

OPORTUNITIES & CONSEQUENCES OF CONDENSATION

Dr. Richard Aynsley, F.AIRAH, F.AIA
Director, Big Ass Fans Aust. Pty Ltd
dick@bigassfans.com

INTRODUCTION

This paper provides a brief introduction to the opportunities and consequences of condensation in buildings. Condensation is looming as the greatest single cause of damage and failure of buildings. It occurs in all types of buildings due to poor design or inappropriate use of materials (Standards Australia, 1992). Once condensation problems such as mould, wood rot, electrical safety issues, and corrosion are established it is very difficult and expensive to rectify. In some cases demolition is the only option. In other cases condensation has caused structural collapse. It should be noted that recent tighter sealing of buildings and increases in thermal insulation in pursuit of energy efficiency have contributed to incidents of condensation problems.

Psychrometrics

Psychrometrics, dealing with the properties and processes of moist air, is a developing science. The tools initially used by HVAC engineers in the USA were developed by Goff and Gratch in 1945. These were upgraded by Hyland and Wexler in 1983 and more recently by Nelson and Sauer in 2001 (Gatley, 2005).

Water Vapour Sources

It is important to remember that there are two sources of water vapour that need to be considered. They are the general atmospheric water vapour associated with the movement of high and low pressure systems across the surface of the earth, and additional water vapour generated by human activity in buildings such as clothes drying, showers and cooking in houses (CSIRO, 1995) and industrial processes in the case of industrial buildings.

Condensation in Buildings

Condensation occurs when the temperature of water vapour in the air falls to dew point temperature. This can occur within the air as fog, on cold surfaces, and within porous vapour permeable materials. Dew point temperature of water vapour in air can be measured directly by detecting the occurrence of dew on the surface of a temperature controlled polished metal mirror. Psychrometrics can be used to estimate dew point temperature from dry bulb temperature coincident relative humidity. Relative humidity without a coincident dry bulb air temperature is not a good indicator of potential for condensation. Temperature and vapour pressure gradients through construction can suggest where condensation may occur.

Influence of Air movement

Air is viscous, that is it tends to stick to surfaces. By comparison the viscosity of air is around 280 times greater than that of water. The viscosity of the air results in a thin air

film attached to surfaces. The average temperature is equal to the average temperature of the surface and the temperature of the main body of surrounding air. This air film offers significant thermal resistance to heat flow when there is no air movement, as indicated by typical values in the table below.

Thermal Resistance of Air Films [no air movement]

Surface Position	Heat Flow Direction	Resistance High Emittance Surface $m^2 \cdot K/W$	Resistance Low Emittance Surface $m^2 \cdot K/W$
Horizontal	Upward	0.11	0.23
Horizontal	Downward	0.16	0.80
45° Slope	Upward	0.11	0.24
45° Slope	Downward	0.13	0.39
22.5° Slope	Upward	0.11	0.24
22.5° Slope	Downward	0.15	0.60
Vertical	Horizontal	0.12	0.30

The thermal resistance of air films can be significantly reduced by air movement across a surface. This is indicated in the table below.

Thermal Resistance of Air Films [with air movement]

Air Movement	Position of Surface	Heat Flow Direction	Resistance $m^2 \cdot K/W$
6.00 m/s	Any Position	Any Direction	0.03
3.00 m/s	Any Position	Any Direction	0.04
0.50 m/s	Any Position	Any Direction	0.08

This reduction in the thermal resistance of air films due to air movement can be used to reduce the occurrence of condensation on indoor surfaces. In many cases the minimum temperature of the air film, at the solid surface, is only a fraction of a degree below dew point temperature. This means that if the stagnant air film is disturbed by air movement the temperature of the air adjacent to the cold surface can be raised above dew point temperature. Building envelopes typically require drainage planes and airways and vapour barriers and permeable membranes to control moisture penetration and condensation in vulnerable locations.

HVAC OPPORTUNITIES

Night Sky Temperatures

The most useful parameter for characterizing the radiative heat transfer between horizontal non-spectral emitting surfaces and the sky is sky temperature, T_{sky} (ASHRAE, 2007). If S denotes the total downward radiant heat flux emitted by the atmosphere, then T_{sky} is defined as:

$$T_{sky}^4 = S / \sigma$$

where $\sigma = 5.67 \times 10^{-8}$ W/(m²·K⁴)

The sky temperature is a function of atmospheric water vapour, the amount and type of cloud cover, and air temperature. The lowest sky temperatures occur under an arid, cloudless sky. The monthly average sky temperature depression below ambient air temperature typically lies between 5K and 24K throughout the continental USA. Australian data are provided in the JCU field study section below. Sky temperatures below 16°C are needed for effective nocturnal radiant cooling systems for buildings.

