Ventilative cooling potential of buildings in Australia

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Abstract. The demand for space cooling is the fastest growing end-use of electricity in buildings since many rely on the use of air-conditioners only to control the indoor climate. Ventilative cooling is a passive cooling technique, which involves the use of outdoor air to lower buildings’ indoor air temperature. In order to determine whether ventilative cooling may have the ability to reduce cooling loads, a detailed analysis of the local climate is needed. The aim of this study was to identify which Australian geographical regions have a suitable climate for the utilization of ventilative cooling techniques. The assessment of climatic potential for each geographic location was carried using two approaches: (i) a methodology which does not require detailed knowledge of the building characteristics, and; (ii) building performance simulation of a ‘typical’ Australian detached home. Results showed that the most populated Australian cities would benefit from the use of ventilative cooling techniques whereas the northern coastal region does not have a suitable climate.

1. Introduction
The amount of energy used by the building sector is steadily increasing worldwide. In developed countries, this sector alone contributes towards approximately one third of the overall energy consumption [1]. Data from the International Energy Agency (IEA) shows that worldwide space cooling is the fastest growing end-use of electricity in buildings and represents approximately 6% of the total energy consumption [2]. A similar trend can be observed in Australia where the Australian Department of the Environment and Energy estimated that in a typical office building Heating, Ventilation and Air Conditioning (HVAC) systems account for approximately 40% of the total energy consumption and cooling alone accounts for approximately 27% of the HVAC energy consumption [3]. The IEA forecasts that if improvements in the energy efficiency of cooling technologies do not match increasing rates of system installations, there could be a potential increase by 60% in air-conditioning electricity demand worldwide [2]. Passive cooling strategies may, therefore, play a central role in minimizing the use of electricity in buildings since they use little or no power. Several passive cooling options are available (e.g. nocturnal radiation, geothermal, ventilation, evaporative [4]), however, the scope of this work is limited to Ventilative Cooling (VC). VC can be employed when the outdoor air is colder than the indoor air [4]. This process has two positive effects: i) it removes heat from a building; and ii) it may generate higher air speeds which facilitates the maintenance of thermal comfort conditions indoors with higher dry-bulb air temperatures [5]. VC can be naturally driven (e.g. wind or buoyancy driven) or mechanically driven and it can be used alone or in combination with mechanical cooling (i.e. mixed mode buildings) to neutralize heat gains in buildings. For example, in hot regions with high daily temperature fluctuations, VC can be utilized at night-time to cool down the thermal...
mass of a building. Artmann et al. proposed a simplified method to estimate the mean Climatic Cooling Potential (CCP) for VC during a time period of N days [6]. However, the Australian climate has not been previously mapped using the CCP. To this end, the aim of this study was to determine which Australian geographic regions are most suitable for the use of VC technologies. In addition, building performance simulations were used to better determine the benefit of using VC strategies in a typical Australian home given that the use of VC depends both on outdoor climatic conditions as well as on building’s characteristics [7, 6]. Four scenarios were modelled, one for each of the four most populated cities in Australia.

2. Methodology

VC potential for the Australian climate was calculated using two approaches: (i) the CCP index [6] which is suitable for all building types and does not require detailed knowledge of the building characteristics, and; (ii) building performance simulation of a archetype standalone Australian detached house.

2.1. Climatic Cooling Potential (CCP)

The Climatic Cooling Potential (CCP) index [6] can be calculated by knowing the hourly: (i) outdoor air temperature for any given location; and (ii) building indoor air temperature. The CCP Climatic Cooling Potential for VC during a period of N days can be determined as follows [6]:

\[
CCP = \frac{1}{N} \sum_{n=1}^{N} \sum_{h=0}^{24} m_{n,h}(T_{b,n,h} - T_{o,n,h}) = \begin{cases} 
  m_{n,h} = 1 & \text{if } T_{b,n,h} - T_{o,n,h} \geq \Delta T_{\text{crit}} \\
  m_{n,h} = 0 & \text{if } T_{b,n,h} - T_{o,n,h} < \Delta T_{\text{crit}}
\end{cases}
\]

Where \( h \) is the time of day, \( T_b \) is the building air temperature, \( T_o \) is the outdoor air temperature, and \( \Delta T_{\text{crit}} = 3 \text{ K} \) is the critical temperature difference below which VC cannot be applied. In this study the time limitations on when VC can be utilized where removed since the present authors believe that there are no underlying reasons why the use of VC strategies should be limited to night-time only [8].

