out of 10, our customers understand the downside of [fibreglass] and are happy to pay the premium for the natural material if they can afford it." (I1 Contractor)*

Alongside this, participants described the use of stories, sentiment and pride as ways to make Yorkshire SWI appeal to a potential customer base. While there is little compositional difference between low-grade Yorkshire wool and low-grade wool from elsewhere in the UK, there could be something positive in the story of Yorkshire wool and building on Yorkshire's sheep farming heritage.

> *"Yorkshire is a strong brand with all the TV shows and Press that is going on at the minute, you know, Yorkshire Vet and the Herriot this and that." (I1 Contractor)*

There was also an assumption expressed by some participants that people who lived in the region would want to buy the fleeces that came from local farms, as people are looking to buy local produce where they can to help local farmers in the current economic climate.

> *"It's surprising how much, how many of the public now want to try and support us more… I think the more the public has got behind us to try and buy local and buy from local farmers and local butchers and things like that." (I3 Farmer)*

Suppliers commented on how farmers sometimes asked them whether it was possible to turn their own wool into insulation, however, there were no economies of scale there to make it possible from a supplier's point of view.

> *"I always get asked by farmers, 'Could I give you my fleeces? And would you just make the insulation and send it back to me? Because I'd love to put my fleeces in my house.' … There's a lot of pride in that." (I11 Supplier)*

One participant described how their only real experience of using SWI was driven by a client's desire to help their local community and how they might suggest to another client in an upcoming meeting that using SWI could be seen positively by residents whilst only adding a little more to the overall project cost.

“I might say to them. Look, do you want to use sheep's wool? Well it'll cost you a bit more, but it might go down well with the locals. It might be a little story for you. Spend £1000 more on the insulation but you get a story out of it.” (I2 Contractor)

This thought was echoed by a private client participant who worked for large landowners and they thought their clients would like to feel that they are supporting their tenants by using locally sourced SWI that their tenants could have supplied.

“I do have clients that, you know, if they own a whole village, they like the fact that they're supporting the local community… it might be that some of the farms that are on the estates, it might be their tenant farmers that are supplying it… It would be better if it was probably like regional based or very close to home.” (I7 Private Client)

However, participants wondered whether there would be demand for Yorkshire wool outside of Yorkshire.

“It's a question of making sure supply and demand balance because someone in Scotland's not going to worry too much of it being Yorkshire wool.” (I12 Supplier)

While participants felt that their social housing and private tenants would view SWI positively, there was some scepticism about whether their tenants would be interested in what sort of insulation had been installed. One participant assumed that those tenants that had a link to agriculture might be more positive towards it.

“I imagine it would be a positive and we don't tend to get many, well I haven't had that many conversations about the choices of materials that go in or how it's done. It tends to be just a, ‘What measures can we get?’ And, ‘If I'm not getting it, when I when will I be getting it?’” (I6 Social Housing Client)

“I think possibly the vast majority wouldn't be interested. I think as long as it's doing the job it's supposed to be there, but I suspect there may be - there will be some who kind of feel it's a positive because I'm sure we'll have some customers who work in the agricultural sector.” (I9 Social Housing Client)

“We've got such a long waiting list that people just would probably like to have any property off us in any state… with the rental market being the way it is. I think people just take whatever they can get when it comes to renting, 'cause it's such a competitive thing and there's so few houses that pop up.” (I10 Private Client)

These types of conversations led to participants talking about the kind of clients they imagined would want to buy Yorkshire SWI.

Participants talked about two main reasons for using SWI, which were breathability and reducing carbon emissions. One suggested that private clients, such as Quakers would be more likely to buy SWI, as their sustainable ethos meant that cost was not their only consideration.

“With people like for example, the Quakers where they have they have their kind of own ethos and they like sustainability and they want to do things in that direction, they would be more inclined to be like, well, actually, yes, it is costing us a bit more, but it works with our policies.” (I7 Private Client)

Alongside this, a supplier participant said that their client base for SWI was homeowners and prestige commercial clients looking to decarbonise their building stock and demonstrate their corporate social responsibility credentials. They complained about the lack of government support to incentivise SWI use. They described how in France, the government encourages the use of natural material insulation by assigning value to the carbon locked away in materials like SWI at an early point in a building's lifecycle. In the UK, carbon models recognise carbon at the end of a building's lifecycle, meaning there is no incentive to use materials like SWI that lock carbon away.

> *"If you look at France, say, that employs something like a dynamic LCA [lifecycle assessment] model to bio-based carbon, a value will be given to about two-thirds of the carbon in the material. In the UK, it's all given back at the end of life, so effectively there's not a mechanism to put a value on the carbon now, which is absurd when you think about it." (I12 Supplier)*

The social housing association participants talked about, while they would like to use SWI, they would be unlikely to do so while it costs more than traditional products. However, they would like to use it in the future if regulations or their policies changed so that using SWI does not increase their costs

> *"If regulation goes down the line of having more embodied carbon, sort of considerations as part of retrofit that we would certainly that would be a driver but really it's cost for the measures is the big thing for a housing association." (I6 Social Housing Client)*

> *"We do consider sustainability in our procurement activities, so that potentially - we don't, we don't very much at the moment, but in our new sustainability strategy, we are going to be increasingly sort of taking sustainability considerations as we procure." (I9 Social Housing Client)*

2.3.4 The rationale for a Yorkshire SWI market.

One of the main reasons for conducting this research is to explore a means of increasing the amount of money that farmers receive for their wool. Participants spoke about how the price of wool has plummeted from around £1.50/kg in around 2012 to as little as £0.10/kg in 2024, although prices are starting to improve. Farmers spoke about the labour that goes into preparing fleeces for haulage and that often it is not worth their while as the profits from fleece sales do not cover the costs of preparing it to sell.

> *"Some of the wool isn't really worth – we say packing - because it costs, it takes about an hour to pack sheet of wool and I've worked out that the Swale[dale wool], if I spent an hour packing each sheet, the Wool Board would pay me about £5." (I5 Farmer)*

However, the demand-side stakeholders (clients and contractors) talked about how the cost to the end-user is the main reason that there is low demand for SWI. Suppliers described how the cost of making SWI from sheep's wool is an unavoidably expensive process. One supplier described this as a conundrum, as they felt that there are no economies of scale that can further reduce the cost: selling more SWI will not reduce the cost.

> *"We purchase a very, very large amount of wool, we manufacture at scale using equipment that's used for bedding when it's not being used for insulation. So we've achieved pretty much every economy of scale that can be achieved and we're producing insulation about as low as cost as you can get." (I12 Supplier)*

They also described how the cost of the raw wool is small compared to the production process, meaning that even if they were given the wool for free they could not reduce the price to the end user by much.

> *"I think any notion that you can make suddenly make sheep's wool insulation for the price of fibreglass, say, if only you did this and if you only you did that it's just not possible. Even if people gave us the wool for free, we couldn't reduce the price of the insulation much more than we sell it for at the minute." (I12 Supplier)*

In the past, the SWI manufacturing company had bought wool directly from farmers instead of farmers sending it to auction through the Wool Marketing Board. While this gave farmers more money, it shifted income away from the Wool Marketing Board and auction process to sell the wool, as opposed to savings being made through efficiencies. Therefore, increasing the amount farmers were paid for their fleeces would simply increase the cost of the product to the end user. The supplier argued that there were many economic benefits from investing in SWI, but that they weren't for farmers.

> *"When it comes to the rationale for the natural fibre insulation, there isn't a rationale for this to add value to the farmer… The rationale for adding value to the farmer is to get people to buy more wool, British wool clothing and to buy more British wool carpets… That gets the farmer more money, not insulation. Insulation adds value to the economy and all sorts of other ways. It's a fantastic product, but the rationale for it's not that… And anyone that can undo that conundrum has never really tried to solve it." (I12 Supplier)*

The farmers that we spoke to had similar views about supplying their wool for SWI. They would be prepared to supply it, and while ideally, they would like the manufacturer to pay more than the Wool Board, it would also be acceptable if they spent less time preparing the fleeces. Another alternative would be if the manufacturer didn't charge them to collect the fleeces, or the farmers were able to deliver the fleeces locally, thereby minimising their costs.

