CONDENSATION IN RESIDENTIAL BUILDINGS Part 2: Hygrothermal analysis

By Richard Aynsley, F.AIRAH

Building Energetics Pty Ltd

ABSTRACT

Condensation in buildings becomes more of a concern as thermal insulation is increased to improve energy efficiency. Examples of steady-state hygrothermal analysis of Australian brick veneer wall construction in temperate winter conditions are provided, as are reinforced concrete masonry in the tropics. A standard is needed for assessing condensation risk in buildings to establish a consensus on appropriate input data and analysis, and assessment procedures for conducting hygrothermal analysis of Australian construction in all climate zones.

Keywords: houses, condensation, hygrothermal, insulation, ventilation, standards.

INTRODUCTION

Australia, with relatively warm climates compared to Europe, has experienced fewer problems of mould in houses resulting from condensation in winter. Over recent decades a common form of wall construction, brick veneer, has undergone changes in timber sizes and use of insulation for increased energy efficiency. With a history of little risk of condensation and mould in brick veneer walls in the past, builders and designers paid little attention to hygrothermal analysis. In hindsight, the changes in brick veneer wall construction over a few decades certainly influenced the risk of condensation.

HYGROTHERMAL ANALYSIS

The following examples of steady-state hygrothermal analysis follow procedures described in UK Building Research Station Digest 110 (BRS, 1969) for heated and ventilated houses, and are based on the Glaser method (Glaser, 1958).

Melbourne and western Sydney, BCA climate zone 6, was chosen as representing major suburban areas where brick veneer walls were used in the 1970s. The Bureau of Meteorology's Melbourne mean monthly climate data indicates the lowest mean minimum monthly air temperature as 6°C in July. No coincident relative humidity is provided for this temperature in the data set. However, coincident mean monthly air temperature and relative humidity of 8.7°C at 79% RH is provided at 9am in July.

Assuming that there is no sudden change in moisture content of the air, between say 5am and 9am, the water vapour pressure at 9am can be used to calculate the equivalent relative humidity at the mean monthly air temperature of 6°C at 95% RH, with a water vapour pressure calculated as 0.89kPa.

The method used in UK Building Research Station Digest 110 (BRS, 1969) for estimating indoor condition in heated and ventilated houses, at normal ventilation rates, is to take the outdoor condition of air and use a psychrometric chart to determine what the water vapour pressure and mixing ratio of the air is after it has been raised to the indoor air temperature proposed for thermal comfort, say 20°C. To this condition, 0.0034kg/kg is added to the mixing ratio to allow for indoor sources of moisture such as washing, bathing, breathing, and the like, to estimate the indoor mixing ratio and water vapour pressure.

In the example, hygrothermal analyses below-water vapour pressures were calculated using psychrometric equations. The resulting indoor condition for Melbourne in July was 20°C at 62% RH or water vapour pressure of 1.43kPa. The typical ventilation rate at the time the Building Research Station Digest 110 (BRS, 1969) was written was one air change per hour.

WINTER HYGROTHERMAL ANALYSIS OF BRICK VENEER WALLS IN WESTERN SYDNEY AND MELBOURNE

In the 1970s brick veneer walls typically consisted of an external skin of 110mm brickwork (density≈ 1690 kg/m^3), a 50mm cavity, reflective foil sarking with an antiglare surface (≈ 0.3) and reflective surface (ε≈ 0.03), 100mm timber stud frame, and 10mm gypsum plasterboard. At that time additional thermal insulation was rare. No widespread mould problems were experienced with these brick veneer walls over a few decades in Melbourne or western Sydney, BCA Climate Zone 6.

It can be seen, from the graph in Table 1, that indoor vapour pressure is higher than outdoor vapour pressure, so vapour flow is from indoors to outdoors. The temperatures through the 1970s brick veneer wall do not fall to, or below, dew point anywhere through the construction when indoor air is heated to 20°C. This suggests that under these conditions there is only slight risk of condensation from indoor or outdoor mean minimum monthly air temperature or relative humidity conditions in July in the 1970s brick veneer wall.

Table 1: Winter Hygrothermal Analysis of a 1970 Brick Veneer Wall for July in Melbourne.