2.2. Hourly air temperature data

The Australian Bureau of Meteorology (BOM) is the national weather agency that monitors weather conditions across the country [9]. Observations from 425 Australian weather stations were made available on-line at a half-hourly temporal resolution. Detailed information regarding the accuracy of the instrumentation and the exact location of each weather station can be found on the BOM website [9].

The climatic data for all Australian state capitals were compared with Australian Representative Meteorological Year (RMY) weather files to ensure that stochastic variations in weather patterns would not have had a great impact on the results. The RMY weather files were developed in 2006 for the Australia Greenhouse Office to be used as inputs to building performance simulation tools in compliance with the Building Code of Australia [10] and are publicly available on-line [11]. The data validation was performed by comparing the cumulative frequency of the CCP obtained from the BOM climatic data and the RMY weather files.

2.3. Building temperature profile

Buildings are generally constructed of materials which have a non-insignificant thermal mass which facilitates sensible thermal energy storage. In order to take this behaviour into account,
Artmann et al. [6] assumed that the building indoor temperature $T_{b,h}$ oscillates harmonically around 24.5°C, i.e. the middle of the ISO 7730 standard [12] comfort band.

$$T_{b,h} = 24.5 + 2.5 \cos\left(2\pi \left(\frac{h - h_i}{24}\right)\right)$$  

2.4. Building performance simulation

To better quantify the cooling potential an archetype standalone detached house (Figure 1) was simulated using Design Builder. The archetype was developed under the Australian National Construction Code Trajectories Project to represent a simplified versions of a typical Australian standalone detached home. The archetype was originally designed to characterize the energy performance of a typical detached home under typical operational conditions. The envelope thermal properties were adjusted to comply with the National Construction Code 2016 Deemed-to-Satisfy (DtS) Elemental Provisions [13]. The simulated building had a gross floor area of 190 m² and a surface-to-volume ratio of 1.17 m⁻¹. A detailed description of the archetype can be found in [13].

![Figure 1. Rendering of the standalone detached house used in the simulations.](image)

The building heating and cooling were no limited in their capacity (i.e. they met the house demand at all times) and the space was conditions 24/7. Cooling was provided only between 30th of Sep. and 31st of Mar. while heating was only provided during the cold season. Windows were allowed to open when outdoor conditions were favourable and cooling was turned off. VC was also provided to the space using an economiser, with a maximum air change rate of 7 h⁻¹ and with a control logic based only on the differential dry bulb air temperature between the outside and inside of the conditioned zone. Heating and natural ventilation set-points were set to 22°C, while cooling set-point was 27°C to allow the indoor air temperature to fluctuate within the same temperature range as defined by Artmann et al. The cooling energy delivered by VC strategies (opening windows and economizer) was then compared with the cooling potential energy, $Q_{CCP}$, estimated with the CCP method.

$$Q_{CCP} = A HR \rho c_p CCP$$  

Where the net floor area of the conditioned zone $A = 167$ m², the height of the ceiling $H = 2.4$ m, the effective air change rate $R = 7$ h⁻¹, $c_p = 1000$ J/(kgK), $\rho = 1.2$ kg/m³. Four scenarios were modelled, which entailed one simulation for each of the four most populated cities in Australia (i.e. Sydney, Melbourne, Brisbane and Perth) employing RMY climatic files.

