CONDENSATION IN RESIDENTIAL BUILDINGS
Part 1: Review

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ABSTRACT

Condensation in buildings has become a concern, as thermal insulation is increased to improve energy efficiency. European standards for assessing condensation risk focus on winter conditions. Simplified psychrometrics used in the European steady-state condensation risk-assessment standard make it unsuited to warm humid Australian climates. The American standard can be used in warm humid regions, as it has been designed to accommodate locations such as Florida and Hawaii. Water vapour transmission data for Australian building materials, based on tests at in-service temperature and humidity conditions, are needed. Australia needs a standard for assessing condensation risk in buildings to establish a consensus on appropriate input data and analysis and assessment procedures for conducting hygrothermal analyses of Australian construction.

Keywords: houses, condensation, hygrothermal, insulation, energy-efficiency, ventilation, standards.

Recent incidents of mould growth inside Australian houses have been published in the ABCB Condensation Handbook (ABCB, 2011). A few decades ago mould on interior surfaces of houses due to condensation was rare. Australia has followed Europe, the UK and the USA in requiring new houses to be more energy-efficient by increasing thermal insulation in the building envelope. There has also been an increasing utilisation of air conditioning of houses in the humid tropical and subtropical regions of Australia. This paper addresses the impact of these changes and other matters such as the ventilation needs of energy-efficient homes and their indoor air quality and energy and operation costs (NHBC Foundation, 2009; LBNL, 1998) not addressed in the Condensation Handbook.

MOISTURE MOVEMENT IN BUILDINGS

Water vapour is water in its gaseous form. Its relatively slow movement by dispersion through porous building materials is driven by differences in vapour pressure. In cold winter conditions in heated and ventilated buildings the vapour flow is from indoors to outdoors. In summer conditions in air conditioned buildings the vapour flow is from outdoors to indoors. Unvented cavities in construction with still air allow faster movement of water vapour, as still air offers little resistance to water vapour transmission.

Ventilated cavities allow even faster movement of water vapour. The rate of water vapour transport in ventilated cavities is determined by the ventilation rate. Typically, more water vapour in building fabric is moved with air flow than occurs by dispersion through porous materials.

In contrast, movement of water in liquid form is relatively slow. Water flow can be driven downward by gravity through porous construction materials or in any direction by capillary forces. These water flows are controlled in building construction by drainage planes using sarking, dampcourses and flashings, and by draining accumulated water to the exterior of the building.

EARLY STUDIES OF INDOOR AIR QUALITY AND VENTILATION IN ENERGY-EFFICIENT HOUSES

A Building Research Station publication (Loudon, 1971) written during the Middle East oil embargo explored the interrelationships of indoor heating, average insulation of the building envelope, ventilation rate and relative humidity on the risk of condensation and mould growth in a UK terrace house.

The risk of condensation was found to be low, with standard envelope thermal insulation and ventilation rates. Comparisons were made with equivalent European houses that have higher insulation and lower ventilation rates. The equivalent European house had an indoor air temperature of 12 C obtained with a ventilation rate of 0.5 air changes per hour, and an indoor water vapour input of 7.2 kg/day while achieving indoor relative humidity below 70% RH.

These conditions were considered not ideal but acceptable to many people in the UK. The Ministry of Housing and Local Government (MH&LG, 1961) suggested an air temperature of 18 C in living rooms and 12.8 C in kitchen and circulation space, and bedrooms. Note that the focus was on energy efficiency. There was no mention of indoor air quality, which has now become a major issue in energy-efficient houses.

A recent worldwide review by the Building Research Establishment (NHBC Foundation, 2009) of indoor air quality in energy-efficient houses notes that there have been problems, and suggests less than 70% RH and a minimum of 0.5 air changes per hour are needed for acceptable indoor air quality.

With measurements of air leakage by fan-door pressure tests and caulking to achieve low leakage, mechanical ventilation was found to be essential to achieve indoor air quality. Australian standard AS 1668.2 (Standards Australia, 2007) recommends fresh air ventilation rates for indoor spaces much higher than 0.5 air changes per hour for bedrooms, but they are not mandatory

The 70% relative humidity upper limit to deter mould growth can be achieved by controlling ventilation fans using relative humidity sensors.

Reliance on occupants opening windows for natural ventilation was not considered acceptable, as surveys (NHBC, 2009) showed that less than 20% of occupants in new energy efficient houses ever open the windows. A detailed study of the relative performance of a range of mechanical ventilation systems for energy-efficient houses was conducted by Lawrence Berkeley National Laboratories (LBNL, 1998). This study includes relative system and operating costs. The more expensive systems cost US$2,000 and had annual operating costs around US$900 in 1998 dollars.