Material	Thickness m	Thermal resistance m².K/W	Temperature difference K	Weather-side Surface temperature °C	Room-side Surface temperature °C	Vapour resistance MN.s/g	Vapour press Δ kPa	Vapour press kPa	Dew Point Temperature °C
Construction Elements				**6**				**0.89**	
1 External air film	0.01	0.040	0.31	6.00	**6.31**	0.00	0.00	0.89	**5.30**
2 Brickwork 110 mm	0.110	0.170	1.31	6.31	**7.61**	5.50	0.01	0.90	**5.42**
3 Semi-reflective cavity	0.050	0.720	5.53	7.61	**13.15**	0.00	0.00	0.90	**5.42**
4 Alum. foil sarking	0.001	0.000	0.00	13.15	**13.15**	400.00	0.53	1.43	**12.32**
5 Semi-reflective cavity	0.100	0.712	5.47	13.15	**18.62**	0.00	0.00	1.43	**12.32**
6 Plasterboard 10mm	0.010	0.060	0.46	18.62	**19.08**	0.45	0.00	1.43	**12.33**
7 Internal air film	0.01	0.120	0.92	19.08	**20.00**	0.00	0.00	1.43	**12.33**
Total resistance		**1.822**	**14.0**	**20**		**405.95**	**0.54**	**1.43**	
(Heat flow horizontal in winter)									

Outdoors: 6°C at 95% RH (0.89 kPA) **Indoors:** 20°C at 62% RH (1.43 kPa) Melbourne, July

If condensation did occur intermittently on the interior side of the foil sarking, construction element 4, under extreme conditions, the timber framing had sufficient moisture storage that it could store intermittent condensate and release it during warmer, drier periods. This is reflected by the absence of mould problems observed in this type of wall construction over many years.

Melbourne 1970 Style Brick Veneer Wall, Winter Heated & Ventilated Space with Reflective Sarking

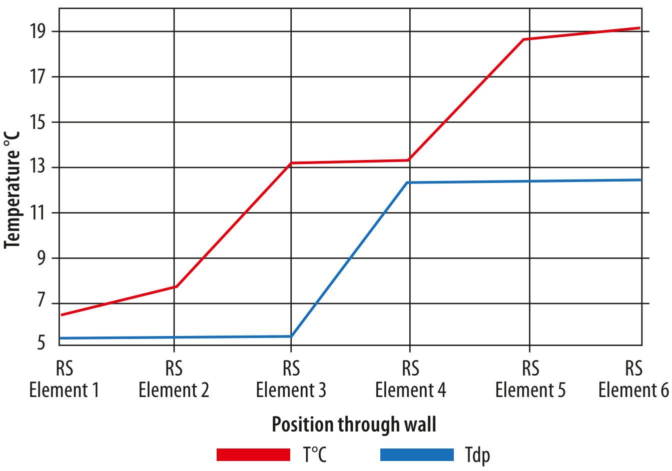

Figure 1

Energy-efficiency requirements in the Building Code of Australia were introduced in the 1990s. A number of changes occurred in brick veneer walls in Melbourne and western Sydney between 1970 and 2011. A typical 2011 brick veneer wall had 90mm stud framing, housewrap over the studs and a 90mm R2.5 fibreglass batt insulation. But few builders or designers bothered to analyse the implications of these changes on the risk of condensation.

In hindsight, a hygrothermal analysis in Table 2 suggests condensation will occur behind the sarking within the fibreglass batt insulation where air temperature in the graph has fallen below dew-point. This is a serious condition because damp fibreglass loses much of its insulation values and compounds the condensation problem.

By carefully choosing a low-vapour resistance house wrap and adding a higher vapour resistance vapour retarder behind the plasterboard, the condensation on the warm side of the sarking can be controlled. It can be seen, from the graph in Table 3 that with these modifications, the dew-point has been lowered by increasing resistance to vapour flow with the vapour retarder behind the plasterboard and decreasing the dew-point within the fibreglass insulation.

