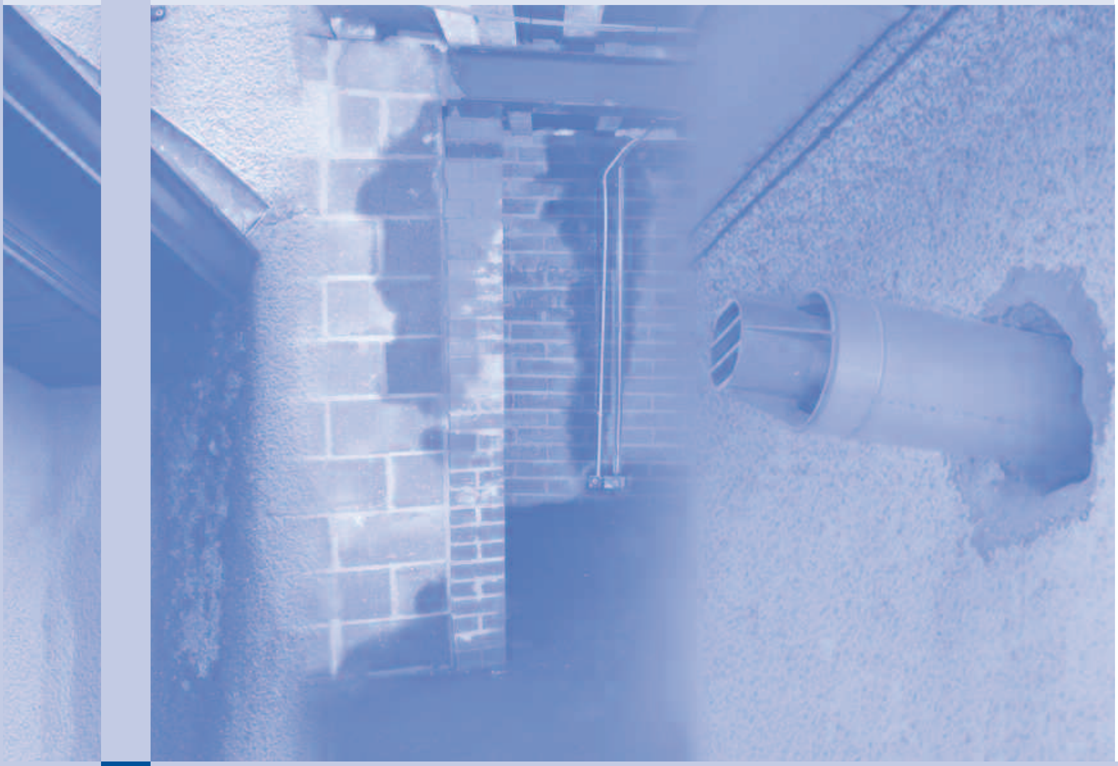
Learning the lessons from systemic building failures

NHBC FOUNDATION
Housing research & development in partnership with BRE Trust



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September 2008

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FOREWORD

At a time when UK house building is facing perhaps the fastest and most pronounced changes (in terms of output, construction methodology and regulatory impact) in its history, this review is a timely reminder of the need to keep sound design criteria at the fore.

Within the past 30 years, a number of systemic building failures have come to light in various countries. These include deterioration of pre-cast reinforced concrete, moisture penetration of external insulation and failure of structural insulated panel roof systems. Other problems, while not related to a particular building system, have arisen which reflect systemic failure in design and construction standards. With conventional construction, information is available from many sources, but with innovative construction systems and materials new detailing has to be developed. If the design is to be built successfully and to give satisfactory long-term performance it is important to ensure that new, previously unproven, details are robust.

This review outlines some historic problems with house construction relating to materials, moisture, design and detailing. Using examples to illustrate problems that have arisen with innovative forms of construction, it identifies solutions as well as exploring some of the reasons for the problems and issues that have arisen as a result.

There is little doubt that much change will take place in housing construction over the coming few years as we respond to the challenges of, among other issues, raising energy efficiency standards. I am confident that this review will help the industry to avoid repeating the mistakes of the past and so ensure that the homes we will be building will be robust and long lasting.

Rt. Hon. Nick Raynsford MP

Chairman, NHBC Foundation

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Figure 7a: Katherine Adams, BRE.

Figure 7b: Taylor Lane.

Figure 25: Centre for the Built Environment, Leeds Metropolitan University.

Figure 29: James Jones and Sons Ltd.

Figure 30a-d: Unilin Systems.

Figure 30e: James Jones and Sons Ltd.

Figure 32: Peter White, BRE

Image on page 25: Taylor Lane

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1 Introduction

Within the past 30 years a number of systemic building failures have come to light in various countries, including:

- Failure of pre-cast reinforced concrete (PRC) houses in the UK
- Moisture penetration of external insulation finish systems (EIFS) in British Columbia, Canada, the United States and New Zealand
- Failure of structural insulated panel (SIP) roof systems in Alaska, USA.

Other failures have also occurred that, while not related to a particular building system, reflect systemic failure in design and construction standards. Designers who shun traditional detailing (eg projections at eaves, drips on sills and the provision of movement joints) because they detract from the visual impact of the building expose the structure to a greater than necessary risk of failure. Similarly, operatives who use inferior materials or cut corners in order to save time will expose the structure to unnecessary risk of premature failure.

Historically, there has been a continuous cycle of innovation in construction practice (Figure 1), and unforeseen problems have inevitably arisen. However, for serious problems solutions have been found, lessons have been learnt and improvements have been made, often in an incremental way. As a result, in parallel with continuous innovation there has been continuous refinement in building regulations and an increase in our overall knowledge of what constitutes good practice. Research has also enabled the development of tools that allow performance to be predicted and problems to be avoided as, for example, with interstitial condensation calculations.

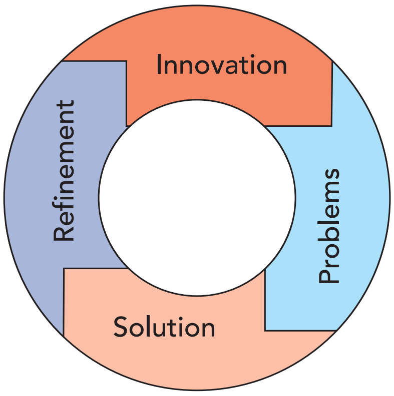


Figure 1 A continuous cycle of innovation in construction practice.

Although our overall knowledge has increased, it seems that our ability to pass that knowledge on to successive generations of professionals has decreased. There may be some understandable reasons for this. Training of designers and craft operatives concentrates on what needs to be done, but does not always impart an understanding of why it needs to be done in a certain way.

All too often the designer concentrates on the aesthetic appeal of the building and leaves the builder to work out the detailed construction on site. With conventional construction the operative has a large body of information from materials' suppliers and other sources, such as NHBC's Standards, that helps him or her choose an appropriate solution. With innovative construction systems and materials, new detailing has to be developed that allows the particular design to be built. In many cases this leads to poor solutions, such as a reliance on sealants where, for example, a properly detailed flashing might be more appropriate.

The purpose of this review is to briefly look back at some historic problems with residential construction and remind the reader of the solutions, and also, by way of a few examples drawn from the international community, to look at problems that have arisen with innovative forms of construction. This review will describe the reasons for the problems and the issues that have arisen as a consequence.

1.1 The role of moisture

Moisture is one of the main causes of deterioration in dwellings and can arise from a number of sources:

- Rain penetration through the structural envelope
- Leakage from faulty services and appliances within the dwelling
- Condensation of moisture vapour in the air
- Groundwater via rising dampness
- Moisture resulting from the water used in the construction process, eg in plasters and mortars, and from construction in wet weather
- Flooding.

During the life of a structure, it would be optimistic in the extreme to expect there to be no instances of the fabric getting wet. It is essential that once the cause of the problem has been addressed the fabric is able to dry out and that it should, if necessary, be reparable at reasonable cost.

In modern construction, where innovative construction systems are beginning to replace cavity masonry, the control of moisture is becoming ever more critical. Increased levels of airtightness in dwellings mean that mechanical ventilation systems are increasingly being specified to deal with moisture generated within the building by occupants and their everyday activities such as cooking and bathing. If the ventilation strategy is deficient in any way (poorly specified, poorly maintained or prone to breakdown) then humidity levels will tend to rise, increasing the risk of condensation. With construction systems that include a vapour control layer, condensation may occur within the fabric of the external walls if it is faulty. This is called 'interstitial' condensation.

