

Special issue on enthalpy, moisture and ventilation issues in buildings

For it is the chief requisite for life, for happiness, and for everyday use. (Pollio *et al.*, 1914, p. 226, Book VIII)

In the first century BC, Vitruvius was clear on the role of the building's roof to protect the walls and foundations from rainwater (Pollio *et al.*, 1914, p. 177, Book VI, Chapter 3) and the removal of the water by the use of drains (Pollio *et al.*, 1914, p. 156, Book V, Chapter 9). Recognized as an issue since antiquity, there has been a great deal of fragmented research on building moisture, but the topic still represents a problem area in too many buildings. Research has tended to focus on local problems, and as a result the lessons and associated knowledge are either not relevant, or more dangerously used inappropriately, for other locations or climates.

This special issue brings together a wide range of international research into moisture in buildings. There are six papers from around the globe, including Europe, North America and Oceania. Three papers explore moisture issues in roof spaces, two deal with moisture in the floor and sub-floor and one paper is about moisture in walls. The results and models reported in this special issue will contribute to a better international understanding of issues of moisture in buildings, as well as providing improved guidance to practitioners faced with either not wishing to create future moisture problems or to resolve current problems.

The physics of moisture in buildings is a topic that is reaching some level of maturity, though there is still significant work to be done, both in research and implementation. For much of the construction industry simplistic answers dominate. Simplifications of the physics have their place, but only when made with an understanding of their impact on the proposed application.

An example of this is the application of the Glaser Method (also known as the Dew Point Profile) to assess condensation risk. The method lacks consideration of the storage of moisture or heat, or the movement of air, which on the one hand can lead to overly conservative outcomes or on the other extreme poor moisture performance due to the incorrect use of a vapour barrier. As Joseph Lstiburek writes, "Vapor barriers are also a cold climate artefact that have diffused into other climates more from ignorance than need" (Lstiburek, 2011). The fact is, constructions are rarely subject to steady state conditions (or even close to) for long periods in much of the world, particularly in more temperate regions (ASHRAE, 2005, Chapter 23; Rose, 2005, pp. 79-84). A key downfall of the Glaser method is the lack of acknowledgement that the relative transport rates of heat and moisture are substantially different. While equilibrium with respect to temperature across a construction can come about relatively rapidly, moisture equilibrium can take substantially longer.

Rainwater penetration water represents a major concern around the world, yet the stochastic nature of failures due to this mechanism makes it difficult to predict. The very expensive "leaky homes" problem seen both in the temperate climates of Canada and New Zealand, resulted from systemic industry failures, with the common thread being external water reaching parts of the construction that it was unable to escape from.

This special issue is dedicated to Harry Trethowen, now retired from BRANZ, one of the leaders in the field of understanding moisture and heat movement in buildings.



The problems took from months to years to become visible leading to often very expensive consequences (Parliamentary Library, New Zealand, 2002).

On the other hand, diffusion and capillary-driven transport is easier to model. In recent times, the toolset has been growing with the creation of computer-based, physics-driven simulation tools such as the WUFI family (<https://wufi.de/>), Delphin (<http://bauklimatik-dresden.de/delphin/index.php>) and others. These tools give the designer and researcher the ability to study moisture movement in great detail, even with simplified inputs. The current suite of tools pulls together coupled moisture and heat transport equations, including material storage, solar radiation and a whole host of other aspects of the physics. Little of this complexity is presented to the user as the underlying equation sets are hidden from view, making these software packages friendly to a wide variety of users. Tools that were once in the researchers' realm are now being used in practitioner level applications.

As we strive for higher performing structures, hygrothermal tools play an important role, but users must be clear as to the implications of not only large but also small changes to their assumptions. A small difference to a single input can have large effects in the results, leading to the untrained implementing a solution that results in issues which can be difficult to spot and in the long term may even be destructive. Boundary conditions are critical regardless of the tool as are the material properties. Both of these are pain points, as more often than not, they can be subject to substantial guesswork. While external environmental data are relatively common, understanding occupant behaviour and its impact on the indoor environment is not.

Many products also do not have the technical data available to undertake a thorough moisture analysis. The results of these tools are commonly used as if emerging from a black box, the user needs both rigour and a connection with reality in order to rely on them. The difficulty in the coming years will be ensuring users of such powerful tools have enough understanding of the underlying processes to ensure the result are both realistic and useful, as the old saying goes; garbage in, garbage out.

At the macro level, the researcher and practitioner community can improve moisture management. Hindsight allows us to acknowledge that buildings have always leaked but moisture management has often been left to chance, rather than being explicitly engineered into the construction. Much traditional construction has allowed the relatively free movement of moisture (and air), but the modern use of high vapour resistance elements in conjunction with high thermal resistance, and better air management has resulted in a reduction of the ability of the construction to cope with moisture if used improperly. Current research is clear that the critical point to understand is that managing heat and moisture flow comes down to a question of balance. The flows of moisture into and out of constructions are critical, but so is the need to manage both internal and external moisture sources. Merely blocking the obvious moisture pathway may result in unforeseen buildup of moisture with associated long-term problems.

We cannot ignore air leakage, as air movement can carry moisture much more rapidly than diffusion or capillary transport. A goal from the outset for any construction is that it should manage moisture effectively, i.e. it should not trap moisture if it does condense but allow it to escape and the materials to dry when conditions allow. This should not just be a mere moisture solution, but an overall construction moisture management approach.