> *"If it's easy to say somebody came with a wagon and I was able to just put [the wool] in with a big grab and put into the wagon… then there's literally no work… Whereas at the moment if I were to sell it to the Wool Board, it would take me probably a couple of days hard labour for no return." (I5 Farmer)*

> *"We really don't want to take it too far. You know, it all costs money… If you've got a decent price for it, that would make a lot of difference, but when it's only 10p a kilogram, which is what it's been this last time, you know it's a waste of time bothering." (I4 Farmer)*

Another participant talked about how they would be interested in supplying wool for SWI as they were currently stockpiling their low-grade fleeces until they thought of a use for them.

> *"We have, like stacks of wool from the last couple of years that, like the cheaper bits that we can't sell and we've, they're just here and we thought, well, we could use that maybe for - we're trying to think what we could use it for ourselves, you know? So if it can be of use to somebody else then yeah." (I3 Farmer)*

2.4 Conclusions

In summary, findings from the interviews suggest that:

- There is interest in using SWI but there is an assumption that it costs substantially more than mainstream alternatives, and most people would be unwilling to pay more to use it.
- Farmers would be willing to supply fleeces to a SWI manufacturer as long as it is financially advantageous. This could be because they are paid more for the fleeces, or their costs to prepare fleeces for sale are lower.
- Setting up a manufacturing plant specifically for Yorkshire SWI requires both expertise and financial investment. However, there is already a SWI manufacturer operating in West Yorkshire.
- The process of manufacturing SWI is expensive. The cost of raw wool makes up a very small proportion of the overall cost.
- In order to produce SWI in collaboration with the UK-based or Austrian manufacturers, the demand for Yorkshire (or British) SWI would need to increase.
- Demand could be stimulated by raising awareness of the benefits of SWI as a more sustainable, safe and ethical product and challenging assumptions that the cost of installing SWI is *substantially* higher than mainstream alternatives.
- Other clients besides social housing and private landlords could be considered as end users, such as prestige commercial clients with net zero carbon ambitions, those with a historic building portfolio or a sustainable ethos.
- Increasing demand for SWI is unlikely to produce a large drop in its manufacturing costs, so customers will always need to pay more.

3 Building Monitoring Advice

3.1 Background

The use of SWI as an alternative to more commonly applied insulation products such as mineral wool or rigid board may provide a range of positive impacts beyond the obvious reduction in embodied carbon. Specifically, a review of SWI literature indicates favourable performance during the product lifetime; improving air quality, controlling moisture levels, and reducing sound transmission [1].

While there is some evidence to support the positive impact of SWI over fossil-based alternatives, this typically comes from laboratory testing. Laboratory tests, while valuable, lack the external validity of field tests. Laboratory tests are typically undertaken in a controlled environment over a short time period, using small samples in an idealised condition. This is for good reason: to ensure consistency in methods when evaluating different materials. It does not, however, replicate the reality of construction (and particularly retrofit), where insulation materials are often installed in challenging circumstances that preclude optimal application. To gain a more realistic insight into the performance of SWI, it is, therefore, beneficial to capture *in situ* performance data. This enables a true appraisal of actual performance, supporting a comparison of expected outcomes to identify any underperformance from the original design intent.

The following sections of this report outline a range of monitoring options to evaluate *in situ* performance of SWI at 15 Silver Street, together with the practical considerations of undertaking monitoring. The section concludes with recommendations specific to the SHEEPISH project at Silver Street.

3.2 Monitoring options

3.2.1 Energy consumption

Monitoring energy consumption supports the evaluation of energy usage for both the full building and for submetered zones or circuits. The type of monitoring equipment required depends on the fuel source (typically gas or electric) and the objective of the monitoring.

Where the research aim is for a high-level appraisal, for example, a pre- and post-retrofit comparison or to compare energy consumption with an average benchmark figure, utility provider smart meters may provide sufficient coverage.

If the research aims are more precise, it may be beneficial to install submetering to give greater capacity for disaggregation of energy demand. This adds significant complexity, particularly when dealing with gas submetering, and requires a separate data logging and acquisition device. The process of installing submetering also requires an electrician and/or gas-safe engineer and may also require approval from the utility provider. It is possible to monitor electricity without external contractors by using a current clamp; however, these are less accurate, relying on spot-measurement of the electricity current to derive consumption.

Energy consumption may also be evaluated via measurement of the delivered heat. Heat meters may be installed within the space heating pipework, to accurately account for delivered heat. This approach accounts for the heating system efficiency and gives greater detail than gas monitoring, however is relatively complex and requires specialist installers in addition to a dedicated datalogger.

Equipment options

Measurand	Equipment	Description	Pros / Cons
Electricity	Submetering	Install own individual meter, installed on any circuit of interest, to measure disaggregated electricity consumption.	High level of accuracy and granularity possible. Requires an electrician to install and a separate data logger to capture readings.
	Smart meter	Request smart meter consumption data from utility provider.	Simple. Home may already have a smart meter. Data will be total consumption, not separated between circuits. Data may also be low resolution (e.g. monthly) depending on utility provider.
	Current clamp	Install own clamp on incoming electric feed.	Simple. Own installation possible. Data will need conversion into consumption and has reduced accuracy. Requires a separate data logger to capture readings.
Gas	Submetering	Install own individual meter downstream of the utility meter.	High level of accuracy and granularity possible. Requires a gas engineer to install and a separate data logger to capture readings.
	Smart meter	Request smart meter consumption data from utility provider.	Simple. Home may already have a smart meter. Data may be low resolution (e.g. monthly) depending on utility provider.
Heat	Heat meter	Install own individual meter on the boiler to record delivered heat.	High level of accuracy and granularity possible. Requires a gas engineer to install and a separate data logger to capture readings.

3.2.2 Temperature and thermal comfort

Monitoring the internal temperature within a building produces an incredibly versatile dataset, which may be used to infer thermal comfort, occupant heating behaviour, and fabric performance.

Any measurement of temperature must carefully consider the sensor type and location. Where possible, temperature measurements should be made at a location that is representative of the location under investigation. For example, if monitoring a living space, the measurement would optimally be taken at the centre of the space to best reflect the conditions an occupant is experiencing. It is, however, often not possible to position sensors in an ideal location due to the negative impact this may have on the space itself, restricting usability and being overly intrusive.

To overcome this, it is acceptable to take measurements in pragmatic locations at the room perimeter, but the location of measurement must be considered. Location convenience must not come at the expense of data quality. Sensors must be located away from sources of heat (e.g. appliances, direct sunlight, radiators) and are representative of the centre-space (i.e. not on a windowsill or behind furniture). Where an environment is heterogeneous, it is best practice to measure temperature at multiple locations, both in the horizontal and vertical plane. Best practice suggests measurement heights of 1.7m, 1.1m and 0.1m vertically, with sensors positioned in multiple locations within the room and an equally weighted average applied when characterising the entire space [2].

For the evaluation of thermal comfort, there are numerous standardised indices available, such as the comfort ranges given in CIBSE Guide A [3], the predicted mean vote thermal balance model [4] and the adaptive thermal comfort model [5]. Methods vary in their complexity, with simple comfort indices requiring only air temperature for comparison with threshold values or optimum temperature ranges. For more complex comfort evaluations, it is necessary to measure radiant temperature, localised air movement and humidity. It may also be necessary to monitor the clothing and activity of individuals within a space.

Temperature data may be used to infer heating behaviours through analysis of change over time. It is possible to identify when heating systems are turned on and off by the rising and falling of internal temperatures. Additionally, it may be possible to determine heating setpoint through identification of the point at which temperature ceases to increase and instead oscillates around a fixed value. This analysis can be useful when comparing behaviour between buildings, or for a single building before and after a retrofit.