Multi-port supply systems with filters, heat and moisture exchangers, and indoor air pressurised to 10 Pa above outdoor air pressure, were recommended for energy-efficient houses in hot and humid climates. Multi-port supply plus single-port exhaust systems with filters and heat exchangers, and indoor air pressurised to 10 Pa above outdoor air pressure were recommended for energy-efficient houses in cold climates.

HYGROTHERMAL ANALYSIS

There are steady-state as well as hour-by-hour hygrothermal analysis methods for assessing risk of condensation in construction (examples are provided in Part 2 of this paper). The latter method, developed over the past decade, requires substantial input data on environmental conditions as well as construction material properties not currently available in Australia. This restricts its use in Australia.

While this method can model accurately, time-dependent water vapour dispersion through solid materials, computation of water vapour transport in air-filled cavities is problematic due to lack of knowledge of potential ventilation in cavities.

The simpler steady-state method (Glaser, 1958) is widely used and considered conservative because it ignores the safe moisture storage in materials such as bricks, timber and plasterboard. It is much less conservative for construction that has little moisture storage capacity, such as lightly clad steel-frame construction.

In cold climates, expanded polyethylene foam R0.2 thermal break strips are provided between the steel studs and external claddings to avoid cold thermal bridging and prevent pattern staining by mould on the surface of interior plasterboard.

Brickwork can safely store substantial amounts of water and release it during warmer dryer periods of the year. From research in the US (Lstiburek, 2002), brickwork in a modest 186 sq m brick veneer house can safely absorb and release 1892 litres; timber 189 litres (113 litres in Australia as less sheathing board is used); and plasterboard 19 litres. However, damp bricks can encourage growth of moss and lichen or suffer damage when freezing and thawing occurs.

Hygrothermal analysis methods in various countries use different calculation methods and assessment criteria. Each method is likely to achieve a different result. This is why a consensus standard is needed to suit Australian construction and conditions.

CHOOSING MATERIAL PROPERTIES USED IN HYGROTHERMAL ANALYSIS

When choosing material properties to use in hygrothermal analysis it is important that the properties closely match those of the actual materials used. This is easier said than done. Very few Australian building material manufacturers currently publish the vapour-resistance properties of their products. Past condensation problems in buildings in the UK and the US resulted in tables of vapour resistance data for local building materials but these do not necessarily reflect those of materials used in Australia.

For example, vapour resistance for aluminium foil is shown as typically 1000 MN.s/g in Appendix C of the ABCB Condensation Handbook based on information from the British Standard BSI EN ISO 13788:2002 (BSI, 2002). The aluminium foil materials used as vapour barriers on studs of brick veneer walls in Australia conform to the Australian/New Zealand Standard AS/NZS 4200.1:1994 (Standards Australia, 1994).

Typical Australian aluminium foil sarking used in walls would have a medium vapour resistance classification of around 300 MN.s/g. However, hygrothermal analysis requires specific vapour-resistance vales for materials under in-service conditions. The AS/NZS 4200.1:1994 standard cites ASTM E96 (ASTM, 2005) as the standard to be used for determining the vapour transmission of pliable membranes used in Australian buildings.

To complicate the issue, the Glaser steady-state method is not the only method of analysis available. Some Australian practitioners are trying to use the popular dynamic hour-by-hour WUFI software (ORNL, 2012) without a complete input data set. There is also a wide range of practices in determining outdoor and indoor air temperature and humidity conditions.

Mean monthly data are used in the UK, while in the US moving-monthly means, and means over three months, are used. Ventilation rates are often overlooked in analysis. Also, different criteria such as dew point and a 70% RH limit over specified periods of time are used to assess the relative risk of mould or condensation.

Given the very high liability if extensive toxic mould develops in a building, it is important that an Australian consensus standard is developed as soon as possible to establish appropriate input data, methods of analysis and risk-assessment procedures. Without accessible and reliable vapour resistance data for Australian products, hygrothermal analysis could be very misleading, and increase the liability of building owners, builders, building designers and HVAC professionals.

SUMMER CONDENSATION IN NATURALLY VENTILATED HOUSES IN THE HUMID TROPICS

Before the impact of Cyclone Tracy on the city of Darwin on Christmas day, 1974, walls of most residential construction in Australia's humid tropics, BCA climate zone 1, were uninsulated timber studs clad externally with fibre cement over a sarking, and lined internally with plasterboard. The metal-clad roofs had reflective sarking that also acted as a radiant barrier, limiting radiant gain to occupants from hot ceilings, and draining overnight condensate from the underside of the metal roof to the roof gutter. The buildings were naturally ventilated, using ceiling fans for occupant cooling.