1.2 The impact on the consumer

It is easy to look at systemic building failures as simply a technical problem that, when properly investigated, will yield a technical solution. However, the impact on homeowners can be devastating and can remain long after the technical issues have been resolved.

PRC houses in the UK were built as part of a large programme of construction of non-traditional houses after the Second World War, mainly by local authorities. Many of these dwellings were purchased under the 'Right to Buy' scheme introduced in the 1980s. Subsequently it became clear that many PRC homes were suffering severe structural problems that the purchaser could not have been aware of at the time of purchase. In all some 30 house types were designated 'defective' under the housing defects legislation brought forward in 1984. This legislation empowered local authorities to operate a Scheme of Assistance for affected homeowners, via either repurchase or grants for repair.

In 1985 PRC Homes Ltd (a wholly owned subsidiary of NHBC) was established to license repair systems developed for affected house types in order to assist private owners. For houses repaired through the scheme, general 'mortgageability' on standard terms was reinstated and there was the additional benefit of a 10-year warranty. For the many tens of thousands of PRC houses that were not dealt with through the scheme, including those that were not in private ownership at the time that they were designated defective, mortgages are not generally available on standard terms.

A key impact on consumers, however, in addition to the financial burdens, even in those homes that could be repaired, is the stress and disruption faced whilst repairs were undertaken. This has also been true for consumers in British Columbia and the other places where systemic failures of this type have occurred. As an industry we have a clear obligation to seek to avoid re-creating problems of this nature at any time but there is an increased need for care and robust risk assessment at times of rapid change and innovation. It is hoped that this review will assist that process of protection for the end users of our output – the home buyers and occupiers.

2 Housing construction problems

2.1 Poor design detailing

There appears to be a belief on the part of some designers that ‘modern’ buildings do not need ‘traditional’ detailing. Many traditional details, such as a projections at eaves and verges (see Figure 2) and a drip on a window sill, were developed to protect the structure from the weather by providing a degree of shelter and directing rainwater away from the building.

Figure 2 Generous overhangs at eaves and verge help to protect buildings from the weather.

Omitting a drip from window subsills, as illustrated in Figure 3a, will increase rain absorption of the wall below. With no projection at the sill, water streaming down the window will be directed over the brickwork below, increasing the risk of rain penetration. This would have been potentially quite serious in the days of solid masonry construction, but now that cavity construction is the norm the water can usually be safely discharged via weep holes. However, if there were to be debris in the cavity (see Fig. 3b) or mortar accumulations on the wall ties the risk of rain penetration would be increased by the omission of the drip on the sill.

Increased intensity and frequency of rainfall is predicted as a consequence of climate change, and flooding events appear to be increasing in severity. These factors will place greater requirements on the fabric of dwellings to resist moisture.

Figure 3a Flush brick-on-edge subsill.

Figure 3b Debris in the cavity such as mortar droppings can form a path for water to track across the cavity.

Penetrations through claddings can be difficult to seal properly. Figure 4 shows the attachment of a substantial bracket for a mast to carry aerials and a satellite dish. It will be difficult to get an effective seal around the bracket where it passes through the cladding (in this case a boarded finish is to be used). Surface tension will encourage rainwater to track down the lower diagonal brace, potentially allowing water to penetrate the structure. A more robust solution would be to redesign the bracket so that the diagonal brace slopes downwards away from the building. Alternatively, fixing blocks could be installed behind the cladding so that the bracket could be fixed on the face of the cladding.

Figure 4 The bracket for aerials and satellite dishes has a lower brace that will encourage water to track towards the building.

Figure 5 shows a roof abutting a wall where the detailing cannot manage rainwater effectively. The problem is due partly to poor design and installation of the rainwater goods, but the design of the flashing detail is also poor. At 'A' a piece of render stop bead has been applied at the end of the flashing. This point will be vulnerable to the entry of water behind the rendering. A 'kick-out' or 'diverter' flashing to deflect water directly into the gutter would have been better.

Figure 6 shows a raised architectural feature around a window on the same development. The green stain above is again the result of water over-topping a faulty gutter. It is interesting to note that the stain stops when it meets the raised render but is visible on the soffit immediately above the window. This indicates that some water may be passing behind the raised render.

Figure 5 Poor detailing at junction.

Figure 6 Water has penetrated behind the raised decorative feature.

2.2 Moisture originating during the construction phase

During the construction phase the structure is particularly vulnerable to moisture from adverse weather. During this phase partially built structures and components being transported to site, or being stored on site ready to be used, can be exposed to large amounts of rainwater. Steps can, and should, be taken to minimise the impact of bad weather.

Perhaps the most obvious action that should be taken is to protect materials and components during transit and storage. Many materials, such as bricks and blocks, are often shrink wrapped by the manufacturer. This protection should be left in place as long as possible prior to use. If materials are unprotected when delivered then protection should be provided to prevent materials becoming saturated with rainwater. Figure 7a shows poorly stored blocks on site. The blocks are totally unprotected, allowing them to absorb large amounts of moisture which can lead to a number of adverse effects:

- Wastage of damaged or soiled materials increases
- The completed structure needs longer to dry out
- Surface staining and efflorescence
- Poor adhesion of mortar and renders to surfaces contaminated with mud
- Increased cracking of wet-applied plaster and render finishes
- Porous materials are more susceptible to frost damage in cold weather.

Figure 7a Poorly stored blocks become saturated with water in bad weather.

Figure 7b Prefabricated units protected from adverse weather during transportation.

Figure 7c Timber framed panels awaiting installation. They are stored in a purpose-made frame and individually wrapped in polythene for protection.

Figure 7d Structures becoming wet during construction.

Problems may be more acute with materials that are sensitive to moisture, such as timber components, which can warp making them more difficult or impossible to install properly. Figure 7b shows prefabricated modular units fully protected for transportation, and Figure 7c shows timber framed panels which are stored in a purpose-made stand to prevent distortion and protected from the weather with polythene sheeting.

Materials and components remain vulnerable once they have been incorporated into the structure as illustrated in Figure 7d.

Some structures are more resilient to permanent damage than others. The masonry structure will be largely unaffected once the structure has dried out, but the timber frame structure may suffer permanent damage if exposed to wetting for a prolonged period.

The problem may be more acute if the moisture is 'locked in' to the structure before it gets a chance to dry out, as occurred recently in Hammarby Sjöstad, Stockholm.[1] During the summer and autumn of 2000 some apartments were constructed during a period of very heavy rainfall. Their structures were poorly protected from the weather which resulted in the closed timber frame panels which formed the external walls becoming saturated. Before the walls had a chance to dry out they were directly clad with an external insulation system which effectively trapped the moisture in the walls. As a result the structure of some of the apartments suffered severe mould growth and blue stain fungus attack. Remediation works were extensive, in some cases requiring the external cladding, sheathing board from the timber frame walls and insulation within the panels to be completely removed before the full extent of the problem could be determined. As a result of the problems the construction company rethought its internal policy on quality control to prevent further problems. They also developed new and improved working practices such as:

- The introduction of a requirement that time was allowed in the schedule for the drying process
- Installation of the outer envelope only to be carried out after the roof is sealed
- Walls to be protected immediately after installation
- Insulation, plastic film and internal plasterboard only to be installed after the wall elements have been surveyed for moisture and accepted.

2.3 Failure of rendered finishes

Render has been used for decades as an effective way of reducing rain penetration in areas exposed to severe weather. However, a poorly designed render system can result in serious problems for masonry walls, especially those of solid construction. Figure 8 shows a detached final coat of render that will encourage rain penetration and represents a hazard to people passing by. The render mix incorporated a 'soft' building sand rather than a well-graded sand.