There is still a great deal of confusion in understanding where the moisture or vapour management planes should be placed in relation to the thermal resistance, or whether a variable vapour check is the appropriate tool. Construction industries worldwide are slow to changing, and old "rules of thumb" can clash with modern analysis techniques. Part of the reason for this confusion is that the seasons play a critical role in the management of moisture, and different climates present different concerns. In temperate climates heat and moisture migrate just as they do in cooler climates, but the risk of mould growth becomes

the greatest concern. In cold climates, issues of freezing become important, with the consequence of liquid water expanding and changing form as it turns into ice resulting in physical damage.

Problems that can be found regardless of climate can be minimized by maximizing warm surfaces which not only provide comfort but also condensation management. The use of better-quality windows (whether double or triple glazed, with or without thermally broken frames) is a consideration. Thermal bridge reduction, particularly in interstitial spaces where damage can go unnoticed is important, regardless of the climate.

The construction cannot be left to its own devices to manage moisture. The occupant plays a critical role – not only in ensuring moisture loads are appropriately managed, but also to ensure the moisture management systems are maintained. This list is extensive, but common issues that building occupants can help manage are simple things like ensuring gardens are not built over sub-floor vents, making sure ventilation provisions are used and maintained, maintaining plumbing and drainage systems (both indoors and out) – the list goes on, but the role of building owner or occupant cannot be forgotten.

Issue papers

The issue opens with a paper (Isaacs, pp. 366-394) exploring the evolution of moisture management in sub-floor spaces. Through analysis of a wide range of publications in the USA, UK and New Zealand, it explores the historical development of the use of ventilation and moisture barriers. The lack of moisture management of sub-floors can have catastrophic effects, but unlike fire, earthquakes, floods or structural failure, the consequences can take considerable time (often years) and will damaging to the building fabric may not result in loss of life or injury. The length of time from the first publication dealing with sub-floor moisture management to the creation of a specific (in modern language) “deemed-to-satisfy” requirement raises questions as to the time and research required to support modern building codes.

The sub-floor void conditions created by the use of retrofitted thermal insulation are explored through the long-term monitoring of 15 UK houses (Pelsmakers *et al.*, pp. 395-425). It was found that the conditions could be favourable to the growth of mould, which could have implications for house occupants if the spores were transferred to the household spaces, although it was not possible to compare insulated vs non-insulated, or damp vs non-damp sub-floors. It highlights the need for long term, ideally high resolution, monitoring as well as physical inspection. The paper raises questions that could be beneficially investigated by further research.

The dynamic simulation, hygrothermal analysis tool – WUFI is used by Lee *et al.* (pp. 426-447) to establish loads and performance criteria for framed wall assemblies. Their examples explore how environmental loads, such as rain penetration and air exfiltration, can be related to design limits including indoor humidity, insulation ratio and maximum allowable rain penetration. As well the conventional consideration of clear field assembly, the paper explores the role of critical junctions such as window sills and wall framing. Both high- and lower-vapour permeable membranes can have roles, although the design limits and benefits are required to be considered for the specific project and location climate. The paper also sets out a path to develop tools applicable for a wider range of climates and construction scenarios.

The remaining three papers deal with issues of moisture in roof or attic spaces, providing guidance as to the moisture movement from the interior to the building envelope into the attic space and opportunities resulting from energy retrofits which reduce this flow.

The air permeability of common ceiling linings and penetrations is explored by Rupp and Plagmann (pp. 448-460). The leakage paths between living spaces and roof cavity spaces include not only the air permeability of the ceiling type and materials, but also the

insertion of downlights and access hatchways. Using a specially designed test facility allowing the installation of roofs up to 38 m², characteristic air leakage data have been determined for four ceiling types (acoustic tiles, tongue and groove timber, plywood tight fit and loss fit), two joint types (scotia on plasterboard and plasterboard) and five penetrations types (hinged access hatch, two incandescent downlights, a halogen downlight and a LED downlight). A case study explores air and moisture movement into the roof space, using a simple mass-balance equation, suitable for use in the absence of more elaborate simulations.

A spreadsheet model based on ASHRAE Fundamental Handbook and Standards is used to Rose (pp. 461-472) to explore whether attic ventilation must be preserved in energy retrofits. The results show that the lowered moisture contributions across air-tightened ceilings may compensate effectively for added insulation (which lowers the attic air temperature) and the reduction in moisture dilution provided by attic ventilation. These results provide support for the policy of allowing attic ventilation reductions that are proportionate to ceiling air leakage reductions as part of weatherization efforts. However, given the limitations of the model, continued field observations remain critical.

Kölsch (pp. 473-487) use hygrothermal simulation to explore moisture issues in cathedral ceiling roofs (also known as skillion roofs) with ventilated roofing tiles. In Europe, the requirements for increasing levels of thermal insulation have led to a reduction in the use battens to support clay or concrete roof tiles. This has led to the creation of “non-ventilated” roofs with the potential for medium- and long-term moisture problems. The model explores conduction and radiative heat flow, as well as moisture movement. A simplified model, based on field tests, uses the outside climate with effective-transfer parameters and is shown to be appropriate. Similar models could be developed for other roof types such as metal or bituminous-coated sheets, but would require appropriate field research to establish the transfer parameters. The model, as well as provided valuable insights into roof thermal performance, can be used to design improved moisture-tolerant roof structures, develop optimized roof materials and components or to determine the causes of moisture damages.

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