Potential Impact of Evaporative Cooling Technologies on Australian Office Buildings

Dr Paul Bannister FAIRAH FIE Aust1, Hongsen Zhang2, Dr Stephen White3
1Director of Innovation, DeltaQ Consulting Services Pty Ltd, Paul.Bannister@dqcs.com.au
2Director, Enerefficiency Pty Ltd, Hongsen.Zhang@enerefficiency.com
3Energy Efficiency Domain Leader, CSIRO, Stephen.D.White@csiro.au

Abstract
This paper presents the results of a preliminary simulation-based study of the potential energy efficiency benefits of a range of evaporative cooling technologies for Australian office buildings across the full range of Australian climates. It is found that dewpoint coolers offer the most promising savings potential (13-55%) across climate zones 2-7 (i.e. all climate zones other than Darwin and Thredbo). In climate zone 8 (Thredbo) it is shown that a direct/indirect evaporative cooling arrangement can wholly supplant the need for a chiller. Overall, the results indicate that there is significant potential for the application of evaporative cooling technologies in Australian office buildings outside the tropics.

Introduction
Evaporative cooling technologies do not currently play a significant role in commercial office building air-conditioning in Australia, other than in cooling towers. In the context that Australian office portfolios have made substantial improvements in energy efficiency1 (NABERS, 2020) and are committing to net-zero targets (Climateworks, 2019), this study was undertaken to determine whether evaporative cooling can contribute to the achievement of net-zero energy office buildings in Australia.

The application of various forms of evaporative cooling has been extensively researched (e.g. Chaudhari et al 2015 for a review of publications). In addition to conventional direct and indirect evaporative cooling, dew-point cooling has become commercially available (Glanville et al 2011). In terms of application in Australia, Guan et al (2015) tested the use of a novel hybrid direct/indirect evaporative cooler across Australian capital cities and identified significant potential for energy savings in all capitals other than Darwin, which is in a tropical climate zone.

However, the context of the present study was to evaluate the application of evaporative cooling technologies in integration with a conventional variable air volume (VAV) air-conditioning system, which is the dominant air-conditioning system type in larger Australian office buildings, operating to “normal” commercial air-conditioning parameters. This creates a more constrained – and more industry-acceptable - framework for assessment than the novel system used by Guan et al (2015), where the technology used was unconventional, variable airflow was not employed and the comfort conditions controlled based on operative temperature.

To this end, simulation modelling is used to test a range of direct and indirect evaporative cooling technologies applied to the airside of a conventional VAV system serving a medium-sized commercial office building. Work reported in this paper was undertaken for the PRIME Net Zero Energy HVAC Technology Road Map project.

Methodology
The office building was modelled in the thermal simulation package IES<VE>, an industry-standard simulation package accredited under ASHRAE 140 (2014). The use of IES <VE> as an industry-accepted package has benefits in terms of the credibility of results to the industry, in spite of the need to create a custom model for the dewpoint cooler; as discussed below, the fit of the custom model is sufficient for results to be credible. It is also noted that IES has superior interface-level capabilities for the representation of realistic HVAC control which to some extent compensates for its lack of a native dewpoint cooler model.

The simulated building has the following characteristics:
- 8 storey building with underground car-park.
- 50% window-wall-ratio (WWR). This is a typical WWR for the office building in Australia.
- 25m by 25m floorplate, 4 perimeter and 1 centre zone per floor, the total area is 5,000m². The square floor plate was used to ensure the building orientation has no impact on the simulation result.
- Floor to ceiling height is 2.7m. This is the typical floor to ceiling height for offices.
- Plenum height is 0.9m. This is the typical plenum height for office buildings in Australia.
- Building façade and HVAC systems were modelled as compliant with NCC 2019 Section J provisions (ABCB, 2019).
- Chiller was modelled as a water-cooled chiller of IPLV 8.7, COP 6, using IES default chiller part load buildings that started rating in 2010 as a result of the mandatory Commercial Building Disclosure Scheme (www.cbd.gov.au).