Strong renders tend to shrink and crack on curing, as illustrated in Figure 9. If a strong render is applied to a relatively weak background it will detach, allowing water to penetrate behind the render – see Figure 10. Because the render is dense and impervious the rate of drying is very slow, leading to a number of problems with the fabric:

- In solid masonry construction, embedded timbers such as wall plates and the ends of joists that bear on them suffer from decay
- In cavity masonry, corrosion of wall ties can lead to structural problems
- Penetrating damp leads to damage to internal decorative finishes and to mould growth, potentially with associated health problems for occupants in severe cases
- With some bricks bedded in cement mortar, sulfate attack can occur if the masonry is kept damp for prolonged periods. The interaction of sulfates with the cement mortar causes the mortar joint to expand, further opening up cracks as in Figure 11. In severe cases structural problems can ensue.

Various solutions have evolved to deal with specific problems. Stainless steel wall ties replaced galvanised steel ones, and the use of joist hangers has reduced the amount of embedded timber. However, in all cases the problems would have been reduced if moisture had been excluded in the first place. For rendered finishes that means using a render that is designed to exclude as much moisture as possible but that allows any moisture that does penetrate to dry out. A good render should have the following attributes:

Low shrinkage Cracking in renders mainly results from shrinkage of the render on curing or drying. In order to minimise cracking the render should not be too strong and should be produced with well-graded sands. Its moisture content should not be too high, which implies the use of plasticisers to make a workable mix. The plasticiser can be a modern additive or the partial replacement of cement by lime in the mix.

Vapour permeable The use of well-graded sands and a plasticised mix will increase permeability.

Good adhesion Proper preparation of the substrate is essential. Substrates should be clean and free of dust and loose material. Backgrounds of high or variable suction can be treated with a spatter dash coat. Providing a mechanical key by raking out mortar joints also improves adhesion.

Figure 8 Poorly specified render with detaching final coat.

Figure 9 Cracking in render typical of a strong mix.

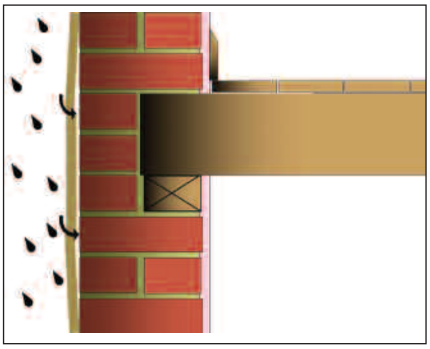


Figure 10 Cracks allow moisture to accumulate in the walls, which can lead to rotting of embedded timbers.

Figure 11 Example of sulfate attack on cement render on a parapet.

Appropriate strength Renders should be neither too strong nor too weak. As a general rule, a render should be weaker than the substrate. However, if a render is too weak it will not be durable.

More guidance on renders can be obtained from BRE Good Building Guide 18.[2]

Modern polymer render systems are available as one-coat decorative renders or multi-coat weathering renders. The preparation and application procedures for these renders can be significantly different from those for conventional sand/cement renders, and may differ from system to system. Most manufacturers issue detailed guidance on the use of their own products and offer training courses for operatives. Systems are normally covered by third-party certificates such as those provided by BBA or BRE certification, which have detailed requirements for the installation of the product, usually including the use of trained operatives.

Figure 12 shows bond failure of a polymer render system. Although the operatives who applied the render were competent with conventional render systems, they were not familiar with, or trained to apply, the polymer render. Figure 13 shows cracking in newly applied render over expanded polystyrene used as external insulation. Investigation revealed several poor workmanship issues including an inadequate thickness of base coat and missing reinforcement.

These two examples illustrate the importance of proper training in the application of polymer renders.

Figure 12 Polymer render failure.

Figure 13 Cracking in newly applied polymer render.

2.4 Underside corrosion of sheet metal roof coverings

Sheet metal has been used as a roof covering for centuries. Initially, cast lead was the main material and it was used on many ancient buildings, but more recently other metals such as copper, zinc, aluminium and stainless steel have been used, as in Figure 14.

Corrosion of the underside of sheet lead roof coverings has been known about for centuries. In the 1970s it was felt that the rate of occurrence of severe cases was increasing.[3] A subsequent study by the Ecclesiastical Architects' and Surveyors' Association concluded that the reason was increased condensation resulting from heating, inadequate ventilation or insulation, and occupancy. The problem was exacerbated by organic acids originating from timber deckings.

Figure 14 Copper-covered roofs on houses in open country. These roofs were laid in 1947 and have given excellent service.

Other metals are also prone to corrosion and should be protected when used on some timber deckings, depending on the specific combination of metal and species of timber. Some timber preservative treatments can also have a deleterious effect. On timber deckings the underlay is normally Type 4A (ii) to BS 747 'Roofing felts (bitumen and fluxed pitch)' but this may not give complete protection over treated deckings. An impermeable barrier such as 500 gauge polythene sheet beneath the underlay would be better. The various parts of BS CP143 Sheet roof and wall coverings[4] and BS 6915 Design and construction of fully supported lead sheet roof and wall coverings – code of practice[5] give more detailed and practical guidance.

Keeping moisture from the underside of a fully supported metal roof can be difficult because there are a number of possible sources of moisture. The most obvious measure would be to ensure that construction materials are not wet before the roof is installed, ie installation should not be undertaken in wet conditions. It is worth remembering that even apparently dry materials, especially porous materials such as timber, can contain substantial amounts of moisture.

With cold roof constructions it is preferable to provide ventilation beneath the deck so that any moisture vapour from the building itself can be rapidly ventilated away.

Moisture can also penetrate beneath the metal itself via a mechanism known as 'thermal pumping'. Solar radiation heats up the air immediately below the sheet metal, causing the air to expand and be expelled. Subsequent rainfall causes the air to cool, creating a partial vacuum that sucks in water flowing over any standing seams or laps that are not completely airtight. Small shielded ventilators penetrating the roof covering can be used to solve the problem.

2.5 Steel corrosion in Pre-cast Reinforced Concrete (PRC) dwellings

In the early 1980s inspection of an Airey house revealed cracking to the structural PRC columns. Figure 15 shows a recent image of cracking to a PRC column in an Airey house.

Figure 15 Cracking to PRC column in Airey house.

Subsequent investigations of other PRC dwelling types revealed similar problems. The cause of the deterioration was found to be corrosion of steel reinforcement, resulting in cracking of the concrete. The rate of deterioration varied widely both between and within different house types. Factors that affected the rate of deterioration were:

- Location. The incidence and extent of damage was generally higher and more advanced in wetter, colder parts of the country
- The rate of carbonation of the concrete. Embedded steel in new concrete is protected from corrosion by the alkalinity of the cement paste in the concrete. Carbon dioxide from the air reacts with the cement paste and reduces the alkalinity – this is 'carbonation'. When the carbonation reaches the steel reinforcement, the natural protection of the concrete is removed and corrosion can occur. The rate at which carbonation occurs is influenced by the quality of the concrete in terms of its permeability and the type of aggregate used
- The amount of cover to the reinforcement. In some cases cover was as little as 6 mm

- The level of chlorides in the concrete. Chloride ions have the effect of increasing the rate of corrosion and were present from a number of sources. Chlorides were sometimes incorporated into the concrete mix deliberately (ie 'cast-in') to speed up the set of the concrete or to allow casting in colder weather. Other external sources of chloride were from unwashed marine aggregates, from wind-driven sea spray in coastal areas or from de-icing salts. Chlorides from external sources tend to be more damaging than the 'cast-in' additives because the latter are chemically bound up in the concrete structure.

2.5.1 Implications for UK practice

As a result of the investigations mentioned above, and other subsequent research, the factors that affect concrete durability are now much better understood. Tests have been developed to identify problem aggregates, factors (such as water : cement ratio; compaction; and aggregate type) that determine the quality of concrete have been identified and appropriate guidance documented, and the importance of good cover (50 mm) to steel reinforcement is now well known. Where 50 mm cover is not practical, stainless steel reinforcements can be specified.

2.6 Moisture penetration through external wall insulation systems

In British Columbia from 1985, reports of serious moisture penetration problems in timber framed buildings that were clad with face-sealed external insulation finish systems (EIFS) began to emerge (see Box 1). Large numbers of dwellings, in particular a large number of apartments (condominiums), were affected by decay in the timber frame, with associated problems resulting from mould growth. The problem became known as the 'leaky condo syndrome'.