The net radiative cooling rate, R_{net} , of a horizontal surface with absolute temperature, T_{rad} , and a non-spectral emittance, ϵ , is then:

$$R_{net} = \epsilon \sigma (T_{rad}^4 - T_{sky}^4) \quad \text{kJ}/(\text{m}^2 \cdot \text{day})$$

Most non-metallic building materials have an emittance of around 0.9. Polished aluminium foil for comparison has an emittance around 0.03 to 0.05.

Field Studies at James Cook University

During the summers of 1999 through 2001 a PhD research student at James Cook University's Australian Institute of Tropical Architecture, Phuong Dan, conducted field studies of the potential of passive cooling techniques for buildings in Townsville (Dan, 2002). These studies included nocturnal radiant cooling using exposed and wind-shielded collectors with air and condensate as heat transfer media. Prior to this study nocturnal radiant cooling in humid tropical regions was generally considered improbable. This study showed that there is potential for cooling radiators in some warm humid regions.

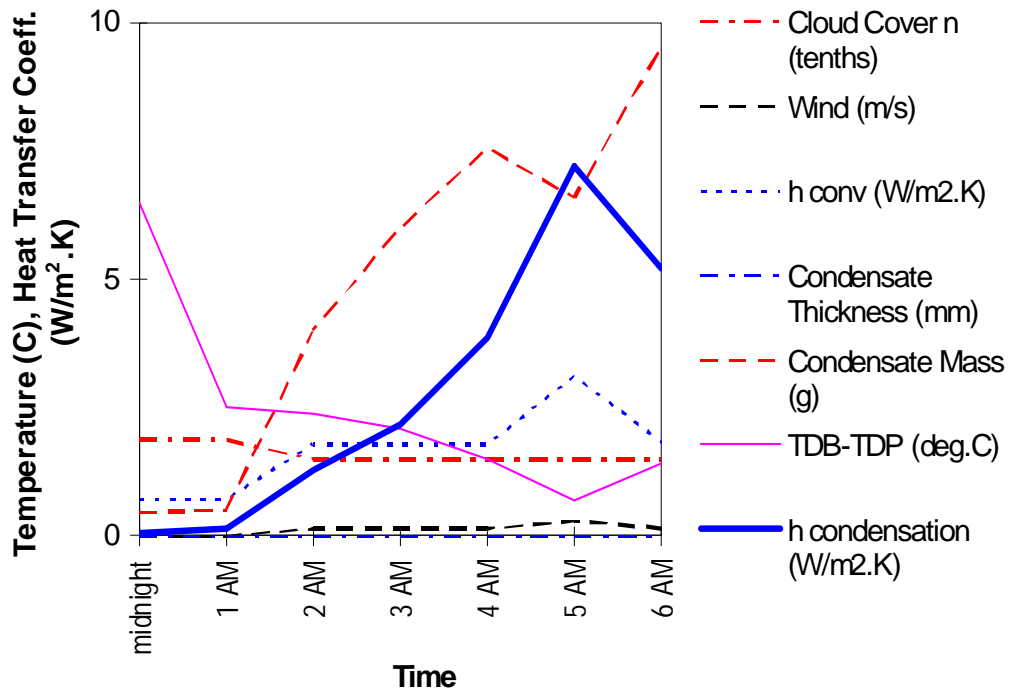


Figure 1. Condensation and Heat Transfer Coefficients

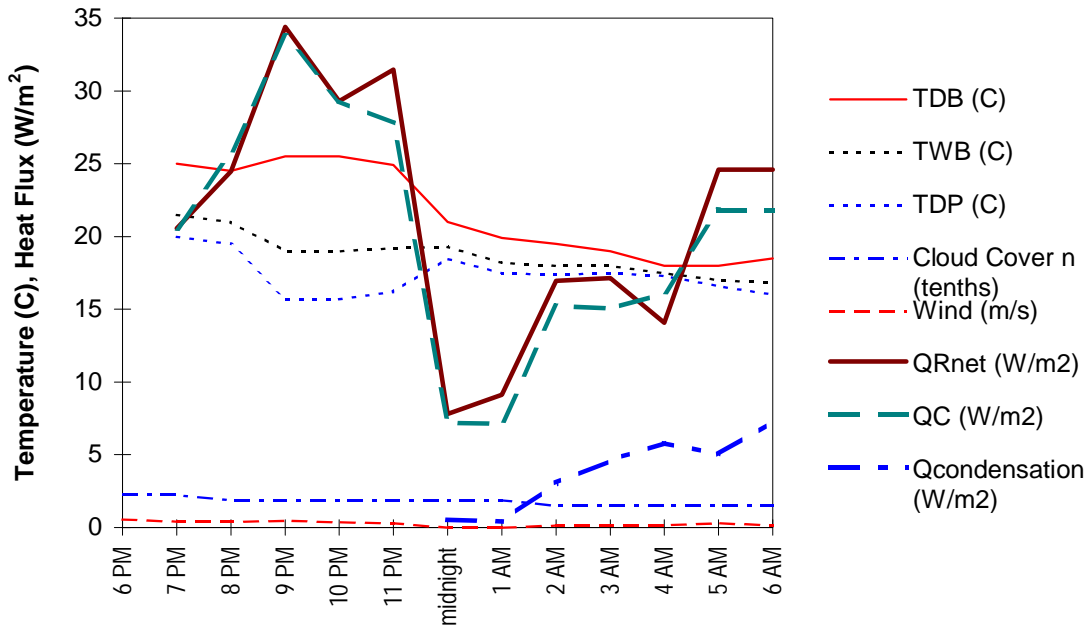


Figure 2. Heat Fluxes

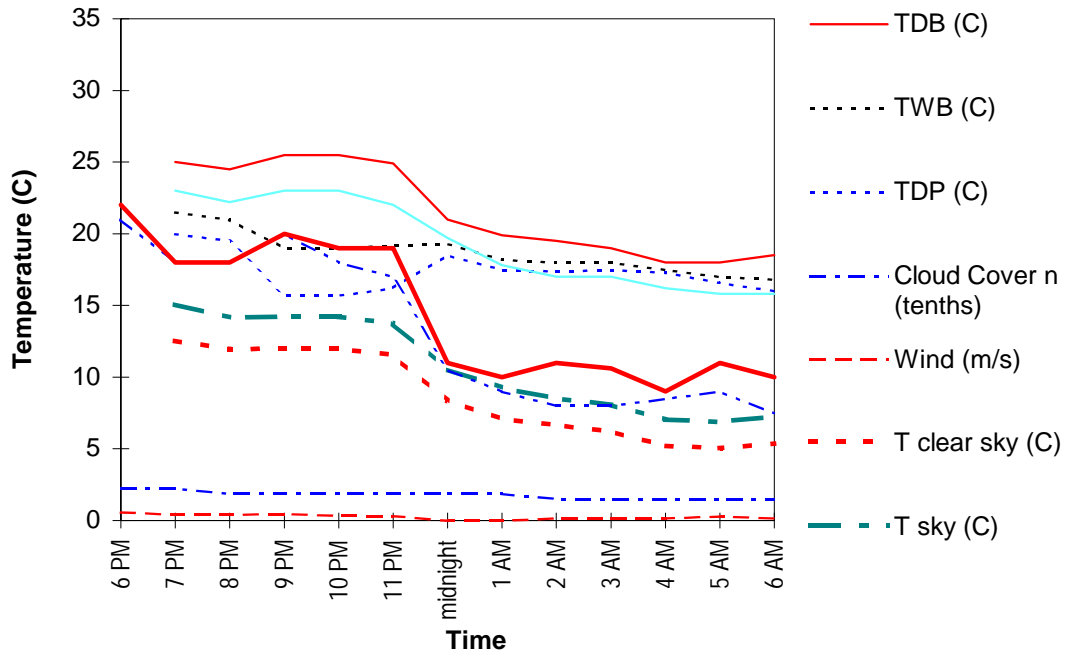


Figure 3. Sky and Radiator Temperatures



Figure 4. Non-wind-shielded Radiator under test



Figure 5. Wind-shielded and non-wind-shielded radiators

CONSEQUENCES OF CONDENSATION

Condensation on metal roofs