1 NABERS 2020 records that the average energy intensity of buildings rated under NABERS has dropped by 25% from 2010-2020 for buildings that were voluntarily rating prior to 2010 and by 45% across the same period for
characteristics, with a chilled water temperature rest based on outside air temperature.

- Boiler was modelled as a condensing boiler of nominal 90% efficiency using detailed part load curves and a hot water temperature reset based on outside air temperature.

Full details of the model are available in Zhang et al (2018). The building form is shown in Figure 1.

The building simulation was run in each NCC Volume 1 (ABCB, 2019) climate zone using IWEC weather data from ASHRAE for the following locations: CZ1 Darwin; CZ2 Brisbane; CZ3 Alice Springs; CZ4 Wagga Wagga; CZ5 Sydney; CZ 6 Melbourne; CZ 7 Canberra; and CZ8 Thredbo. A summary of key climate statistics for these locations is provided in the Appendix at the end of this paper.

**HVAC Configurations**

The HVAC configurations modelled are as follows:

- **SC 1**: A conventional VAV system as shown in Figure 2. This is the baseline against which the evaporative cooling scenarios are tested. Note that by default, the design parameters of the evaporative cooling scenarios are the same as this scenario unless required to change to match the revised configuration.

- **SC 2a**: A VAV system with direct and indirect evaporative cooling as shown in Figure 3. In this system, the indirect evaporative cooling works by saturating the exhaust air using water sprays or similar and then operating a heat exchanger between this evaporatively cooled airflow and the outside air intake. Direct evaporative cooling is also available to the supply air. The design pressure drop across the heat exchanger was modelled as 100Pa, based on supplier data.

- **SC 2b**: This is a VAV system with a dewpoint cooler (Glanville et al, 2011) added to the outside air intake, plus direct evaporative cooling to the supply air as shown in Figure 4. In a dewpoint cooler, notionally two volumes of air are drawn through the cooler’s heat exchanger, with one volume being passed into the building and the other volume circulated through the other side of the cooler’s heat exchanger while being saturated with water, and then rejected to atmosphere. At the theoretical limit, a device of this nature could generate a supply air stream that has a dry bulb temperature equal to the dewpoint of the outside air, hence the device’s name. The pressure drop through the dewpoint cooler was modelled as 150Pa, based on supplier data.

- **SC 2c**: This the same system as SC 2b except with no direct evaporative cooling. All systems have the ability to use 100% OA in economy cycle operation, with full modulation available.

![Figure 1. Building form as modelled](image)

![Figure 2. HVAC Configuration SC 1: a conventional VAV system, used as the baseline scenario.](image)

![Figure 3. HVAC Configuration SC 2a: VAV system with direct and indirect evaporative cooling (the latter being the combination of the exhaust airstream direct evaporative cooler and the heat exchanger).](image)

![Figure 4. HVAC Configuration SC 2b: VAV system with dewpoint cooler and direct evaporative cooling.](image)
were subject to a degree of basic optimisation before being adopted.

**SC 1 Standard VAV**

The following control was used\(^2\):

- The zone setpoint was set to be 22.5°C with 2°C deadband and 0.5°C proportional band either side. The minimum VAV turndown was set as 50% for centre zones and 30% for perimeter zones.
- The supply air temperature of the AHUs was modelled as follows. The heating supply air temperature was reset from 30°C to 22.5°C for the average zone temperature from 21°C to 21.5°C. The cooling supply air temperature was reset from 22.5°C to 12°C for the average zone temperature from 23°C to 23.5°C. No heating or cooling is provided when the average temperature of the zones is between 21.5°C to 23.5°C.
- The economy cycle was modelled to achieve the target outlet temperature reset from 22.5°C to 12°C for the average zone temperature from 21.5°C to 22°C. The economy cycle is available when the outside air dewpoint is below 15°C, the outside air dry bulb temperature is below 24°C and the outside air dry bulb temperature is less than the return air dry bulb temperature. This control strategy is to ensure the economy cycle is operating before the chilled water comes into play when the conditions are appropriate.
- An efficient fan curve was used with an \(x^{\frac{3}{2}}\) turndown to 30% flow when no further decrease was assumed. This represents a variable pressure and variable volume fan control. The overall fan efficiency was modelled as 60%.
- The minimum outside air was modelled to be modulated between 30% and 100% when the high select zone CO\(_2\) concentration changes from 800 ppm to 1,000 ppm. The 100% minimum OA flow was 11.25 l/s per person.