BOX 1

External insulation finish systems are the same as external insulation systems used in the UK. They comprise slabs of an insulation material (eg polystyrene, phenolic foam, mineral wool) fixed to the exterior of a building to provide thermal insulation. The insulation is protected by a reinforced render system, which can be a conventional Portland cement render (often referred to as 'stucco' in other countries) or a thin polymer render (also known as 'synthetic stucco').

There are two basic types of EIFS:

- Face sealed systems, which rely on the render itself and sealants around openings etc. to keep water out of the structure.
- Drainable or 'Water Managed' systems, which incorporate a second line of defence designed to direct any moisture that penetrates the render system to the outside.

By the late 1990s the problem had escalated to the extent that British Columbia's New Home Warranty Program (their equivalent of NHBC) collapsed. By 2002 some 50,000 affected homes had been identified.

The response to the problem in British Columbia was to establish a Commission of Inquiry into the quality of condominium construction. The enquiry heard evidence from a wide range of people. The enquiry did not find fault with external wall insulation systems per se, but found that there was ineffective regulation of, and accountability for, the building process and poor application of building science in the use of the systems. The factors that contributed to the problem are reproduced from the Commission's report in Appendix A.[7]

In 1995 the Buildings Envelope Research Consortium (BERC) was formed via an initiative of the Canada Mortgage and Housing Corporation (CMHC). The purpose of BERC was to facilitate research into the building envelope problems in the coastal climate of British Columbia.

One of the first pieces of research conducted was a survey of 46 buildings of which 37 had problems, the other 9 being controls.[8] The purpose was to compare problem buildings with the controls to determine what attributes of construction led to problems. The key findings were:

- Problem buildings tended to have a higher exposure to wind
- The absence of overhangs above walls contributed to moisture damage
- The control buildings had fewer architectural features and details and more of the details were provided with flashings
- Almost all the problems were associated with details such as windows (penetration through both the frame joints and the interfaces with the wall), decks, walkways, balconies and penetrations on walls
- All cladding types experienced performance problems, although the number of problems reported on stucco walls was greater
- In the coastal climate area, face sealed wall assemblies were sensitive to design and construction details, making it difficult to achieve acceptable performance. Rainscreen wall assemblies were thought to offer the best opportunity to achieve acceptable performance.

The study concluded that greater attention needs to be paid to water management principles (associated with control of moisture entry, drying potential and drainage). It concluded also that local climatic conditions need to be taken into account when establishing effective water management strategies in construction.

Another major initiative was the Moisture Management for Exterior Wall Systems (MEWS) project. Laboratory tests carried out by the National Research Council of Canada found that significant amounts of water could penetrate the cladding through faulty seals.[9] For example, the amount of moisture penetrating a 90 mm portion of missing sealant on a vertical window joint ranged from 0.1 to 0.4 litre/min depending on test conditions. Tests also showed that EIFS claddings let through more water than other cladding systems. The same laboratory also reports that moisture penetrating to the studwork is reduced by 90% if a drained cavity is included.[10]

The concept of the '4 Ds' (deflection, drainage, drying and durability) was also developed to summarise a strategy for moisture management. The principles are:

- **Deflect** moisture away from a building by the use of overhangs and other measures such as flashings
- **Drain** moisture out of the structure if it gets past the cladding
- **Dry** the structure by providing ventilation
- Choose **durable** materials that will not degrade should they get wet.

Similar problems to those experienced in British Columbia have been reported in other countries including the USA, Sweden and New Zealand, and the issues surrounding them are broadly the same as in British Columbia. The response in the US was basically regulatory in that some states have effectively barred the use of non-drainable systems, whereas the response from New Zealand was that the Building Industry Authority established an inquiry in the form of the Weathertightness Overview Group.

The report of the overview group identified deficiencies in the Building Act and the Building Code.[11] In order to address the latter a risk assessment approach based on the '4 Ds' principles was developed and incorporated into the compliance document for the New Zealand building code as 'Acceptable Solution 1'. See Section 3 on Risk-based assessment of design details.

In Sweden, following investigations into problems resulting from moisture ingress into timber framed walls during construction (see section 2.2), problems were noted in timber framed buildings directly clad with external insulation systems that could not be explained solely by construction in wet weather. A report[12] by SP Technical Research Institute of Sweden states that damage was caused by water infiltration through defects in the façade after completion of the house. Figure 16 shows a cross section of a construction found to be susceptible to damage. Damage usually occurs in the sheathing material and the outer part of the wood frame structure.

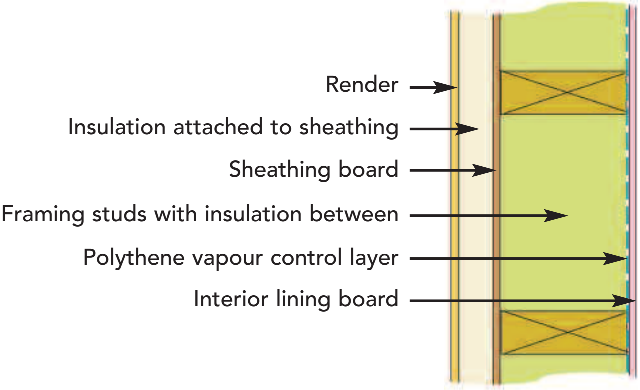


Figure 16 Cross section of wall found to be susceptible to moisture penetration in Sweden. Based on a diagram in reference 12.

In a number of surveys undertaken by SP they have found that construction detailing around fastenings and joints on the façade are unsatisfactory from the perspective of preventing moisture entering the fabric. In particular, cracks have opened up at the side junctions of balconies, windows, terraces and canopy attachments. Below these areas moisture contents in the sheathing board have been found to exceed 28%.

The SP report points out that in most cases problems noted to date have been found when the wall has been opened up for other reasons, giving reason to suspect that there will be significantly more damaged houses as yet undetected. In June 2007 funding was secured for a research project to undertake a comprehensive review of the extent of moisture damage in rendered, undrained walls. The aims and methodology of that project are detailed in a further SP report,[13] which concludes that undrained constructions such as that in Figure 16 represent a high risk from the point of view of moisture ingress and should not be used.

2.6.1 Mechanisms for water to penetrate external wall insulation systems

There are a number of ways that moisture can penetrate external wall insulation systems, either as a liquid through gaps in the system or as vapour. Rainwater running down the face of a structure can be encouraged into the system by gravity, capillary action or surface tension or by an air pressure difference. The air pressure difference can be caused either by wind forces acting on the structure or, in unventilated systems, by thermal pumping, as described in section 2.4.

Rain striking the face of a building can be driven into gaps under its own momentum, and liquid water can also enter the system via leaking service pipes penetrating the building envelope. Substantial amounts of moisture can be incorporated into the structure by using building materials that are wet or working in wet conditions.

External insulation systems with thin reinforced render systems are generally regarded as impervious to liquid moisture, but that is not necessarily the case. For certification purposes the appropriate standard against which renders are assessed is MOAT 22.[14] The water impermeability test subjects the render face of a sample to liquid water at a pressure of 50 Pa (equivalent to a 5 mm head of water). The pass criterion is that the render withstands the passage of water for two hours. Since the test is concluded at the end of the two-hour period, it is not possible to say whether prolonged exposure to water would result in liquid water passing through the render, but it is known that the render can absorb water and in doing so may soften.[15]

Moisture in the vapour phase can get behind the insulation system from within the building itself, as a result of either a missing or an ineffective vapour control layer or a faulty installation of services (eg extract fans or tumble dryer vents improperly sleeved). Also, if the render can absorb moisture in prolonged rain events, strong sunshine may drive water through the render as moisture vapour.

Some insulation materials (phenolic foam, wood fibre and mineral wool) have the capacity to hold substantial amounts of moisture. Manufacturers often claim that their materials are water repellent, which may be the case for many. However, water repellence can be overcome under certain conditions, such as when liquid water is forced in under pressure (which would be the case with a thermal-pumping mechanism) or if it were to condense within the insulation from the vapour phase.

Phenolic insulation is known to release acidic compounds when it gets wet, and a number of cases have been reported where galvanised steel roofing sheets have been corroded as a result of contact with wet phenolic foam.[16] There is therefore potential for galvanised steel in contact with wet phenolic foam, or with moisture that has been in contact with the foam, to corrode, although to date no instances of corrosion in external wall constructions are known.