Finally, internal temperature may be used to infer fabric performance. The level of insulation in the building fabric has an effect on the rate at which a room’s temperature rises when heated and falls when heat provision is stopped. It is generally the aim of insulation to reduce the time taken to achieve a heating setpoint and slow down the rate of heat loss to the external environment. Commercial services may be purchased to calculate the heat transfer coefficient of a dwelling based on temperature measurement together with meter readings [6]. Comparison of heat-up and cool-down times are best suited to projects with a before and after dataset, or those with a robust control dwelling.

Equipment options

Measurand	Equipment	Description	Pros / Cons
Air temperature	Temperature sensor	A thermometer for air temperature measurement (typically electrical resistance, to support data logging)	Simple, cheap and a good degree of accuracy. Care must be taken over sensor position. Considerable error possible if sensor location is badly selected.
Mean radiant temperature	Black globe sensor	A black globe in the centre of which is placed a temperature sensor. Used to measure radiant heat gains and losses.	Simple, cheap and a good degree of accuracy. Care must be taken over sensor position. Considerable error possible if sensor location is badly selected.
Air velocity	Omnidirectional anemometer	A device to measure average air movement across the X, Y and Z axes. Whilst not a temperature measurement, this is an important variable in quantifying thermal comfort.	Essential variable for more accurate thermal comfort evaluations. Complex to measure in practice, with sensor location often presenting a challenge.

3.2.3 Moisture and damp risk

Monitoring moisture over an extended period is valuable in identifying any risks of damp or mould. When considering moisture, it is important to differentiate between airborne moisture and the moisture saturation of building materials.

Airborne moisture is water in the air, and may be measured using a hygrometer to determine absolute and/or relative humidity. This is important in identifying the risk of damp, with comparison to guidance thresholds a typical method [3]. Where an issue is found, it may then be possible to identify the source of the airborne moisture and provide a solution for this (e.g. increased ventilation).

Airborne moisture is also a factor when considering occupant comfort, and has an appreciable effect on air quality and thermal comfort. Where the internal air has a high moisture content, this may condense on cooler surfaces and lead to surface moisture and, left unchecked, this moisture will penetrate the building material and have a negative impact. Regarding sensor location, the same considerations as temperature measurement apply.

Material saturation refers to moisture within a building material. This may be present during the original installation from the construction stage or may have accumulated as a result of moisture contact from another source (e.g. a leak, driving rainwater, or internal condensation accumulation). Moisture may be on the surface of a material or within the structure (interstitial condensation) and is likely to move throughout a material where the material is porous.

The measurement of material moisture content is done using a protimeter, which measures current between two metal prongs inserted in the material. For long-term measurements, a protimeter may be embedded in a material and the moisture content logged at regular intervals to show longitudinal wetting or drying. For the greatest accuracy, moisture measurement should be taken from wood/timber products, which may be inserted as dowels into a material of interest. Due to the seasonal nature of material moisture, any monitoring should be undertaken for a long period of time (typically several years) to understand where moisture is accumulating versus periodic cycles of wetting and drying.

A less invasive method of moisture evaluation is to use thermal imaging to identify surface moisture. Wet surfaces exhibit different behaviour to dry surfaces when observed in the infrared spectrum, making it possible to identify areas of damp and moisture. Such measurements are only possible as a spot measurement taken at one point in time, however, and are highly affected by the local context at the time the thermal image is taken, so care must be taken during their interpretation.

Equipment options

Measurand	**Equipment**	**Description**	**Pros / Cons**
Airborne humidity	Hygrometer	A device to measure the relative or absolute humidity in the air.	Simple and cheap to measure. Care must be taken over sensor position. Considerable error possible if sensor location is badly selected.
Material moisture content	Protimeter	A device embedded into building materials to measure change in moisture over extended periods (> 1 year). These are typically sacrificial and are left in place after monitoring ends.	Relatively simple to measure. Location of measurement is very important, and care must be taken to interpret results correctly. Devices are often sacrificial.
	Thermal camera	Thermal imaging may be used to identify surface moisture and material saturation. Repeated visits may show change over time.	Non-invasive and quick.

			Must be done by a qualified/knowledgeable individual to avoid misinterpretation of results. Also, only possible for spot measurement.

3.2.4 Air quality

The measurement of indoor air quality is an important consideration when determining occupant health and well-being. It is, however, incredibly complex and care must be taken in the correct selection of equipment and relevant measurands. The quantities to be measured should be appropriate to the research aims, and measurement locations should be representative of the wider environment and free from influence by external sources. Regarding sensor location, the same considerations as temperature and airborne humidity measurement apply.

Air quality measurement may consider volatile organic compounds (VOC), which encompasses a vast cocktail of chemicals such as benzene, ethylene glycol and formaldehyde. These chemicals are commonly associated with off-gassing from fossil-based paints and materials. They may also, however, be caused by cleaning products and other household chemicals, so it is important to control for contamination and avoid drawing inaccurate conclusions. A device required to measure a single VOC will often require a dedicated sensor, using light-scattering or ultraviolet measurement methods. It is also possible to gather a cumulative measurement of VOCs, which does not differentiate between the separate pollutant families.

It is also possible to measure larger particulates, such as those produced by fossil fuel combustion. Particulate monitoring may use light scattering or pumped filtration devices, with the ability to measure particles of different sizes and separate their occurrence. As with VOCs, the measurement of particulate matter does not identify specific details of the particulate, and would require filtration and microscoping analysis in a laboratory. It is important to control for cross-contamination, as typical activity in a space can produce high quantities of particulates (e.g. disturbing dust when vacuum cleaning).

Measurand	**Equipment**	**Description**	**Pros / Cons**
Volatile organic compounds (VOCs)	Air quality sensor	A device to measure the occurrence of specific or aggregate pollutants in the air.	Can give valuable data for occupant health. Very complex to collect accurate data. Expensive.
Particulates	Particulate counter	A device to measure the occurrence of particulates of a given size in the air.	Can give valuable data for occupant health. Very complex to collect accurate data. Expensive.

3.3 SHEEPISH monitoring - options appraisal

The nature of 15 Silver Street, which is undergoing significant refurbishment including a change of use, precludes analysis that compares performance before and after retrofit. Similarly, the nature of the building limits the comparison of zones with and without SWI, as there is not a representative ‘control’ space. Any monitoring to evaluate performance should, therefore, consider only the performance of SWI in isolation.

Monitoring energy consumption is likely to have limited value, as this is heavily affected by the energy behaviours within the heated space. Total energy consumption for space heating may provide interesting context for 15 Silver Street, and this can be done using data provided by a utility smart meter. More targeted energy monitoring that isolates energy consumption for specific areas of the building will likely be insufficient to evaluate sheep’s wool performance. As this will likely incur significant costs for limited value, submetering of energy is not recommended.

Air temperature monitoring may provide some insight into the comfort within spaces equipped with SWI. It may also be possible to determine heat-up and cool-down durations, accounting for differing heating behaviours.

If temperature monitoring is undertaken, care must be made to ensure that:

- Multiple sensors are used within the space, to account for heterogeneity
- The sensors are located away from sources of heat (e.g. radiators/sunlight/appliances)
- The specific context of the space is considered during analysis i.e. room function, occupancy characteristics, heating patterns, etc.

Monitoring temperature will not provide a dataset that is capable of asserting that SWI performance is better or worse than alternative materials. This is due to a lack of a control case study, in addition to the compounding uncertainty introduced by the differences in room size, orientation, occupancy, etc. As such, any conclusions drawn from monitoring air temperature should acknowledge the case-study nature of the research.

There is limited value in monitoring airborne moisture beyond flagging a risk of surface condensation. As any risk will primarily be driven by moisture produced by the occupant, it is unrelated to the SWI and therefore of limited value.

There may be potential and value in monitoring material moisture content. Given that the SWI will be embedded in the building structure, wireless protimeters may be used that connect with a phone via Bluetooth to transmit data. These devices have a lifetime of several years, and may be used to build a timeline of moisture content in embedded timber. As with previous measurements, it is unlikely that data may be used to produce a comparison with more common materials, but may present an interesting case study of moisture accumulation (or otherwise) in close proximity to SWI.

