Practical Application of Hygrothermal Modelling to Forensic Failure Investigations

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Abstract

We present a series of ‘lessons learned’ in hygrothermal modelling from real-world investigations of moisture in buildings. These are illustrated through two case studies which used various tools including on-site monitoring and hygrothermal simulation. Our focus is to demonstrate the benefit of hygrothermal modelling, which can deliver greater understanding of the movement of moisture through the building fabric than traditional approaches. One important outcome is that condensation through occupation, often considered the main culprit of moisture-related damage, is not always the cause. Construction defects and a significant increase in the moisture sensitivity of modern designs (and materials) are often the factors that determine the failure and decay of contemporary building systems.

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1. Introduction/Background

The authors are engaged in the investigation of construction-related failures, mainly in the UK. Through this work it is apparent that water remains the main culprit for the failure of systems and materials in this industry. We carry out forensic investigations to: establish the mechanisms of such failure; identify the root cause(s); and specify effective remedial works to reduce or eliminate the damage. Whilst it is typically obvious that moisture is the direct cause of damage, it is not always straightforward to determine the mechanism of failure. A common question (in relation to roofs, in particular) is: ‘leak or condensation?’

Traditional investigation of this question might involve visual observations, intrusive investigations, superficial moisture measurements, application of chemical dyes/tracers, and material sampling. Recently, we have also applied transient hygrothermal modelling tools, such as WUFI 6.4, to better understand the moisture-related phenomena at work.

By adjusting the detailed parameters in the software, we have been able to simulate potential construction defects to identify possible causes of the situation observed on site and to assess the sensitivity of the design to (excess) moisture. WUFI requires a combination of skill and experience to appreciate the significance of each parameter and the relevance of this to real-world construction and behaviour. We present and discuss two case studies which illustrate this point.

Our assessment considered three criteria set out in BS 5250:2011 Code of practice for control of condensation in buildings:

1. The design of the structure and the heating system should ensure that, over the coldest month, the average relative humidity (RH) at internal surfaces does not exceed 80%, to limit the risk of mould growth. [1]
2. Any interstitial condensation which might occur in winter should evaporate during the following summer, to prevent an accumulation of moisture year on year.
3. The risk of material degradation should be assessed in terms of the maximum level of condensate which might occur.

1.1. Case Studies

Case Study 1: Severe decay was observed to the plywood and oriented strand board (OSB) sheathing within a timber-framed construction clad with either brick masonry or powder-coated aluminium panelling. In-situ monitoring revealed abnormally high relative humidity (RH) within the wall cavity. Further investigation identified that a breather membrane had been installed on the interior side of the walls, in lieu of an air and vapor control layer (AVCL). Because of this error, condensation was suspected as the cause of the damage. We carried out a hygrothermal analysis of the two wall assemblies (brick cladding and metal cladding) to assess the condensation risk to the exterior sheathing. The analysis indicated that interstitial condensation was not likely to form at the sheathing. This was because the closed-cell insulation used in the assemblies features a highly vapour resistant foil facing which effectively acts as a vapour barrier, if tightly fitted.

In the brick clad wall assembly, even when construction defects (such as the incorrect choice of interior membrane and/or air infiltration through the insulation) were introduced, the overall behaviour of the assembly did not change; no risk of condensation was observed. However, the situation was somewhat worse when the effects of construction moisture (e.g., rain exposure or condensation leaks) were considered. When the assembly was modelled with wet OSB (initially ~20% wood moisture content by mass,
WMC), the RH and water content values exceeded the recommended threshold. However, this situation persisted only for a few months; the board dried to below 15% WMC within one year of installation. The only situation in which a wall assembly did not pass the analysis was the metal clad version, modelled with an unventilated cavity and either the OSB or plywood having an abnormally high initial moisture content. In this case, the sensitive materials exhibited a drying behaviour, but the RH remained above 80% (with corresponding 18% WMC) after 4.5 years.

**Case Study 2:** Unventilated flat roof: a prefabricated cold deck, unventilated, insulated timber cassette construction. Severe degradation of the OSB deck had been noted by maintenance teams working on an area of the roof. An intrusive investigation of this area revealed that the AVCL had been punctured by the installation of services. Rot had affected the upper portion of the cassette glulam beams, but the damage to cassettes was localised, with adjacent cassettes not exhibiting damage. This contrasted with a survey conducted over the other roof areas using Tramex instruments, which showed that elevated moisture levels were concentrated towards the ridge and around the roof lights (Figure 1).

Multi-parametric WUFI simulations, showed that, despite the punctures to the AVCL, the decay was most likely caused by water trapped in the roof, due either to leaks or moisture trapped during construction. The observed rate of decay was much faster than could be explained by damage to the AVCL alone (one year observed, vs two years modelled, Figure 2). Thus, although the roof design was vulnerable to moisture ingress, it was not the theoretical design *per se* that had ultimately caused the failure.

1.2. To rectify the situation, the roof was provided with a new, ventilate

![Figure 1 - Roof relative moisture profile. Blue (low) to grey (high).](image)

![Figure 2 - OSB deck moisture content with damage to AVCL](image)

Wireless moisture sensors were installed in the new roof, confirming that the works had the desired effect.

1.3. Discussion

Condensation is a leading cause of damage in buildings. However, the source of condensing moisture is not always warm, moist air from within the building (as is often suspected). Transient hygrothermal modelling has shown that modern designs lack resilience to moisture, especially when foreseeable construction defects are considered. In addition, apparently small, aesthetic changes to a design can have a significant effect on its performance.

By providing a ‘comprehensive’ model of heat/moisture transport and storage mechanisms, software such as WUFI has great utility for failure investigation, particularly as a means for simulating circumstances to explain conditions observed on site. A significant benefit is the ability to deconvolute multiple and/or competing mechanisms that may cause or prevent failure. The software also provides a way to evaluate the robustness of a design and the potential effectiveness of remedial works. However, the model inputs must be carefully selected to reflect the real-world situation, and the outputs require expert interpretation. As such, it is most powerful when combined with information from traditional investigative techniques.

1.4. Conclusions

Transient hygrothermal modelling has become a valuable analytical tool for assessing real-world performance of the building envelope. It is of particular use in situations where a construction diverges from industry standards or from the intended design, or where construction defects may affect the overall response of the system to moisture.

The technique demonstrates that contemporary designs have a poor tolerance to moisture and are particularly reliant on defect-free execution.
1.5. References

[1] BS 5250:2011+A1:2016 - Code of practice for control of condensation in buildings. BSI, 2016.