Unwanted gaps in the cladding can be classified into two types:

1. Those that relate to the cladding system itself, and are the result of either poor workmanship, poor design of details or degradation of the system over time
2. Those that result from works undertaken by others, such as service penetrations, and that cannot be attributed to the original installer.

Figure 17 shows cracks in a render that have been made good with a sealant. The photograph was taken in late November after a few days of rain, although on the day it was taken there was no rain. The render immediately adjacent to the cracks is darker in colour than the body of the render, indicating that it is drying more slowly than the rest.

Figure 17 Repaired cracks in external render.

Figures 18 and 19 show details from external insulation applied to an existing masonry dwelling some 20 years earlier. The insulation has given excellent service, with no problems of moisture penetration (this would have been helped by the fact that the insulation was applied to previously rendered walls). The images illustrate the effects of ageing on an installation. Figure 18 shows a vertical movement joint where the sealant is de-bonding from the render stops. However, this is not the original sealant, which has already been replaced by the sealant shown. Figure 19 shows gaps that have opened up around a window sill. The gaps are 3 to 4 mm wide and will allow moisture to penetrate.

The issue of systems 'ageing' highlights potential problems for the future. When referring to durability one BBA certificate for external wall insulation systems states:

> *The system should remain effective for at least 30 years, provided any damage to the surface is repaired immediately, and regular maintenance is undertaken including checks on joints in the system and on external plumbing fitments to identify leakage of rainwater into the system, enabling steps to be taken to correct the defects.*[17]

Experience has shown that the average UK householder is unlikely to carry out (or pay for others to carry out) regular inspections of the external fabric of their house. It is much

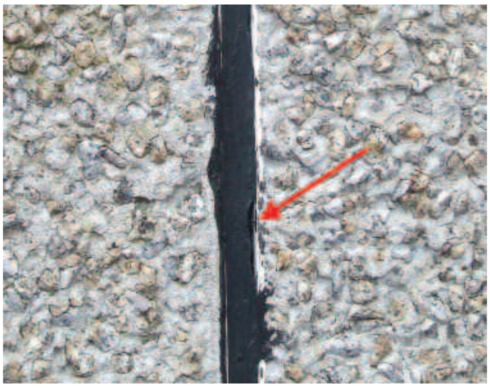


Figure 18 Movement joint with bond failure in mastic.

Figure 19 Gap around sill.

more common for householders to react to a problem once it manifests itself inside the property, by which time considerable damage to the fabric may have occurred. They also may not be made aware when purchasing the dwelling that the system requires such inspections, and may not know how to go about finding a suitably qualified tradesperson to undertake repairs.

Work undertaken by others

Work undertaken by other tradesmen after the insulation system has been installed is normally related to the installation of services. Common examples are the fitting of boiler flues, waste and other pipes, vents and cables, all of which pass through the cladding to the outside. The trades involved may not be aware that the exterior of the building is clad with external insulation, and may not know how it is built up.

In the majority of cases, the precise position for the penetration is determined inside the building, and so the hole is started from inside. A great deal of damage can be done where the cutting device breaks through on the outside, although this can be made good using a variety of available materials.

Figures 20 to 22 show a variety of service penetrations. Figure 20 shows a boiler flue shortly after installation but before the exterior was made good. The large amount of damage to the external insulation system will be difficult to seal effectively. If it did not have protection from the eaves, moisture ingress would be very likely. A cover plate would improve the appearance but if poorly sealed might not keep out water in a more exposed location. The cable in Figure 21 has sensibly been looped downwards to form a drip for rainwater, but the hole it passes through is not sealed. In Figure 22 the vent cover is sealed with a sealant (which may not be effective against such a rough background). One of the pipe penetrations is not sealed at all and the other has been poorly made good with a mortar. If the mortar used in the repair is stronger than the render or is poorly bonded then it is likely to allow moisture into the fabric.

Figure 20 Extended boiler flue.

Figure 21 Cable penetration.

Figure 22 Various service penetrations.

The original installer cannot be held accountable for these works since they were out of his control. However, the system should be designed with such abuses in mind, so that when moisture does penetrate it cannot do any damage.

2.6.2 Implications for UK practice

The construction of buildings in the UK is regulated by the building regulations. In England and Wales the requirement under building regulations for resistance to moisture is covered by requirement C2: Resistance to moisture, which states:

> The floors, walls and roof of the building shall adequately protect the building and people who use the building from harmful effects caused by:
>
> a. Ground moisture
> b. Precipitation and wind-driven spray
> c. Interstitial and surface condensation
> d. Spillage of water from or associated with sanitary fittings or fixed appliances.

Approved Document C provides guidance on various wall construction/cladding options, eg requiring a ventilated space between cladding and building on timber framed structures. The Northern Irish and Scottish equivalents make similar requirements. It is important to understand, however, that the scope of the requirements in Part C is limited to "securing reasonable standards of health and safety for persons in or about buildings" and does not seek to protect the building fabric for its own sake.

NHBC Standards include detailed guidance to control the risk of rain penetration. For example, they require that external insulation systems over timber frame include a 15 mm drained and ventilated cavity, and over light gauge steel frame a 15 mm drained cavity.[18]

The consequences of moisture penetrating behind external insulation systems will depend on:

- The detailed construction and materials used
- How easily the moisture can dry out
- The hygro-thermal conditions within the wall structure.

When deciding on the most appropriate design solution, it is prudent to assume that water in one form or another will penetrate the system. With that in mind the potential consequences in terms of the well-being of the occupants and the fabric should be assessed and appropriate steps taken to minimise adverse consequences.

The number of possible combinations of construction and conditions within the structure is large so a few basic construction types are discussed below.

2.6.3 Masonry construction

External insulation is normally applied directly onto masonry substrates, and the history of performance as a retrofit measure is good. The dwellings in Figure 23 were externally insulated some 20 years earlier and have performed very well in an exposed location in Cornwall. The system used was conventional render over mineral wool batts applied as a retrofit measure to previously rendered hollow blocks.

Sealants are approaching the end of their design life (some have already been replaced), but as the substrate is rendered block no serious problems would be anticipated.

Figure 24 shows a development of four flats built in 1999 with externally insulated solid walls. The façade shown faces directly onto the sea in an exposed coastal location. Careful attention to detailing around openings (eg the use of stainless steel render stop beads to allow robust silicone sealant joints to be achieved against the window frames) has contributed to the good performance.

Figure 23 Good performance of 20-year-old render over external insulation.

Figure 24 Careful detailing has given good performance in an exposed coastal location.

2.6.4 Timber frame construction

Timber frame construction in the UK is well established and in general has a good track record. Some problems of timber decay have been noted in directly clad non-traditional systems built up to the mid 1970s, but the extent of decay was modest compared to the problems seen in other countries. Research into the problems by BRE found:

> Instances of decay may be encountered in direct claddings, particularly on exposed elevations at sites where the driving rain exposure is high. However, the decay is usually localised and the weathered timber easy to cut out and replace.[19]

Where decay was found the four main sources of moisture are cited as:

- Rainwater penetration through the external envelope
- Condensation generated by water vapour from within the dwelling
- Rising damp, which occurs if the dpc is ineffective
- Leaking plumbing or domestic appliances.

Many of the dwellings involved in the study would not have had a vapour control layer (the inclusion of which only became common practice in the 1960s). Modern timber frame constructions should, in theory, not suffer from interstitial condensation resulting from moisture vapour generated within the dwelling. However, as Figure 25 illustrates, vapour control layers are often damaged, both before occupation during the construction process and after occupation, by follow-on trades installing services.

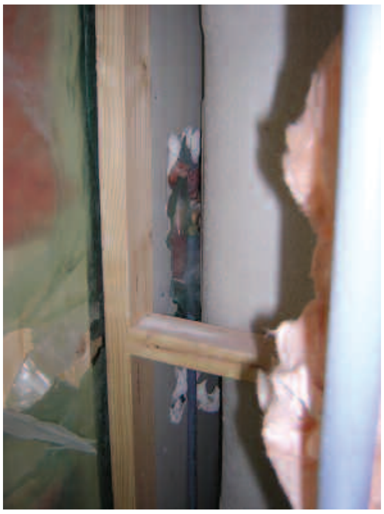


Figure 25 Damage to vapour control layer by 'follow-on' trade.