Air quality is extremely complex and there is limited value in long-term monitoring given that the SWI is embedded in the building structure. There may, however, be value in monitoring air quality during and immediately following installation to evaluate off-gassing effects and particulate creation during installation. Air quality monitoring devices can be hired for this purpose. For maximum coverage, these should monitor total VOCs and large particulates (PM10).

3.4 SHEEPISH monitoring recommendations

Given the overall appraisal of monitoring options outlined in the previous section, the following recommendations have been developed. Where a link to a product or monitoring device has been provided, this is for example only and should not be regarded as explicit direction. There are many alternatives available to suit a range of budgets and accuracy requirements. Please fully explore equipment options before purchase/rental and seek expert guidance on the use and maintenance of equipment to ensure good quality data and avoid wasting time and resources.

- Long-term material moisture monitoring

Embedding wireless protimeters into timber that is in close proximity to the SWI would provide an interesting dataset to evaluate the hygroscopic properties of sheep's wool through cyclical wetting and drying. These devices work best when inserted in wood, so it may be necessary to introduce wooden dowels into insulation products and/or local brickwork for attachment.

Wireless devices are sacrificial and are sealed into the building fabric. They typically have a battery life of 2-3 years when logging at weekly intervals. Connection is via a separate datalogger or via Bluetooth mobile app. Options for wireless equipment include Protimeter BLE[1] and Hygrotrac[2]. If longer-term monitoring is required, protimeter sensors may be via wired connection, with connecting wires trailing out from the wall[3]. Measurements would then require periodic recording using a compatible device[4].

- Installation air quality

Monitoring indoor air quality during the installation of both SWI and more commonly used materials may provide a useful dataset for comparison. It is possible to hire battery-powered devices with logging capability for both VOCs[5] and particulates[6]. Devices are typically worn by an individual within a space to most accurately reflect their exposure. The measurement of both VOCs and particulates may then be compared to exposure guidance produced by the UK Health and Safety Executive [7] and the World Health Organization [8].

It is important to reiterate that the monitoring of air quality is incredibly complex. Care must be taken to avoid cross-contamination that can lead to an incorrect conclusion. Any construction activity is likely to produce dust and introduce a range of airborne pollutants, and this should be considered when trying to isolate the effect of SWI from this overall environmental context.

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[1] https://www.moisture-meter-direct.co.uk/products/protimeter-ble-new?variant=8310869000279&currency=GBP&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic&utm_term=&utm_source=google&utm_medium=cpc&gad_source=1&gclid=Cj0KCQjw-r-vBhC-ARIsAGgUO2A8DPOe_RsTKnuUlMXhPwydfFineIQOS80AzljQj9Rwb1FANg4YkJ4aAoDcEALw_wcB

[2] http://www.merlinlazer.com/HygroTrac-Kit-with-10-Standard-Sensors

[3] https://www.test-meter.co.uk/protimeter-dual-pin-moisture-probe?_gl=1*xonzmf*_up*MQ..&gclid=Cj0KCQjw-r-vBhC-ARIsAGgUO2BdarRV0sCpU4tNI5WGqvtvSY433sj9hdR8egenAFbLiWqw8QtOD_0aArBVEALw_wcB

[4] https://www.test-meter.co.uk/protimeter-surveymaster-moisture-meter?_gl=1*15sr6sp*_up*MQ..&gclid=Cj0KCQjw-r-vBhC-ARIsAGgUO2BdarRV0sCpU4tNI5WGqvtvSY433sj9hdR8egenAFbLiWqw8QtOD_0aArBVEALw_wcB

[5] https://products.shawcity.co.uk/products/tiger-cub-ppb-personal-pid-monitor

[6] https://products.shawcity.co.uk/products/sidepak-am520

4 Hygrothermal Simulation

Sheep's wool and other natural material insulation products can have hygrothermal properties that are much different to more traditional insulation products. Moisture behaviour and breathability of alternative insulation is often considered to be a benefit of such insulation products. Conversely, insulation based on natural materials can be more vulnerable to decay due to the accumulation of moisture over time. This section uses hygrothermal simulation to assess the risk of moisture accumulation over time in the external elements of the case study building (15 Silver Street), following retrofit with alternative insulation products including SWI.

4.1 Overview of Hygrothermal simulation

Hygrothermal simulation models the movement of heat and moisture through materials in a representation of a building element in response to internal and external climate conditions. External element build ups were based on proposed designs for the case study building including four external wall build ups and three roof build ups.

The hygrothermal simulation was carried out using the WUFI Pro ver. 6.7 software. WUFI Pro is a 1-dimensional simulation package, capable of modelling the movement of heat and moisture through layers of a building element. Layers are assigned thicknesses and properties by the user, and the influence of internal and external climate is also modelled. External climate data including temperature, humidity, wind, rain and solar irradiation was generated using Meteonorm software to generate a 2020's reference year for the Yorkshire area.

Material properties were selected from the WUFI materials database. Where possible, exact materials matching those specified in the proposed design were used, where an exact match could not be found in the WUFI database a close match was chosen and adapted using the manufacturer's published material data. The hygrothermal properties of the heritage materials present in the case study building were unknown, the best match was chosen from the WUFI database, however, this introduces an element of uncertainty. The hygrothermal properties of the sandstone used in some of the walls of the case study building were unknown, so two sandstone materials were chosen from the WUFI database, one with a high vapour resistance and one with a low vapour resistance to represent two possible extremes due to the sandstone properties.

Each case was simulated for a virtual 3-year period in the WUFI software, in seven cases no significant increase in total water content was observed, indicating that the water content was in equilibrium. In one case total water content was increasing after three years, in this case, the simulation period was extended to 10 years to assess whether water accumulation was a long-term trend.