SUMMER HYGROTHERMAL ANALYSIS OF A CONCRETE MASONRY VENEER WALL IN DARWIN'S HUMID TROPICS

The hygrothermal analysis of an insulated concrete masonry wall of an air conditioned house in Darwin in summer was conducted using the Glaser method set out in the BRS Digest 110 (BRS, 1969) Table 4. The outdoor conditions were taken as 30°C at 72% RH, vapour pressure 3.03kPa being mean monthly conditions in Darwin during the most humid month of February. Indoor conditions were taken as 22°C at 50% RH, vapour pressure 1.31kPa provided by the air conditioning system.

The construction consisted of 20mm of cement render over 190mm concrete masonry cored limestone aggregate blocks (density ≈ 2200 kg/m³ and vapour resistance of 3.64MN.s/g). Thermal insulation and vapour resistance data for these blocks was found in the ASHRAE Handbook of Fundamentals (ASHRAE, 2009).

Table 2: Winter Hygrothermal Analysis of a 2011 Brick Veneer Wall for July in Melbourne.

Material	Thickness m	Thermal resistance m²K/W	Temperature difference K	Weather-side Surface temperature °C	Room-side Surface temperature °C	Vapour resistance MN.s/g	Vapour press Δ kPa	Vapour press kPa	Dew Point Temperature °C
Construction Elements				**6**	**6**			**0.89**	
1 External air film	0.01	0.040	0.17	6.00	**6.17**	0.00	0.00	0.89	**5.30**
2 Brickwork 110 mm	0.110	0.170	0.74	6.17	**6.91**	5.50	0.46	1.35	**11.40**
3 Non-reflective cavity	0.030	0.170	0.74	6.91	**7.65**	0.00	0.00	1.35	**11.40**
4 Building wrap	0.001	0.000	0.00	7.65	**7.65**	0.12	0.01	1.36	**11.52**
5 Fibreglass R2.5 batt	0.090	2.655	11.56	7.65	**19.22**	0.45	0.04	1.39	**11.93**
6 Plasterboard 10mm	0.010	0.060	0.26	19.22	**19.48**	0.45	0.04	1.43	**12.33**
7 Internal air film	0.01	0.120	0.52	19.48	**20.00**	0.00	0.00	1.43	**12.33**
Total resistance		**3.215**	**14.0**	**14**	**20**	**6.52**	**0.54**	**1.43**	
(Heat flow horizontal in winter)									

Outdoors: 6°C at 95% RH (0.89 kPA) **Indoors:** 20°C at 62% RH (1.43 kPa) Melbourne, July

On the interior side a 90.5mm light-gauge cold-formed steel stud wall is bolted to the concrete floor slab and is set 20mm away from the interior face of the block wall. This 20mm space creates a drainage cavity between the concrete block wall and a waterproof but highly permeable building wrap is screwed to the steel studs before the block wall is laid. Fibreglass batts R2.7 90mm thick, between the 90.5mm steel studs, provide further thermal insulation. Material properties for the plasterboard, wall wrap, and fibreglass were obtained from manufacturers' data sheets and the ABCB Condensation Handbook (ABCB, 2011). Thermal insulation building materials used in Australia must comply with AS/NZS 4859.1 (Standards Australia, 2002).

It can be seen, from the graph in Table 4, that indoor vapour pressure is lower than outdoor vapour pressure so vapour flow is from outdoors to indoors. There is a separation of at least 5.44°C between the temperature profile and the dew-point profile throughout the wall, so there is little risk of condensation.

Melbourne 2011 Style Brick Veneer Wall, Winter Heated and Ventilated Space with Wall Wrap and FG Insulation