2.6.5 Steel frame construction

Like with timber frame, older non-traditional steel frame constructions also suffered from moisture ingress, leading to corrosion of the steel. Again, the water ingress was at vulnerable points of the structure such as around openings. Investigations by BRE found some cases of severe corrosion of the steel frame, but in general corrosion tended to be superficial. The study concluded:

> The majority of steel houses are expected to give good performance into the foreseeable future, and should have a life on a par with rehabilitated dwellings in conventional construction. [20]

Modern (light gauge) steel frame construction differs from non-traditional constructions in a number of ways:

- The steel is thinner and is galvanised
- Modern steel frame is insulated on the outside of the frame to create a 'warm frame' construction – non-traditional steel frame constructions were not insulated. Keeping the frame warm reduces the risk of interstitial condensation
- Modern construction practice is to install a vapour control layer where a condensation risk analysis indicates it is needed – systems built prior to the 1960s would not have a VCL.

The Steel Construction Institute (SCI) quotes a design life of >200 years for galvanised light steel sections in warm frame applications, provided there is no risk of water ingress or condensation.[21]

The NHBC requirement for a 15 mm cavity on framed constructions is somewhat contentious in that the external wall insulation industry believes that the cavity is not always necessary. The industry acknowledges that in some cases a 'second line of defence' against moisture penetration is needed; however, there are no recognised methodologies to determine when such a system would be required. SCI has developed a methodology for light steel frame construction, and while they acknowledge that the assessment process is 'subjective' and 'relatively simplistic' it could provide a basis for assessing robustness, albeit on a relatively arbitrary scale.[22]

The external wall insulation industry also acknowledges that from time to time mistakes will be made on site. With that in mind they have developed an insurance-backed guarantee scheme (for up to 20 years) for systems covered by third party accredited certificates (such as BRE or BBA certificates). However, since most certificates only apply to masonry backgrounds, it will be some time before guarantees will be available for framed structures.

As part of the process for issuing a guarantee, workmanship is much more closely monitored than it would otherwise be and any alterations affecting the system would not be covered unless they were undertaken in accordance with the system supplier's recommendations.

2.7 Rot in SIP roof panels in Juneau, Alaska

Juneau has a very moist climate with consistently high relative humidity (75% or more) and rainfall (roughly 1500 mm per annum). As a consequence moisture-induced failures are the most common.

In 1997 the roofs of a number of relatively new dwellings in Juneau showed problems of rot in the oriented strand board (OSB) of the structural insulated panels (SIP) from which they were made. By 2001 around 60 roofs required complete replacement, and the number was still growing. While it would be easy to blame the climate for the problems, the fact that many dwellings showed no problems indicated that other factors were the main cause of the decay.

The problem tended to be concentrated in the upper surface of the panels at the junctions between adjacent panels and at the ridge. Site investigations revealed a number of inadequacies with installation of the panels, but found that inadequate sealing between the panels was the main cause of the problem.

Opinions regarding the precise mechanism for the failure vary slightly. The most likely explanation is that air leakage around the panels carries moist air between them, resulting in condensation in the area of the upper OSB layer, causing it to rot.

A number of factors were at play in determining the extent of the problem. Where rot was found, the overriding factor was inadequate sealing of the joints between panels. In February 2002 a 'Question and Answers' article was posted on the SIPA (Structural Insulated Panel Association) website that summarised the results of an investigation led by Joseph Lstiburek of the Building Science Corporation. One of the conclusions of that investigation was that:

> If joints had been sealed at panel perimeters at the lower interior surfaces, failures would not have occurred.[24]

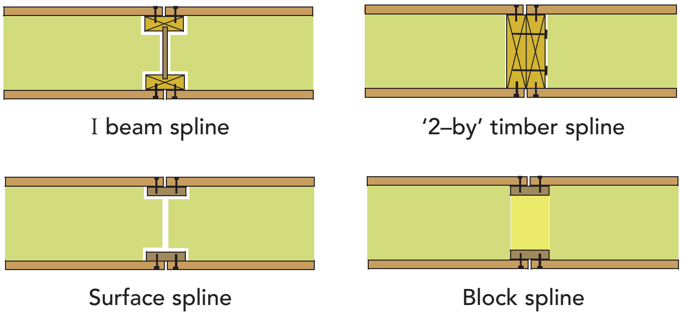
Elsewhere in the report Lstiburek lists three categories of joint failure, which can be summarised as:

1. No sealant was present in the joints
2. Sealant was present but was ineffective because it had been applied in a haphazard manner
3. Sealant was applied but the sealant had failed in adhesion.

The first two categories were the result of poor workmanship, whereas the third was attributed to the difficulty of applying sealants under typical weather conditions in Juneau.

Andrews reports feedback from a builder, Bill Heumann, that the type of spline can also influence the vulnerability to air leakage.[21] According to Heumann roof systems incorporating I-beam splines were much more vulnerable than systems using solid timber or surface splines. Heumann is reported to have claimed that the pockets cut into the foam to accommodate the splines were oversize and outside the tolerances given in manufacturers' literature. As a result the panels did not fit tightly. This view was backed up by other builders and engineers quoted in the report.

Panels are joined together using splines, of which there are four types; I-beam, '2-by' solid timber, surface splines (strips of OSB) and 'block splines' (which are effectively smaller SIP panels). No reference has been found to the use of block splines in Juneau. The various types of spline are illustrated in Figure 26.


I beam spline

'2–by' timber spline

Surface spline

Block spline

Figure 26 Different types of spline for SIP roof panels.

Other details not requiring a separate spline are also possible, such as that illustrated in Figure 27.

A typical roof construction described in the reports related to Juneau is shown in Figure 28.

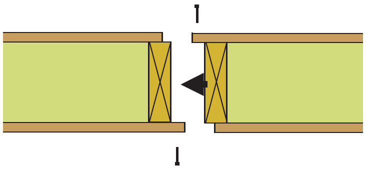


Figure 27 Alternative jointing method for SIP.

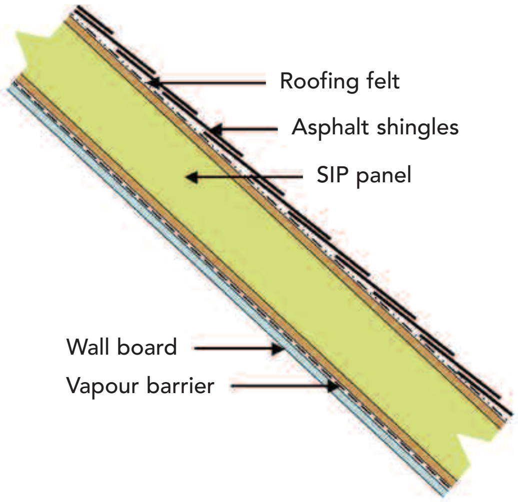


Figure 28 Typical SIP roof construction used in Juneau.

If moist air leaks between the panels, condensation is very likely to occur on the underside of the roofing felt. The lack of ventilation between the SIP and the roofing felt means that any condensed moisture will not be able to dry out and moisture will accumulate. It is this fact that caused the panels in Juneau to rot. Reacting to the problem the City and Borough of Juneau Building Division issued a policy on SIP roof panels (see Appendix B). In it they listed the three most significant factors contributing to the failure of SIPs as:

1. Lack of continuous vapour barriers
2. Failure of sealants in the panel joints
3. Lack of ventilation above the panels.

They set out four requirements for the use and repair of structural insulated panels on roofs:

- The inclusion of a vapour barrier on the warm side of the SIP
- Ventilation of the cold face of the SIP by provision of a ventilated air gap between the SIP and the roof covering
- Complete sealing of all voids and interfaces of SIPS including at joints
- An inspection regime to ensure good workmanship.

It should be noted that if SIP panels in Juneau had been installed according to the above requirements there should not have been any problems.

2.7.1 Implications for UK practice

The use of roof cassettes has increased significantly in the UK over the past decade because of the advantages they bring in terms of flexibility of design and increased efficiency of the construction process. Roof cassettes can be designed to span large distances, so room-in-the-roof construction can be achieved with much less structural timber than a standard roof, usually needing only purlins for intermediate support (see Figure 29). This gives a space that is completely open, and simpler to detail in terms of airtightness and thermal insulation. The speed of construction is also increased and it is quite feasible for a watertight roof to be placed in a single day.