From Bureau of Meteorology monthly climate statistics for Darwin, mean monthly 3PM relative humidity is below 70%RH for all months except January and February. Overnight relative humidity, as indicated by 9AM data, exceeds 70% RH for six months of the year: January, February, March, April, Nov and Dec.

Under these conditions traditional naturally ventilated houses are at some risk of mould growth because of the significant periods of time when relative humidity exceeds 70%RH. Consciously choosing mould-resistant materials and surfaces can help. In particular gypsum plasterboard should be avoided in naturally ventilated houses in the humid tropics.

The problem is reduced by making material choices such as glazed tiles or vinyl in lieu of carpet; plastic or metal blinds in lieu of fabric curtains over windows; and moulded fibreglass or timber furniture in lieu of soft upholstered moisture-absorbing furniture.

SUMMER CONDENSATION IN AIR CONDITIONED HOUSES IN THE HUMID TROPICS

After the impact of Cyclone Tracy on the city of Darwin that destroyed approximately 80% of existing houses, local authorities introduced more stringent building regulations. Reinforced concrete masonry walls offered an established construction system with improved resistance to windborne debris impact, structural integrity from footings to roof structure, and resistance to termite attack.

However, a wide range of house construction methods continued to be used. The reinforced concrete masonry walled construction posed a problem of how to insulate these walls when energy-efficiency requirements for thermal insulation were introduced in the 1990s, and air conditioning became more common.

Additional considerations that are applicable to all construction methods and climate zones include thermal bridging through metal studs, sealing penetrations in vapour barriers for electrical and plumbing services, particularly in cold-climate regions where vapour control membranes are close to the internal linings. The Australian house-building industry also has difficulty achieving tight building envelopes and installing effective vapour barriers and vapour retarders. Vapour barriers or retarders in walls need to be connected to vapour barriers or retarders in floors and ceilings. Indoor pressurisation offers a possible solution for air leaks but can be difficult and expensive.

CONCLUSIONS

A couple of decades ago mould on interior surfaces due to condensation in buildings was rare. Recent increases in thermal insulation for energy efficiency and utilisation of air conditioning in Australian houses has resulted in increased risk of condensation in winter in temperate climate regions and summer in humid tropical regions, if hygrothermal analysis is ignored.

A review of European and US building standards on condensation in buildings suggests that the recently developed ASHRAE Standard 160, (ASHRAE, 2009) may be the more appropriate for Australia’s relatively warm climates. The simplified psychrometrics in the British standard BS 13788 (BSI, 2002) are not recommended for use in warm climates. There is no equivalent Australian standard.

Steady-state hygrothermal analysis methods for assessing condensation risk, using conventional psychrometrics, are widely used and seem to be reliable for constructions that include masonry and timber that can safely store significant amounts of water vapour. They are less reliable in light-gauge steel construction, which has very little moisture storage capacity.

Dynamic, hour-by-hour methods work well when critical water vapour movement is by dispersion through porous materials. They are less accurate when water vapour is transported by moving air in cavities. Typically much more water vapour is transported by air flow through cavities in building construction than by dispersion.

Fresh-air ventilation rates recommended in AS 1668.2 are not mandated in Australian buildings. The actual rate of ventilation is often difficult to determine. Uncontrolled ventilation can have a significant effect on the energy efficiency of houses, the indoor air quality and the thermal comfort of its occupants, as well as the risk of indoor condensation. Recommended ventilation systems for energy-efficient houses can be expensive to install and operate (LBNL, 1998). Ventilation is often ignored in hygrothermal analysis, particularly in the case of houses. Low ventilation rates in energy-efficient homes can be detrimental to indoor air quality, and operation cost (NHBC Foundation, 2009; LBNL, 1998).

Australian climate zones in humid tropical regions experience high outdoor dew-point temperature up to 28°C. This is above expected indoor thermal comfort-zone temperatures in air conditioned space. This poses a risk of condensation near leaks in the building envelope, unless the interior of houses are pressurised.

Obtaining vapour-resistance properties of materials used in Australian house construction can be problematic. Much of the existing vapour-resistance data are from Europe, measured at temperatures well below most Australian in-service conditions. Reliable water-vapour resistance data at in-service conditions are needed from Australian building material manufacturers.

Australia needs a standard on moisture control in buildings that reflects the huge span of latitude of the country. ASHRAE Standard 160 (ASHRAE, 2009) offers some useful indications on how to deal with condensation risk in cold, temperate and tropical climate regions.

Without an Australian standard for assessing condensation risk, there is no consensus on what are appropriate input data, hygrothermal analysis methods, or evaluation of results. Without such a standard, assessment of condensation risk is a matter of opinion.

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