In buildings with thin un-insulated sheet metal roofs above ventilated air spaces, particularly in warm-humid coastal regions, heat loss to the night sky can cool the roofing to below dew point temperature. This results in condensation on both upper and lower surfaces of the metal roofing. Condensation on the upper surface can drain into the roof drainage system, but condensation on the lower surface runs down the underside of corrugations until it encounters a batten or purlin. At that point the condensation accumulates until it drips off into the space below. If bulk insulation is below the batten or purlin the water will reduce its R-value and often result in permanent dampness in the lower levels of the insulation where it encourages mould growth and wood rot and moisture stains on the ceiling below.



Figure 6. Mould on a ceiling due to moisture above

In one large un-insulated metal roofed building in the tropical city of Townsville, in Queensland, the large roof space was fitted with ceiling fans blowing upwards. These ceiling fans disturbed the air film on the underside of the metal roofing and continuously circulated air in the roof space effectively raising the temperature of air moving adjacent to the underside of the roof above its dew point temperature.

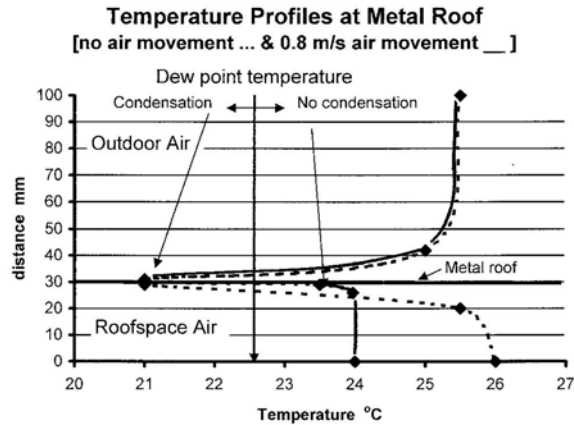


Figure 7. Increased temperature of water vapour near cold surfaces due to mixing and circulation of air to disturb the air film at the surface



Figure 8. Condensation on underside of metal roofing

Condensation and insulation

Condensation and insulation can be a problematic combination. Unless sarking and vapour barriers are appropriately selected and located within building construction dampness can not only significantly degrade the thermal resistance of bulk insulation, but also establish an environment that allows mould to flourish and, once damp bulk insulation rarely dries out. Some expanded plastic foam insulations such as polystyrene also absorb water vapour, however extruded polystyrene does not. Mould not only causes disfiguration of surfaces but also can create a serious health risk to building occupants.

Vapour barriers must be fitted during construction as it is generally not possible to retrofit vapour barriers without reconstructing the entire building. Sophisticated software is becoming available that dynamically models water vapour movement in buildings and indicates appropriate cavity ventilation and location for and type of vapour barriers. The good old days of simply locating vapour barriers on the warm side of the dew point temperature on the temperature profile through construction are over. When informed of the location of the dew point temperature in a building envelope one should ask *how often, at what time and in which month ?*

Condensation on floor slabs

In industrial buildings, such as warehouses with floor slabs on-grade, a large air circulating fan can mix indoor air so that all the air in the space is equal to the average indoor air temperature before mixing. In a typical warehouse there can be a significant difference between air temperature at floor level and air temperature near the roof. After the indoor air is mixed this usually provides a few degrees increase in the air film on the floor which is sufficient to avoid surface condensation in most cases. Large spaces with high ceilings require large air circulating fans to provide sufficient airflow to be effective over a large floor area.