4.2 Case 1 External wall type 1, 3, 4 – Stone wall, high vapour resistance

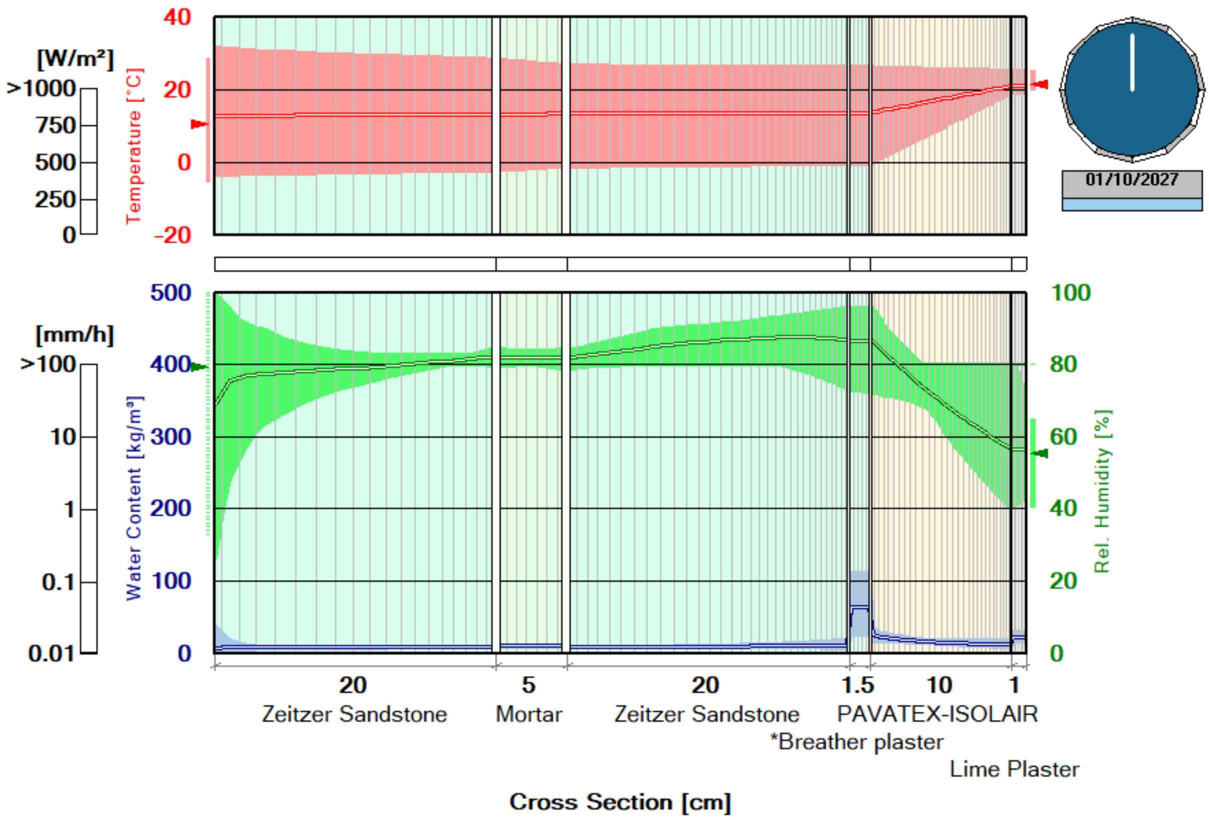

Figure 4-1Hygrothermal profile of Case 1. shaded area indicates range of values, line indicates average value.

Table 4-1 Total water content of Case 1.

	Start	End	Min.	Max.
Total water content (kg/m²)	6.31	5.91	5.62	8.01

Case 1 is a high vapour resistance sandstone wall fitted internally with wood fibre insulation. Total water content in the Case 1 wall declined over time, indicating that the wall is drying.

The greatest relative humidity occurs at the adhesive layer between the stone wall and the wood fibre insulation.

Average relative humidity over 80% occurring within the insulation indicates the potential for biological growth if untreated. The average temperature in this area is below the threshold for biological growth.

Internal surface humidity is low enough that mould growth is unlikely.

4.3 Case 2 External wall type 1, 3, 4 – Stone wall, low vapour resistance

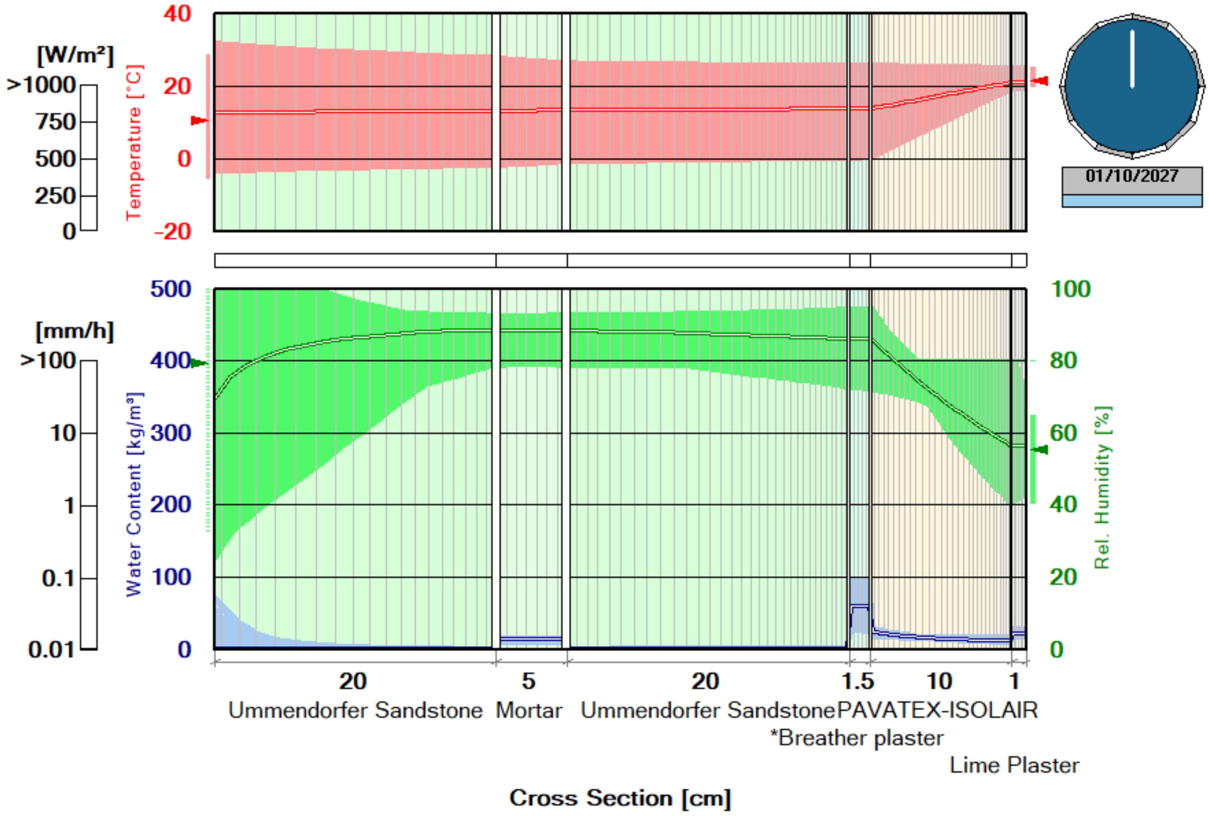

Figure 4-2 Hygrothermal profile of Case 2. shaded area indicates range of values, line indicates average value.

Table 4-2 Total water content of Case 2.

	Start	End	Min.	Max.
Total water content (kg/m²)	3.15	3.16	2.58	5.8

Case 2 is a variant of case 1, a low vapour-resistance sandstone wall internally insulated with wood fibre insulation. The total water content in Case 2 starts lower than in Case 1, however total water content increases by a small amount by the end of the simulation.

The relative humidity is higher through the stone layers in comparison to Case 1, indicating that a lower vapour resistance sandstone allows greater water ingress from the external environment.

Relative humidity in the adhesive and insulation layer is similar to the high vapour resistance Case 1 and the same caution in relation to biological growth should be taken.

Internal surface humidity is low enough that mould growth is unlikely.