**SC 2a Direct and Indirect Evaporative Cooling**

The control for this configuration is as follows:

- The direct evaporative cooling is available when the average zone relative humidity (RH) is less than 60% and the post economy cycle wet bulb temperature is less than 14°C. The direct evaporative cooler is controlled proportionally to achieve an outlet RH ranging from 0% to 95% as the zone temperature ranges from 22.5°C to 23°C.
- The indirect evaporative cooling was modelled to be operating when the average zone temperature is greater than 22°C. The outside air goes through the dedicated fan and heat exchanger when the outside air temperature is 4°C less than the post indirect cooler air temperature and average zone temperature is greater than 22°C, or when the outside air temperature is 4°C greater than the return air temperature and the average zone temperature is less than 21.5°C. Otherwise the

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\(^2\) All temperatures listed are dry bulb unless otherwise noted.
outside air is bypassed and the dedicated fan does not run. The sensible heat effectiveness of the heat exchanger was set to be 70%. The outlet drybulb temperature of the heat exchanger was controlled to be as close to the AHU supply air temperature setpoint as possible.

- The economy cycle control is based on the post heat exchanger condition when the heat exchanger is in operation or otherwise based on the outside air temperature. Other than this, the economy control for SC 2a is the same as that for SC-1.
- The above control strategy gives the sequence of the HVAC component in cooling mode as follows: Outside Air Economy Cycle → Indirect Evaporative Cooling → Direct Evaporative Cooling → Chilled Water Cooling
- Other controls for SC 2a are the same as those for SC 1.

SC 2b Dewpoint Cooler plus Direct Evaporative Cooling

The controls for this configuration are as follows:

- The direct evaporative cooling is available when the average zone RH is less than 60% and the post dewpoint cooler wet bulb temperature is less than 14°C. The direct evaporative cooler is controlled proportionally to achieve an outlet RH ranging from 0% to 95% as the zone temperature ranges from 22.5°C to 23°C.
- The dewpoint cooler was modelled to be operating when the average zone temperature is greater than 22°C, the outside air dewpoint is less than 21°C and the outside air dry bulb temperature is greater than 12°C. The outside air goes through the dedicated fan and the dewpoint cooler if the above conditions are satisfied. Otherwise the outside air is bypassed, and the dedicated fan and dewpoint cooler do not run.
- The economy cycle control is based on the post dewpoint cooler condition when the dewpoint cooler is in operation or otherwise it is based on the outside air temperature. Other than this, the economy control for SC 2b is the same as that for SC 1.
- The above control strategy gives the sequence of the HVAC component in cooling mode as follows: Outside Air Economy Cycle → Dewpoint cooler → Direct Evaporative Cooling → Chilled Water Cooling

Other controls are the same as those for SC 1.

SC 2c Dewpoint cooler only

Controls for this configuration are identical to SC 2b but without a direct evaporative cooler.

Initial Simulation Results

The basic results of the simulations, showing electricity consumption for all HVAC components (electricity – fans, pumps, chillers; gas – boiler) are presented in Figure 6 to Figure 15. Note that for greenhouse gas emissions calculations, 2020 Australian national average figures of 0.77kg/kWh for electricity and 0.21kg/kWh for gas have been used.