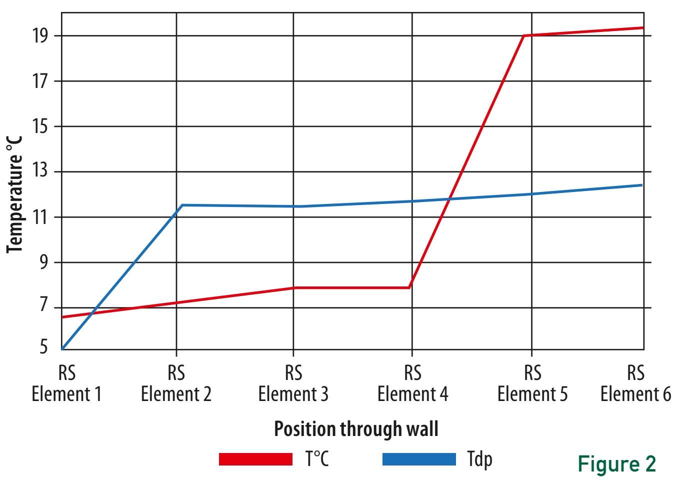

Figure 2

However, the dew-point of outdoor air, 24.3°C, is above indoor air temperature 22°C. In total the dewpoint of outdoor air in Darwin is above 24°C for approximately 1,613 hours per year based on Wooldridge data (Wooldridge, 1979). Given recent global warming it is probably time to update the Wooldridge data.

It should be noted that these temperatures are not contemplated in the BRS Digest 110 because the psychrometric chart provided has a maximum air temperature of 20°C. A detailed discussion of the problem of air conditioning in humid tropical regions is provided in AIRAH's DA20 publication (AIRAH, 2002).

The insulated concrete masonry wall, in Table 4, may appear to be satisfactory in terms of condensation risk, as temperatures through the wall are well above dew-point; however, further analysis may be necessary. 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.

CONCLUSION

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.

Table 3: Hygrothermal Analysis of a Brick Veneer Wall with Moisture Control for July in Melbourne.

Material	Thickness m	Thermal resistance m².K/W	Temperature difference K	Weather-side Surface temperature °C	Room-side Surface temperature °C	Vapour resistance MN.s/g	Vapour press Δ kPa	Vapour press kPa	Dew Point Temperature °C
Construction Elements				**6**				**0.89**	
1 External air film	0.01	0.040	0.17	6.0	**6.2**	0.00	0.00	0.89	**5.30**
2 Brickwork 110 mm	0.110	0.170	0.74	6.2	**6.9**	5.50	0.03	0.92	**5.84**
3 Non-reflective cavity	0.050	0.170	0.74	6.9	**7.7**	0.00	0.00	0.92	**5.84**
4 Building wrap	0.001	0.000	0.00	7.7	**7.7**	2.00	0.01	0.94	**6.03**
5 Fibreglass R2.5 batt	0.090	2.655	11.56	7.7	**19.2**	0.50	0.00	0.94	**6.07**
6 Vapour Retarder	0.001	0.000	0.00	19.2	**19.2**	80.00	0.49	1.43	**12.30**
7 Plasterboard 10mm	0.010	0.060	0.26	19.2	**19.5**	0.45	0.00	1.43	**12.33**
8 Internal air film	0.01	0.120	0.52	19.5	**20.0**	0.00	0.00	1.43	**12.33**
Total resistance		**3.215**	**14.0**	**20**		**88.45**	**0.54**	**1.43**	
(Heat flow horizontal in winter)									

Outdoors: 6°C at 95% RH (0.89 kPA) **Indoors:** 20°C at 62% RH (1.43 kPa) Melbourne, July

Table 4: Insulated and Vapour Controlled Concrete Masonry Veneer Wall in Darwin in February.

				Weather-side	Room-side				
Material	Thickness m	Thermal resistance m².K/W	Temperature difference K	Surface temperature °C	Surface temperature °C	Vapour resistance MN.s/g	Vapour press Δ kPa	Vapour press kPa	Dew Point Temperature °C
Construction Elements				**33**				**3.64**	
1 External air film	0.01	0.040	0.14	33.00	32.86	0.00	0.00	3.64	27.43
2 Cement render	0.020	0.040	0.14	32.86	32.73	2.00	0.45	3.19	25.17
3 Conc. Masonry 190 mm	0.190	0.200	0.68	32.73	32.05	5.48	1.24	1.95	17.13
4 Non-reflective cavity	0.020	0.170	0.58	32.05	31.48	0.00	0.00	1.95	17.13
5 Building Wrap	0.001	0.000	0.00	31.48	31.48	1.92	0.43	1.51	13.20
6 Fibreglass Batts R2.7	0.050	2.622	8.87	31.48	22.61	0.45	0.10	1.41	12.13
7 Plasterboard 10mm	0.010	0.060	0.20	22.61	22.41	0.45	0.10	1.31	11.00
8 Internal air film	0.01	0.120	0.41	22.41	22.00	0.00	0.00	1.31	11.00
Total resistance		3.252	11.0	22		10.3	2.33	1.31	
(Heat flow horizontal in winter)									