The detailed construction of the roof panels in use in the UK varies, and ranges from SIP construction with no internal structural timbers (similar to the type used in Juneau) to panels with structural timbers and only the internal face of the panel clad with a sheet material. A range of constructions are illustrated in Figure 30, all of which are designed to create a ventilated space above the roof panel.

The crucial issue is whether or not the Juneau problem could occur in the UK. The factors that determine how panels will perform are the same whether the roof is constructed in Juneau or in the UK, namely:

- Control of moisture vapour passing through the fabric
- Creating an airtight roof
- Providing adequate ventilation above the panels to safely disperse any moisture that accumulates.

One major difference between the UK and Juneau is that the climate is less severe in the UK, so the risk will be correspondingly lower. Current UK building regulations, standards and construction practice deal well with all these factors but, as with any construction, there is always scope for things to go wrong.

Figure 29 Roof cassettes being installed.

Figure 30a Roof cassette with internal structural timbers. A sheet material is used on the underside only – the foam insulation is recessed to form a ventilation gap.

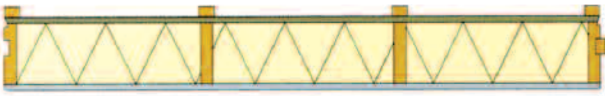


Figure 30b Roof cassette with internal structural timbers. Sheet materials are included on both faces.

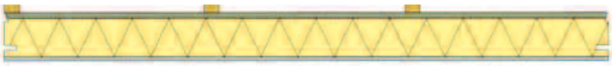


Figure 30c Roof cassette with no internal timbers – ie a SIP panel.

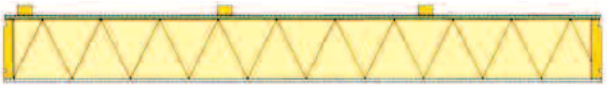


Figure 30d Roof cassette with structural timbers at the edge only.

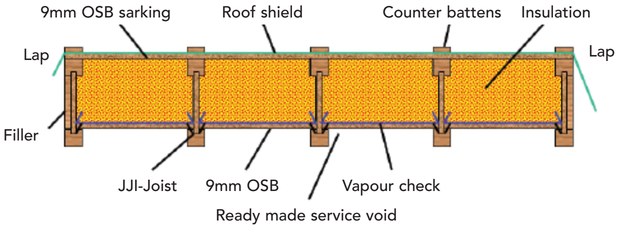


Figure 30e Roof cassette with structural timber I beams. The panel is designed so that the lower flange of the beams form a service void.

Install a vapour control layer

Manufacturers of roof cassettes point out that the foam core is itself an effective vapour barrier and does not readily allow moisture to pass through. The critical areas, however, are the joints. As the experience in Juneau has demonstrated, poor workmanship and a lack of site supervision can lead to joints being created on site that are not effectively sealed. It is therefore prudent to install an effective vapour control layer on the warm side of the panels as a 'first line of defence' against moisture vapour percolating through the roof.

Increase airtightness

Achieving a good seal between the panels and at other points in the structure (ie at the eaves and ridge) reduces the amount of moisture-laden air able to leak through the roof. Making sure that the vapour barrier is continuous would improve robustness and to some extent guard against joints opening up as a result of movement of the structure or later de-bonding of the sealant. Increasing standards of airtightness in the UK and greater use of post-construction testing mean that poor practice will increasingly be spotted before occupancy, allowing sufficient time for remedial action if necessary.

It is most important that the seal is achieved on the lower side of the joint, is continuous and extends as far as possible through the panel (see Figure 31). If only the top side of the joint is sealed, condensation could still occur below the upper sheet of OSB, leading to the possibility of rot.

The roof panels should be dry when sealed (or at least meet with the sealant manufacturer's recommendations) and the joint made before the sealant 'skins' over.

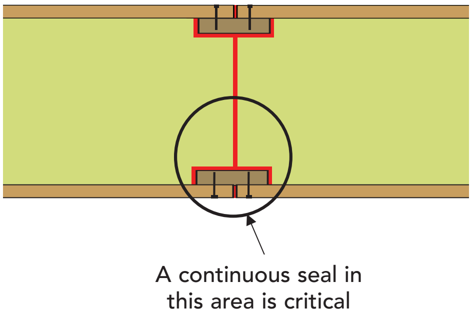


Figure 31 Seal most critical in lower half of panel.

Ventilate above the roof cassette

A continuous ventilation gap above the panels, open at eaves and ridge, will ensure that any moisture that reaches the surface of the panels is effectively removed. Standard tiled or slated finishes on battens and counter battens with a breather membrane will easily achieve the necessary conditions to prevent condensation, but there are some roof finishes (such as standing seam metal roofing) where there is the potential to create a structure with no ventilation above the cassette. Such systems need to be specified carefully.

Figure 32 shows two images of a plywood deck over a roof cassette with a standing seam metal covering. There is no ventilation beneath the plywood deck. The integrity of the vapour control and the airtightness measures is being relied upon to prevent condensation on the underside of the plywood. Mounting the plywood on counter battens to create a ventilation path would have been preferable.

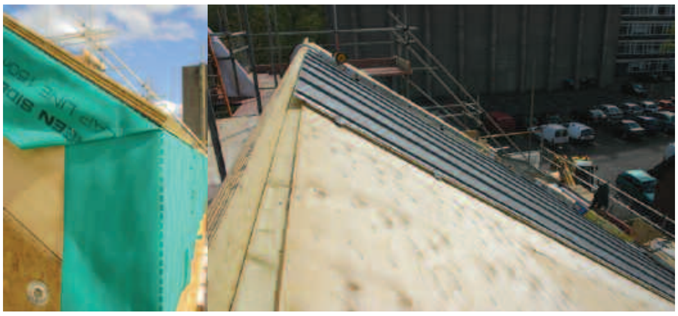


Figure 32 Plywood deck over a roof cassette with a standing seam metal covering. A ventilation space beneath the plywood would be more robust.

3 Risk-based assessment of design details

It may be feasible to use a risk-based methodology for design detailing with external wall insulation systems on framed construction. However, before such a system can be developed all risks must be understood. A few factors that would be relevant to UK construction are illustrated in Figure 33.

In New Zealand a sophisticated system for assessing risk for timber frame construction has been developed, following their review of moisture penetration problems. Several risk factors are included:

- Wind zone
- Number of storeys
- Roof/wall intersection design
- Eaves width
- Envelope complexity
- Deck design.

Each external wall face or elevation is assessed and given a risk rating (from low to very high) and a corresponding risk score for each of the six risk factors. The total risk score is used to determine what types of cladding are permissible (note that the risk assessment relates to timber framed structures). The maximum possible overall score is 28, but scores above 20 are deemed outside the scope of the Acceptable Solution and a redesign of the building may be needed to reduce risk. If the overall risk score is greater than 6, external insulation systems (ie EIFS) must incorporate a 20 mm drained cavity. The full methodology is described Clause E2 of the building code[25] and detailed guidance on its use is given in an accompanying guide to using the risk matrix.[26]

The factors listed above would be equally relevant in the UK, although the actual level of risk may differ because of differences in climate. However, additional factors would need to be taken into account. Different materials and material combinations may affect risk. For example, steel frames may be more vulnerable in coastal areas because the presence of chlorides can accelerate decay in galvanised steel.[27] Since phenolic foam insulation is known to affect galvanised steel sheeting in roof construction, could it also affect light steel frames in wall construction?

The level of maintenance of the systems will affect durability, and therefore risk. In many cases the materials being relied upon to provide the weathertightness of a structure have a limited life. Sealants may need to be replaced several times over the design life of a system. Owner occupiers are much less likely to undertake the regular inspection and maintenance requirements detailed in third party accreditation certificates than a housing association with a comprehensive planned maintenance regime. Thus type of ownership will itself affect risk.

Alterations to the fabric by third parties, such as the creation of penetrations for services, can lead to problems. Low rise dwellings are more likely than high rise to have such works carried out, so the built form may also affect risk.