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3 This figure was selected as notionally optimal, within the constraints of the modelling, after some testing of different figures.
Figure 9. Simulated electricity end use breakdown, all scenarios, Climate zones 3 (Alice Springs) and 4 (Wagga Wagga).

Figure 10. Simulated electricity end use breakdown, all scenarios, Climate zones 5 (Sydney) and 6 (Melbourne).

Figure 11. Simulated electricity end use breakdown, all scenarios, Climate zones 7 (Canberra) and 8 (Thredbo).

Figure 12. Simulated greenhouse emissions.

Figure 13: Simulated reduction in greenhouse emissions relative to SC 1.

Figure 14: Simulated reduction in chiller energy relative to SC 1.

Figure 15: Impact on chiller plant size requirements

It can be seen from the figures that:

- None of the technologies is effective in Climate zone 1 (Darwin).
- Configuration SC 2a (direct/indirect evaporative cooling) presents significant benefits in dry climate zones (CZ 3 Alice Springs, CZ4 Wagga Wagga, CZ7 Canberra and CZ8 Thredbo). Total greenhouse savings are in the region of 12-44%, driven by chiller
potential for greater use of the dewpoint cooler, a series of additional scenarios was run as follows:

- **SC 2c-2:** When the dewpoint cooler is operating, the supply air temperature setpoint controlling the chilled water valve drops from 22.2°C to 12°C as the zone temperature rises from 23.5°C to 24°C.
- **SC 2c-3:** When the dewpoint cooler is operating, the supply air temperature setpoint controlling the chilled water valve drops from 22.5°C to 12°C as the zone temperature rises from 23.25°C to 23.75°C.
- **SC 2c-4:** When the dewpoint cooler is operating, the supply air temperature setpoint controlling the chilled water valve drops from 22.5°C to 12°C as the zone temperature rises from 23.75°C to 24.25°C.

In each of the above scenarios, when the dewpoint cooler is not operating, the supply air temperature setpoint controlling the chilled water valve control operates as per SC 2c. The results in terms of greenhouse emissions are shown in Figure 16 for a subset of climate zones.

![Figure 16. Impact of further control optimisation of SC 2c](https://doi.org/10.26868/25222708.2021.30138)

The achieved savings show some sensitivity to the detail of control, dependent on climate, most significantly for the arid climate zone 3 (Alice Springs). In other climate zones, the impacts are somewhat more marginal. In all cases, the different control scenarios cause only minor modulation of the chiller and fan energy and do not fundamentally change the operation of the system.

### Discussion

#### Results Interpretation

The significant potential for energy savings identified for climate zone 3, in particular, has to viewed in the context of water availability: the average annual rainfall in Alice Springs is 282mm, making water a limited resource, although energy supply and capacity are not unlimited either. In practice the energy savings for a realistic building in Alice Springs would be higher than reported as the base-case option would use an air-cooled chiller of potentially less than half the efficiency of the chiller used on SC-1 for this study. Further work would be needed to

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4 Thredbo has an average of 1.1 days per year with a maximum above 30°C and an average summer peak temperature of 21.6°C, and being inland summer humidity is low leading to fairly limited cooling requirements. For more data on Australian climates, see [www.bom.gov.au](http://www.bom.gov.au).

5 The largest dewpoint cooler in the Seeley Climate Wizard range has a supply air volume of 12,800l/s and a plant footprint of approximately 15m² (Seeley International, 2020)
evaluate the relative costs and benefits of the evaporative technologies in these arid environments.

Given that the majority of Australia’s population is in CZ 5 (Sydney, but also Perth and Adelaide) and CZ6 (Melbourne), the ~15% emissions reduction in these climates are probably the most relevant result. These reductions represent an incremental rather than revolutionary improvement in performance. The higher savings in CZ 7 (Canberra, but also Hobart) combined with the potentially significant reduction in chiller size indicates some potential for more significant outcomes in the national capital and similar cool temperate locations. It is noted that this paper has not attempted to evaluate the cost-benefit ratios for the technologies considered, and clearly this should be the subject of future work. However, the intent of the project was primarily to establish feasibility with a view that individual projects may consider cost-benefits in specific installations.