Outdoors: 33°C at 73% RH (3.64 kPA) **Indoors:** 22°C at 50% RH (1.31 kPa) Darwin, February

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. ∎

Melbourne 2011 Style Brick Veneer Wall, Winter Heated and Ventilated Space with Wall Wrap and FG Insulation

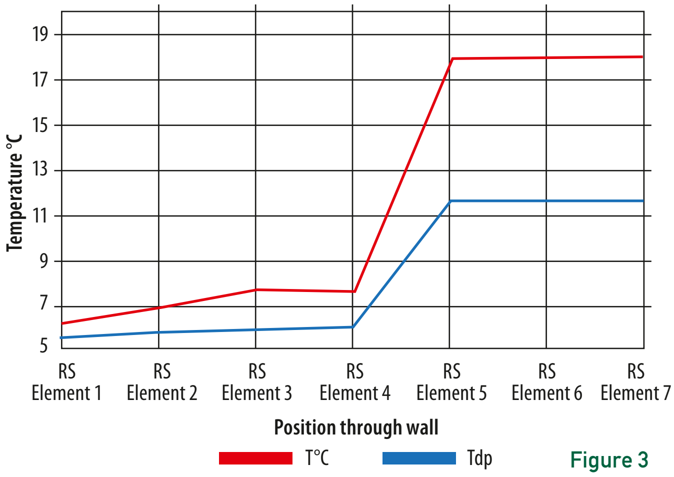

Figure 3

Darwin Concrete Masonry Veneer Wall, Summer Conditioned Space with Wall Wrap and FG Insulation

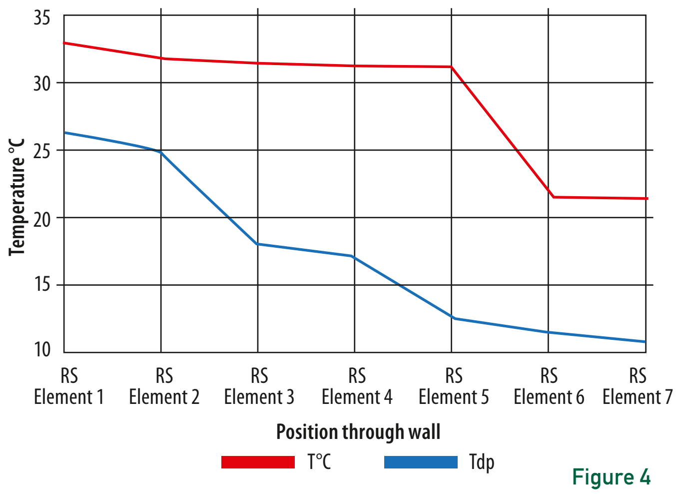

Figure 4

REFERENCES

ABCB (2011) Condensation in Buildings Information Handbook. Australian Building Codes Board, Canberra, ACT, 91 pages.

AIRAH (2000) Tropical Air Conditioning, Design Application Manual DA 20. Australian Institute of Refrigeration, Air-Conditioning & Heating Incorporated, Melbourne.

ASHRAE (2009) ASHRAE Handbook Fundamentals, SI edition, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA. Chapter 26.

ASHRAE (2009) ASHRAE Standard 160, Criteria for Moisture-Control Design Analysis in Buildings. ASHRAE, Atlanta, 16 pages.

BRS (1969) Condensation. Building Research Station Digest 110, Oct., 8 pages.

Glaser, H. (1958) Vereinfachte Berechnung der Dampfdiffusion durch geschichtete Wände bei Ausscheidung von Wasser und Eis (Simplified calculation of vapour diffusion through layered walls involving the formation of water and ice). Kälttetechnik 10, H 11, S. 358-364 und H 12, S. 386-390.

Standards Australia (2002) AS/NZS 4859.1/Amendment 1:2006, Materials for the thermal insulation of buildings – General criteria and technical provisions. Standards Australia, Sydney, NSW.