Figure 9. A large high-volume low-speed air circulating fan in a warehouse

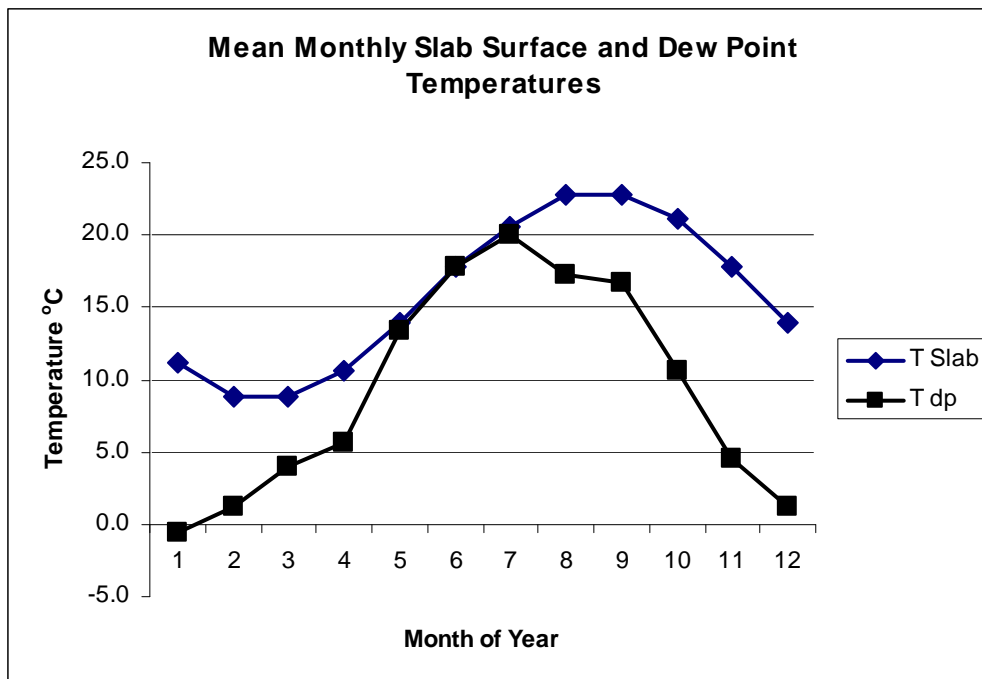


Figure 10. Condition indicating risk of condensation in months 5, 6 & 7

References for Condensation

ASHRAE (2007) ASHRAE Handbook: HVAC Applications, Chapter 33, Solar Energy Use, ASHRAE, Atlanta, GA., pages 33.1-33.29

Gatley, Donald P., (2005) *Understanding Psychrometrics*, 2nd Edition, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA. 382 pages.

CSIRO (1995) Condensation, *Building Technology File*, Number 5, August, CISRO Division of Building, Construction and Engineering, Highett, VIC., 4 pages.

Dan, Phuong (2002) Passive cooling in a warm and humid climate, Ph.D. dissertation in the Australian Institute of Tropical Architecture, James Cook University, Townsville, 300 +pages.

British Standard (2002) BS 5250:2002 Code of practice for control of condensation in buildings, BSI, London.

Standards Australia (1992) AS 1562.1-1992 Design and installation of sheet roof and wall cladding, Standards Australia, Sydney, Page 13.

Further Reading

Armstrong, S and Liaw, J. (2002) The fundamentals of fungi, *ASHRAE Journal*, November, pp. 18-24.

Brennan, T. and Burge, H. (2005) Assessing mold in buildings, *ASHRAE Journal*, Jan., pp.158-164.

Brennan, T., Cummings, J. and Lstiburek, J. (2002) Unplanned airflows & moisture problems, *ASHRAE Journal*, November, pp. 44 -52.

Lstiburek, J. (2002) Investigating & diagnosing moisture problems, , *ASHRAE Journal*, December, pp. 36-41.

Lstiburek, J. (2005) Understanding air barriers, *ASHRAE Journal*, July, pp. 24-30.

Lstiburek, J. (2006) Understanding drainage planes, *ASHRAE Journal*, February, pp. 30-35.

Lstiburek, J. (2007) The hollow building, *ASHRAE Journal*, June, pp. 56-58.

Lstiburek, Joseph (2002) Moisture in Buildings, *ASHRAE Journal*, February, p. 36-41.

Lstiburek, Joseph, and Carmody, John (1994) *Moisture control handbook: Principles & practices for residential and small commercial buildings*, John Wiley & Sons, NY, pp.210.

Straube, John (2002) Moisture in Buildings, *ASHRAE Journal*, January, p. 15-19.

Su, B. (2002) A Field study of mould growth and indoor health conditions in Auckland dwellings, *Architectural Science Review*, Vol. 45, Number 4, Dec., pp. 275-284.

Szokolay, S.V. (1988) Interstitial condensation – a design tool, *Architectural Science Review*, Vol. 31, pp. 29-34.

Szokolay, Steven V. (2004) *Introduction to Architectural Science: The basis of Sustainable Design*, Elsevier, Architectural Press, Oxford, UK, 327 pages.