Conclusion

A simulation model in IES-VE of a 5000m², NCC 2019 Section 3 compliant office building with a VAV system has been used to test a range of evaporative cooling technologies across the major Australian climate zones. Overall, the results indicate that the dewpoint cooler is the most robust evaporative cooling option, with strong applications in arid climate zones 3 and 4 (greenhouse gas savings of 13-55%), and smaller but significant savings in climate zones 2, 5, 6 and 7 (13-19%). The modular nature of dewpoint coolers means that they are a potential retrofit option for building with sufficient roof space although that there are limits on the size of available units that may restrict applicability in larger buildings.

In climate zone 8, it has been demonstrated that a direct/indirect evaporative cooling combination (SC 2a) can effectively supplant the need for a chiller, making this system potentially viable.

Evaporative cooling is rarely applied in office buildings in Australia. Given the substantial savings possible, and the pressure to drive office buildings towards net zero emissions, there appears to be a good argument for the use of evaporative cooling to drive HVAC efficiency beyond the current boundaries of best practice VAV systems. To further this, it is imperative that packages such as IES develop suitable template models of dewpoint coolers to enable designers to test the use of this technology for individual projects; the custom process used for this study is not practical for normal industry use.

Furthermore, the potential savings may be higher for HVAC systems with higher minimum supply air temperatures, such as underfloor systems. Overall, there is a strong case for greater use of evaporative cooling in Australian office buildings.

References


Appendix: Representative Climate Information

The following summary climate statistics have been taken from www.bom.gov.au (mean maximum temperature, mean minimum temperature and 3pm relative humidity) as listed in the tables below.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Mean maxT (°C)</th>
<th>Mean minT (°C)</th>
<th>3pm RH (%)</th>
<th>Notional dewpoint (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CZ1</td>
<td>31.8</td>
<td>24.9</td>
<td>70</td>
<td>26</td>
</tr>
<tr>
<td>CZ2</td>
<td>30.5</td>
<td>21.6</td>
<td>57</td>
<td>21</td>
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<td>CZ3</td>
<td>36.4</td>
<td>21.6</td>
<td>22</td>
<td>11</td>
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<tr>
<td>CZ4</td>
<td>31.9</td>
<td>16.4</td>
<td>29</td>
<td>12</td>
</tr>
<tr>
<td>CZ5</td>
<td>26.7</td>
<td>19.0</td>
<td>60</td>
<td>18</td>
</tr>
<tr>
<td>CZ6</td>
<td>26.6</td>
<td>13.7</td>
<td>46</td>
<td>15</td>
</tr>
<tr>
<td>CZ7</td>
<td>29.7</td>
<td>14.5</td>
<td>34</td>
<td>13</td>
</tr>
<tr>
<td>CZ8</td>
<td>21.6</td>
<td>7.5</td>
<td>50</td>
<td>13</td>
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</table>

Table 1. Summary climate information – January

<table>
<thead>
<tr>
<th>Zone</th>
<th>Mean maxT (°C)</th>
<th>Mean minT (°C)</th>
<th>3pm RH (%)</th>
<th>Notional dewpoint (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CZ1</td>
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<td>19.3</td>
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<td>15</td>
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<td>CZ2</td>
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<td>10.4</td>
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<td>CZ6</td>
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<td>5.4</td>
<td>66</td>
<td>6</td>
</tr>
<tr>
<td>CZ7</td>
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<td>56</td>
<td>4</td>
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<td>CZ8</td>
<td>5.5</td>
<td>-3.6</td>
<td>75</td>
<td>1</td>
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Table 2. Summary climate information - July.