4.4 Case 3 External wall type 2 – Brick wall

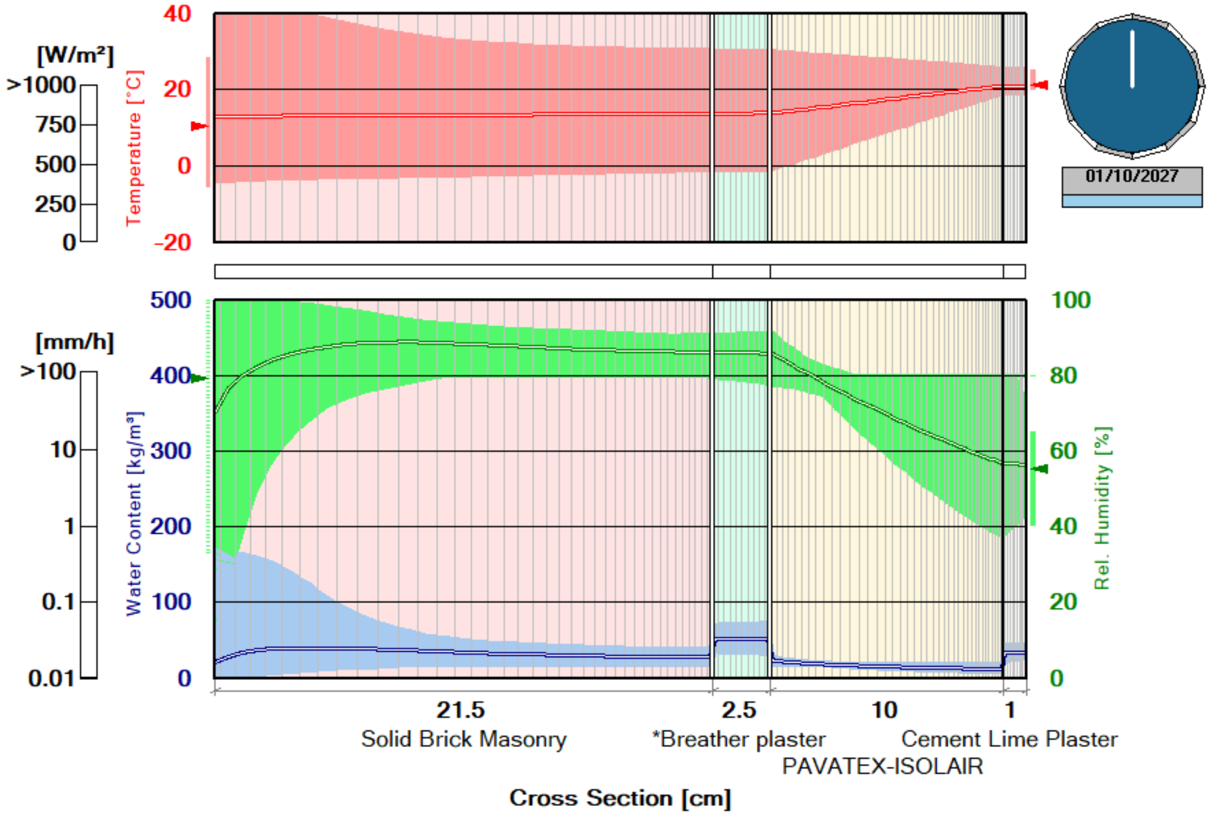

Figure 4-3 Hygrothermal profile of Case 3. shaded area indicates range of values, line indicates average value.

Table 4-3 Total water content of Case 3.

	Start	End	Min.	Max.
Total water content (kg/m²)	7.07	6.99	6.27	16.25

Case 3 is a solid brick wall fitted internally with wood fibre insulation. The simulation was run over 10 virtual years, as water content was still increasing after three years. Peak water content plateaued after 4 years, indicating that water is unlikely to accumulate indefinitely.

Relative humidity within the brick layer of the wall is higher than the inner layers, similar to level in Case 2 low vapour resistance sandstone.

Moisture content in the adhesive layer and insulation is similar to Cases 1 and 2, relative humidity in the insulation is high enough on average to indicate a potential for biological growth, however, the average temperature in this location is below the level that poses a risk.

Internal surface humidity is low enough that mould growth is unlikely.

4.5 Case 4 External wall 5 – new construction, Zinc

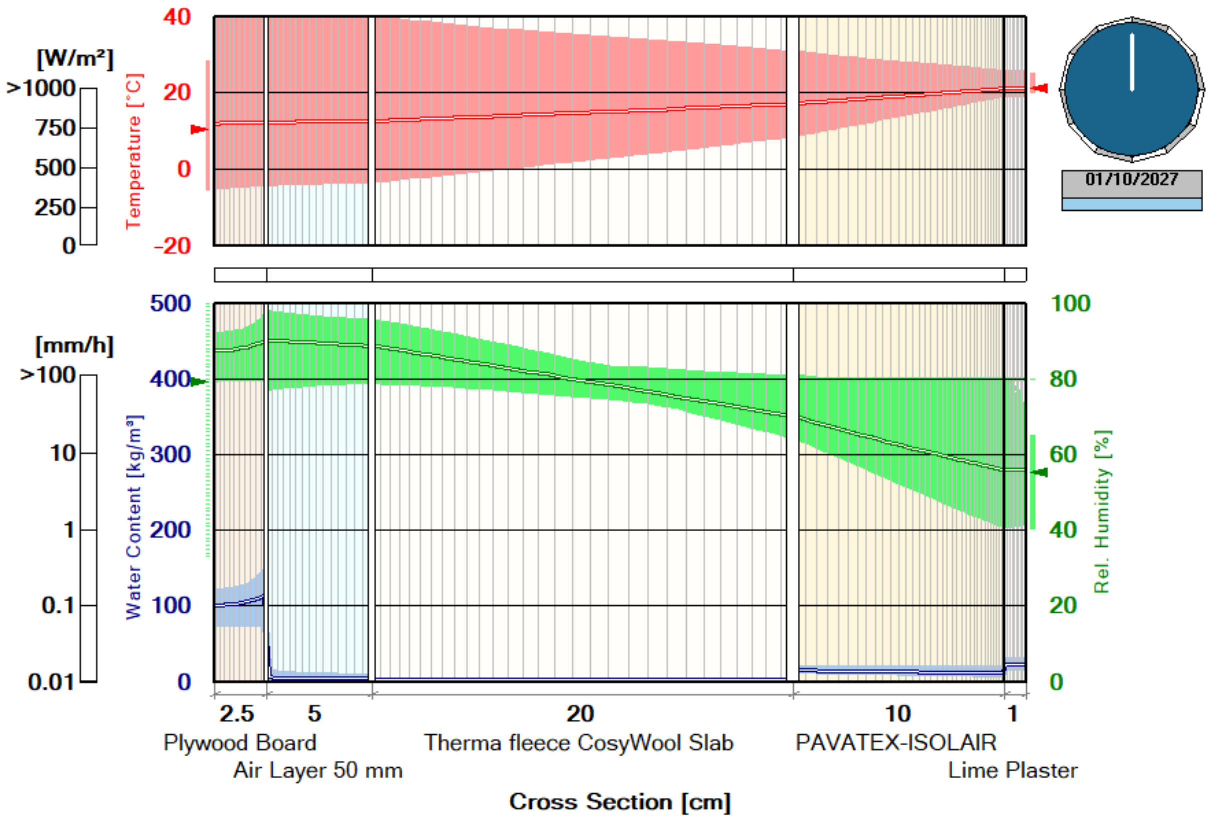

Figure 4-4 Hygrothermal profile of Case 4. shaded area indicates range of values, line indicates average value.

Table 4-4 Total water content of Case 4.

	Start	End	Min.	Max.
Total water content (kg/m²)	4.56	4.5	4.13	5.47

Case 4 is an external wall, consisting of a timber frame finished with zinc-clad plywood externally. SWI is placed between the timbers and finished with wood fibre insulation internally.

Total water content declines by the end of the simulation. Water content is low through the whole of the wall other than the external plywood board which carries the zinc cladding.

The relative humidity is the highest in the outer half of the SWI over 80% on average, declining below 80% in the inner layers of the wall. The regions above 80% on average are also cool enough that biological growth is unlikely.

The use of an external impermeable zinc cladding and an air gap behind the plywood board prevents water ingress from the external surface due to rain.