The development of a comprehensive risk assessment methodology supported by good evidence may be the ultimate goal. However, in the meantime, given the seriousness of problems that have occurred around the world, the approach of managing the risk of moisture penetration in framed construction by providing a drainage cavity is considered wholly appropriate.

Figure 33 Factors influencing the weather-tightness of dwellings.

4 Summary and conclusions

The problems described in this review were chosen to illustrate how a lack of understanding of (or failing to adhere to) sound building science, poor design and/or poor workmanship can lead to problems of moisture ingress and damage to the fabric. The overriding assumption should be that moisture will penetrate the fabric and, with that in mind, the designer and builder should take all reasonable steps to ensure that moisture can safely be drained and/or ventilated to the outside before damage can be done.

It should be recognised that materials and systems will degrade with age, and that routine maintenance and inspections will not always be carried out. The PRC homes problem also illustrates the importance of choosing durable materials for the structure, particularly when it is not possible to inspect the structure without the removal of claddings or lining materials. Buildings may undergo alteration within their lifetime, and such alterations may compromise the ability of the cladding to keep the structure dry. Thus it is prudent to incorporate some form of second line of defence, even if it is regarded as 'redundant' at the design stage.

In practical terms, that means a robust approach to moisture management, both from within the building and from the weather. Moisture vapour generated within the dwelling is prevented from entering into the external wall structure by the provision of properly detailed vapour control layers (VCL). To prevent any moisture that gets past the VCL condensing within the wall, materials should be selected that allow moisture vapour to pass easily to the outside. As a general principle, any individual layer within the structure should have a higher vapour permeability than underlying layers, thus making it easier for moisture to pass to the outside. Where a layer is specified that has a lower vapour permeability than underlying layers, there is potential for condensation to occur and a ventilated cavity should be provided at that point to ventilate away any accumulated moisture.

External moisture should in the first instance be deflected away form the building by the provision of appropriate overhangs, flashings and claddings impervious to liquid water. When water penetrates the cladding, the principle should be to make provision for it to drain to the outside.

4.1 Dos and Don'ts

Do:

- Assume that water will find a route behind a cladding
- Build in 'redundancy'
- Recognise that errors will be made during the construction process – defects will be built in
- Remember that some materials deteriorate with age – especially sealants
- Adopt the 4 Ds principles (deflect; drain; dry; choose durable materials) when designing dwellings
- Anticipate future work that may compromise the integrity of the cladding.

Don't:

- Rely on sealants to keep water out indefinitely
- Assume that regular inspections of cladding and sealants will be undertaken
- Casually experiment with people's homes in search of a short-term fix or an unreasonable acceleration of change.

APPENDIX A

Factors contributing to the Leaky Condo Syndrome, taken from the Barrett Report

The Renewal of Trust in Residential Construction: Commision of Inquiry into the Quality of Condominium Construction in British Columbia (1998).
www.qp.gov.bc.ca/condo.

The building process

The residential building process operates within a set of complex business relationships, statutes, and regulations. The Commission was presented with case after case of ineffective regulation regarding responsibility and accountability at each stage of the construction process. These included:

a) an inability on the part of municipalities to effectively monitor building quality; to ensure inspectors play a meaningful role in maintaining building standards and in enforcing building codes

b) a lack of provincial monitoring to ensure accurate interpretation of the building code, as well as its performance requirements

c) a lack of developer, builder, and general contractor responsibility – often facilitated through protective corporate structures

d) architects who have been unable to maintain professional responsibility in translating designs into quality physical structures

e) engineers who have been unable to ensure their involvement in the process will lead to quality construction of the building envelope

f) a lack of training, skills, and qualifications that have led to a deterioration in the quality of worker performance

g) an inadequate home warranty program which, in the majority of cases, is faced with a conflict of interest between its service to the homeowner and its obligation to the developer

h) a mortgage guarantee system which tends to serve the interests of the residential construction industry and financial institutions, without due regard to the consumer, who buys its services

i) a lack of information from the builder to the strata council to facilitate its responsibilities

j) a lack of understanding as to the roles and responsibilities of strata councils and management companies, which has often left the homeowner confused and alone.

Building science

In addition to economic pressures, climatic conditions, and a systemic failure of the building process, building science also played a role in bringing about this crisis of confidence. The factors related to technology, or building science, include:

a) a poorly interpreted building code

b) municipal by-laws that can lead to inappropriate design, exacerbated by architects who do not understand the implications of their designs

c) the use of new materials without an understanding of how they will be affected by our climate

d) a loss of collective memory, and lack of conventional wisdom, among inspectors, architects, engineers, developers, and contractors regarding the requirements for effective building

e) ineffective communication and transfer of knowledge among the professionals and business people (who understand the issues), to others involved in the building process.

APPENDIX B

City and Borough of Juneau, Alaska – policy on structural insulated panel roofs

(www.juneau.org/cddftp/bldghandouts2003/SIP_ROOF.pdf)

Structural insulated panels (SIP) are premanufactured construction materials used in place of standard 'stick-built' construction techniques for walls and roofs of buildings. Recent reports from engineers and observation by building inspectors indicate that these panels, when used as roofing materials, have exhibited a very high failure rate in Juneau.

These costly and potentially dangerous failures are generally appearing in the top layer of the panels which have rotted and sometimes deteriorated to an oatmeal consistency as well as in the rotting of the wooden joint materials.

The top and bottom layers of SIPs usually consist of oriented strand board (OSB) which is similar to plywood but with smaller pieces of wood veneer heated and pressed into sheets with resin adhesives. In the panels, bonded between the OSB layers is a layer of foam insulation. The edges of the panels usually contain wooden splines that slip together to join the panels.

The most significant factors contributing to the panel failures in Juneau are the cool temperatures along with the elevated relative humidity in Juneau as compared to other locations. The extra moisture inside and outside our buildings makes the proper installation of the panels more critical in our environment. The specific reasons for the failures appear to be:

1) Lack of continuous vapour retarders (usually plastic sheathing often called 'visqeen') on the warm side of the panels thus allowing moisture from the interior of the building into panel voids and joints

2) Failure of sealants in the panel joints to adhere to the wood and foam (wet surfaces) and thus failure to stop moisture from travelling through the joints to the top layer of OSB

3) Lack of ventilation at the top layer of the panels to dispel the moisture.

In order to avoid future problems with SIPs used as roofs, the City and Borough of Juneau Building Division has adopted the following requirements on the reverse side of this sheet for the use and repair of SIPs in roofs.

Requirements for installation and repair of structural insulated panel roofs

Installation or repair of SIPs used in roofs in the City and Borough of Juneau shall meet the following requirements:

1. **Vapour retarder.** The installation or repair of SIPs in roofs shall include a properly installed and sealed vapour retarder on the warm side of the SIP. The vapour retarder shall be rated at no more than one tenth (0.10) perm by a recognised testing agency

2. **Roof ventilation.** SIPs used as roofs shall have a 'cold roof' installed over the panels that provides not less than 1_ inches of air space above the top skin of the panel. Such air space shall be continuous from top to bottom and open to the atmosphere at the top and bottom. Other designs will be reviewed and may be approved on a case by case basis

3. **Sealants.** All voids and interfaces in SIPs, including at joints, shall be completely filled with approved adhesive sealant. Such sealant shall be firmly bonded to the panel materials

4. **Special inspection.** SIPs shall be repaired or installed under an approved Special Inspection Program as defined in the building code. The Special Inspection shall cover the following areas:
    a) Proper installation and sealing of the vapour retarder including continuous installation across support elements
    b) All material surfaces that receive sealants and adhesives shall be dry or meet the manufacturer's specifications
    c) All sealants and adhesives shall be applied within the temperature ranges specified by the sealant or adhesive manufacturer
    d) All surfaces to be adhered or sealed shall be in contact with the sealant within the reaction time of the sealant. Surface skinning of the sealant shall not be allowed before the panels are in their final position
    e) All voids in the panel structure, including voids in connections, shall be completely filled with adhesive sealant
    f) All penetrations of the vapour retarder shall be properly sealed upon completion of the work requiring the penetration
    g) All connections to the structure shall be completed in accordance with the manufacturer’s instructions and the approved plans for the structure.

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