3. Results and Discussion

3.1. Climatic data validation

A total of 425 weather stations were included in the analysis. The data set contained 1 year of data, starting from the 1st of Feb. 2018 to the 31st Jan. 2019. Australia is characterized by a wide variety of climates and comprises six major Köppen climate zones: equatorial, tropical, subtropical, desert, grassland and temperate [14]. However, all the state capitals and the 12th most populous cities, where approximately 75% of the Australian population lives, are located in
either temperate or subtropical regions and their climates are characterized by warm summers and cold winters [14]. The year 2018 was the third-warmest year on record thus far, with a mean-temperature of $1.14^\circ C$ above the 1961–1990 average that is the most recent standard reference period as defined by the World Meteorological Organisation [15]. All Australian capital cities except Melbourne and Perth ranked amongst the eight warmest years on record for annual mean temperature [9].

The results from the BOM climatic data where compared with the results obtained from the RMY data set for all the Australian capital cities. The monthly mean daily CCP calculated with the two data set showed good agreement, however, it should be noted that the CCP values estimated with the RMY weather files during the warm season were higher than those obtained with the BOM dataset in all capital cities. The main reasons for these differences were thought to be: stochastic variations in weather patterns and global warming. The latter significantly affected the climate and as a result in Australia only one of the warmest ten years on record occurred before 2005 [9]. On the other hand, the RMY weather files only contain data for years before 2006, hence, the effects of global warming in the most recent decade were not able to be quantified.

3.2. Climatic Cooling Potential (CCP)

The monthly mean daily CCP for the 11 most populated cities in Australia plus Darwin are presented in Figure 2. The Figure shows that the potential for VC increases as the latitude decreases and that the 5 most populous cities all have a climates that allow the use of VC. This does not imply that natural ventilation alone is sufficient to provide thermal comfort conditions indoors, however, it depicts that even during summer months buildings may benefit from the use of VC to reduce cooling energy consumption. On the other hand, the Figure also shows that Darwin does not have a climate suitable for the use of natural ventilation year-round.

![Figure 2. Monthly mean daily CCP for the 11 most populated cities in Australia.](image)

The temporal and spatial distributions of the monthly mean daily CCP during the warmest months for the southern part of Australia (i.e. latitude belows 24°S) are presented in Figure 3. Figure 3 shows that VC strategies can be usefully employed throughout the summer period in Tasmania. Moreover, even during the hottest months of the year the use of ventilation can be
Figure 3. Monthly mean daily CCP for the warmest months in Australia.

Employed to significantly reduce the energy consumption of buildings in the following locations: South of Western Australia, coastal regions of South Australia, in the great majority of Victoria, near the coast of New South Wales, and in the Australian Capital Territory.

3.3. Building performance simulation

The VC energy delivered to the space, $Q_{VC}$, and $Q_{CCP}$ are presented in Figure 4. The Figure also shows the monthly percentage of $Q_{CCP}$ that is estimated to be used by the house.

The CCP accurately predicted the VC potential for Sydney whilst it did not accurately determined the cooling potential for Brisbane since the CCP index imposes a limit on $\Delta T_{crit}$. This limit leads to an underestimation of the cooling potential in locations which are characterized by high night-time outdoor temperatures. In Melbourne and Perth during the summer period hot days may be followed by ‘mild’ or even ‘cold’ days, hence, cooling is not always needed even in the hottest months of the year. This is the main reason why only a lower percentage of the available $Q_{CCP}$ is utilized in summer. In all cities except Melbourne, VC is also utilized during the ‘cold’ season to cool down the house during relative ‘warm’ days as shown in Figure 4. In Brisbane, for example, VC can be used throughout the year.

4. Conclusion

The present study employed a well-established methodology developed by Artmann et al. [6] to determine the possibility of utilizing VC technologies in Australia. Results showed that the most populated urban areas in Australia would benefit from the implementation of VC technologies to varying degrees to reduce the overall cooling energy consumption of buildings. On the other hand, in the Tropical and Equatorial regions of the northern part of Australia, the use of VC was extremely limited even during winter months.

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