4.6 Case 5 External wall type 6, New wall

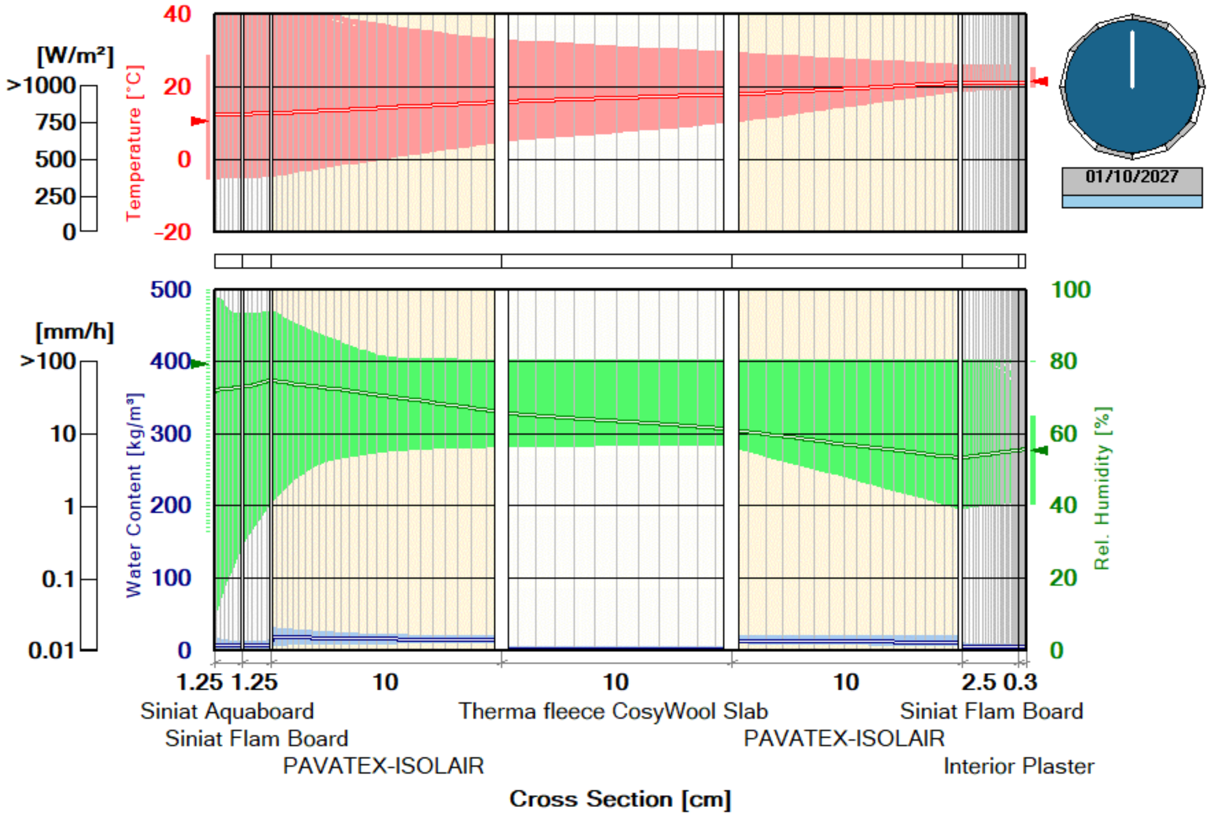

Figure 4-5 Hygrothermal profile of Case 5. shaded area indicates range of values, line indicates average value.

Table 4-5 Total water content of Case 5.

	Start	End	Min.	Max.
Total water content (kg/m²)	4.29	3.15	2.68	4.29

Case 5 is an external wall to an enclosed area, sheltered from rainfall. The wall consists of a timber frame, insulated with SWI between timbers, with wood fibre insulation fitted on both sides. Finished with plaster boards internally and externally.

The total water content of Case 5 declines over the simulation period, ending lower than the initial water content.

Relative humidity is below 80% on average throughout the wall thickness, which indicates that the build up is unlikely to suffer from biological growth. The internal surface is also not at risk of mould growth.

As the wall is sheltered from the rain moisture ingress from the external face is much lower than the exposed walls.

4.7 Case 6 Roof Type A

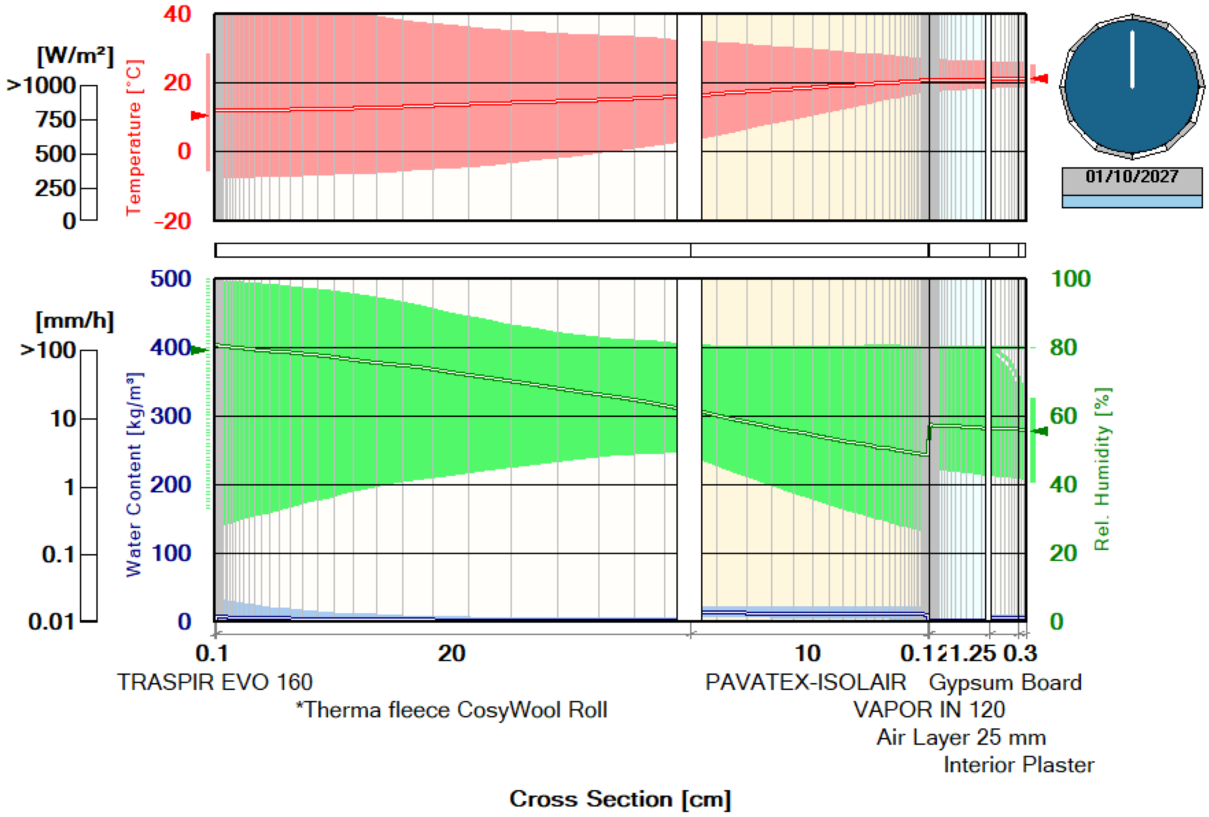

Figure 4-6 Hygrothermal profile of Case 6. shaded area indicates range of values, line indicates average value.

Table 4-6 Total water content of Case 6.

	Start	End	Min.	Max.
Total water content (kg/m²)	2.42	1.33	1.29	2.42

Case 6 is a pitched tiled roof, consisting of timber rafters with SWI in between, and wood fibre insulation below the rafters. Finished internally with plasterboard.

Total water content declines significantly over the simulation period, indicating moisture accumulation is unlikely to be a problem.

Relative humidity within the roof is below 80% in most of the roof, including in the insulation layers, biological growth is unlikely to be a problem in this build up.

The inclusion of a breather membrane and a vapour barrier appears to result in effective moisture control as long as they function correctly.

4.8 Case 7 Roof Type B

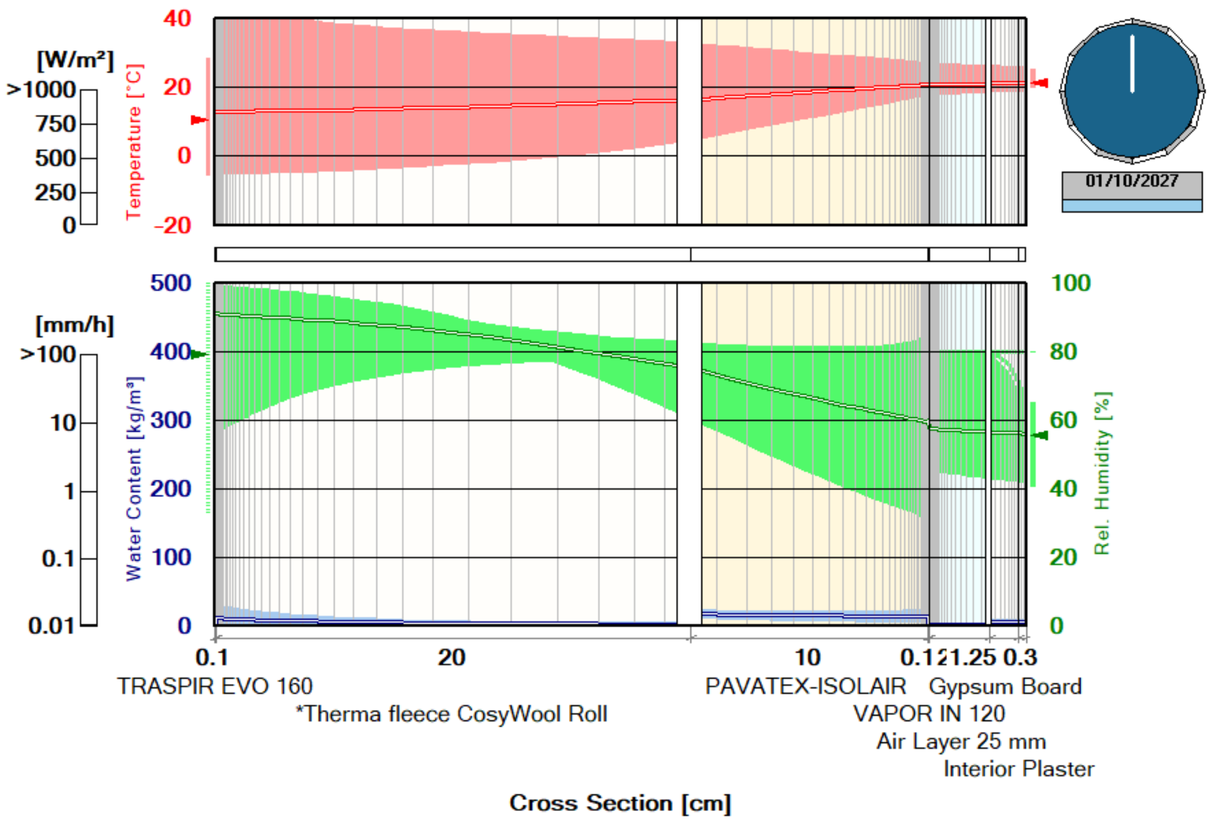

Figure 4-7 Hygrothermal profile of Case 7. shaded area indicates range of values, line indicates average value.

Table 4-7 Total water content of Case 7.

	Start	End	Min.	Max.
Total water content (kg/m²)	2.42	2.29	2.29	2.24

Case 7 is identical to Case 6, however instead of being finished with roofing times a zinc cladding on plywood is used.

The total water content in Case 7 reduces over the simulation period, the reduction is less than in Case 6.

Relative humidity in the outer layers of the roof build up is higher than in Case 6, the majority of the SWI is above 80 RH on average.

The zinc cladding finish has a higher vapour resistance than the tiled finish in Case 6, limiting the capacity of the roof structure to dry to the external environment which in turn results in higher relative humidity.

4.9 Case 8 New Flat Roof

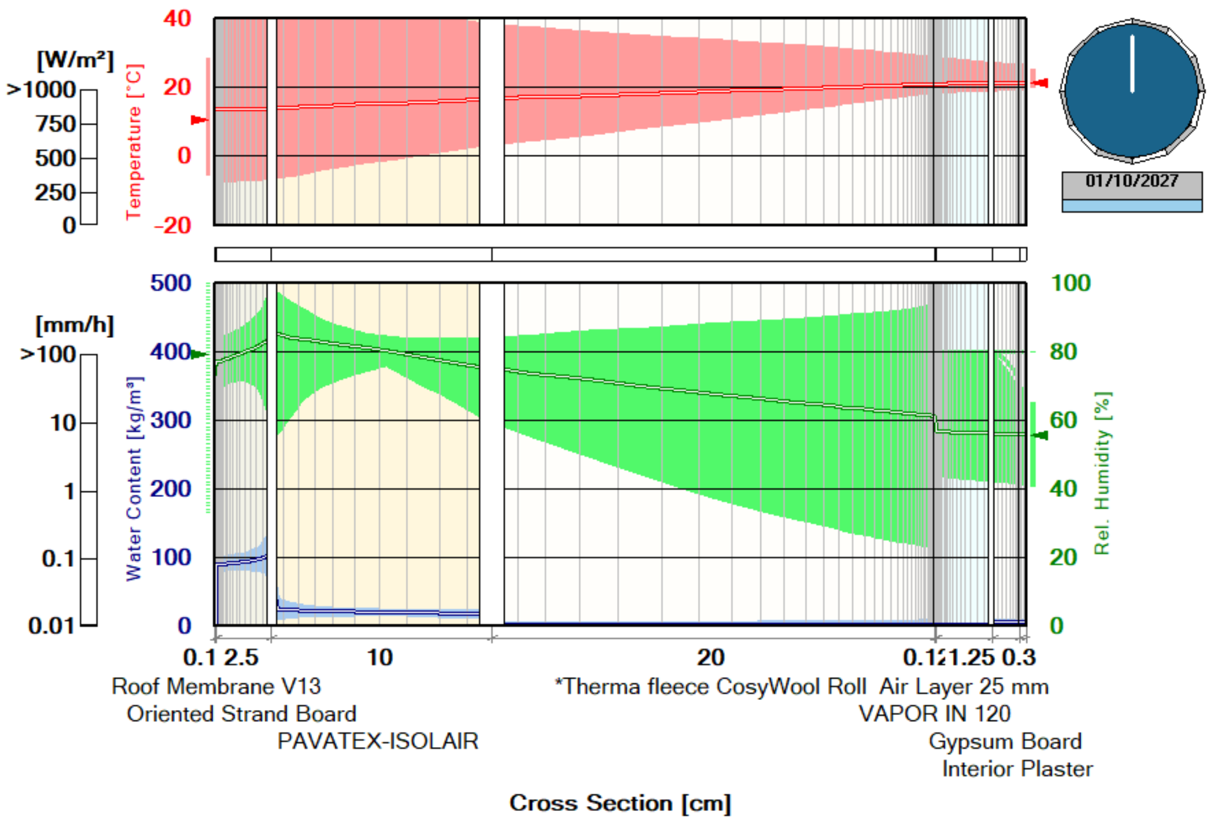

Figure 4-8 Hygrothermal profile of Case 8. shaded area indicates range of values, line indicates average value.

Table 4-8 Total water content of Case 8.

	Start	End	Min.	Max.
Total water content (kg/m²)	4.72	4.63	4.63	4.75

Case 8 is a flat roof, consisting of a timber frame infilled with SWI, with wood fibre board above and finished externally with OSB and a roof membrane. Internally finished with plaster board.

Total water content in Case 8 declines over the simulation period, water content in the layers is generally low and does not accumulate over time.

Relative humidity is over 80% in the outer layers of the wood fibre insulation, declining toward the inner surface.

The internal surface is not at risk of mould growth.

4.10 Hygrothermal Simulation Conclusions

Overall, hygrothermal simulation of the external elements indicates that the proposed build ups have low moisture risk. In each of the cases modelled, total water content declined over the simulation period or reached an equilibrium state that indicates that water accumulation in the building fabric is of low risk.

Relative humidity in the building fabric was found to be within acceptable levels, however, average relative humidities over 80% were found in some of the insulation layers. Due to the use of insulation products based on natural materials, relative humidities over 80% can be conducive to biological growth if temperatures also exceed 15 °C [9]. The average temperature at the locations above 80% RH was below 15 °C, however, care should be taken to ensure insulation materials are adequately treated to inhibit biological growth.

Masonry walls fitted with internal insulation exhibit high relative humidities on the cold side of the insulation layer. This is a common occurrence when insulating internally, as heat flow to the outer layers is reduced and thus drying potential is reduced. However, this does not result in moisture accumulation in the masonry layers, likely due to the breathable nature of the insulation allowing moisture to move out of the wall to the inner face of the wall.

The use of SWI appears to be as safe as the wood fibre insulation also specified in the design of the external building elements of the case study. Where both insulation materials are used in combination neither material exhibits moisture accumulation, relative humidity is simulated to decline across the insulation layer toward the inner surface of the elements in both materials.

5 References

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