Evaluation of noise emissions from evaporative air conditioning units and their environmental impact

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ABSTRACT

Noise from evaporative air conditioners has long been an environmental issue. There is neither an existing database for its estimation nor a cost-effective method to control it. This paper provides *in situ* measured sound power levels from a number of evaporative air conditioners used in residential areas in Western Australia. By analysing the frequency characteristics of the sound power with respect to the modes of operation, conditions of installation and noise propagation, useful information is summarised for evaluating the environmental noise impact of evaporative air conditioners.

INTRODUCTION

Evaporative cooling involves a simple heat exchange between air and water, where water is evaporated, causing a cooling effect. The most common form of evaporative cooling is where a sea breeze moves towards the shore and cool water is evaporated into the air stream, causing the air stream to humidify and thus extracting the latent heat from the air. This causes it to drop in temperature. Thus the air stream is cooler when it hits the shoreline.

The same thermodynamic principles can be applied to cooling a building with an evaporative cooler. As illustrated in Figure 1, the water is pumped down rigid cellulose pads, which soak up the water. The airflow cross-stream evaporates some of this water, cooling it in the manner mentioned above. This cool air is commonly pumped into a building through the use of a fan and can then be distributed throughout the building through the use of ductwork.

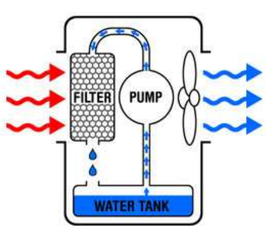

Figure 1. The thermodynamic process of an evaporative cooler (AirTek Corporation).

This type of air conditioning is much cheaper than other designs because of its simplicity and lower power consumption. A refrigerated air conditioner requires copper cooling coils to be installed and a refrigerant to be pumped through for the desired cooling effects, and includes fans for cooling and distribution, whereas an evaporative cooler only requires a fan and water pump for operation. This lower cost of production means that it is marketed as a cheap and effective way to cool a household, making it a very popular air conditioning type in residential areas, as shown in a recent survey conducted by the Australian Bureau of Statistics (2006) (see Figure 2).

Sales statistics (see Figure 3) of the most popular brands of evaporative air conditioners have shown that there has been a slight drop in evaporative air conditioning sales in Western Australia (WA) over the past decade.

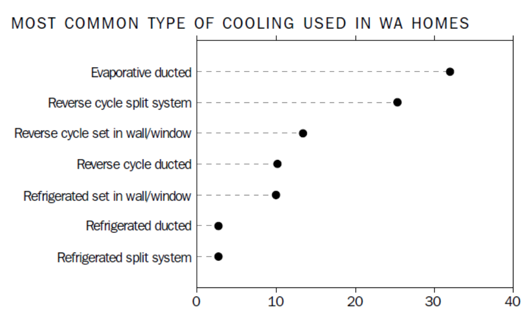

Figure 2. Popularity of air conditioning types (Australian Bureau of Statistics 2006).

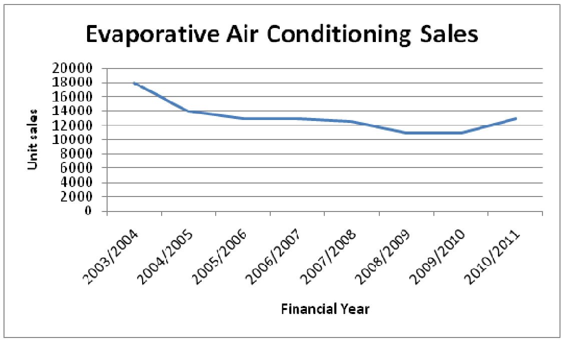

Figure 3. Evaporative air conditioner sales over the past decade (only from major manufacturers) (AirGroup Australia 2011).

Recently, the Australian Bureau of Statistics released information stating that 71% of West Australian households used an air conditioner, with 32% of those households with air conditioners had evaporative coolers. The publication also reported that in 92% of homes with evaporative cooling, the system was ducted throughout the house (Australian Bureau of Statistics, 2006). These statistics indicate that nearly 21% of all West Australian households have a ducted evaporative cooler installed, meaning there were approximately 167,100 evaporative coolers installed at the time of the survey (2006). With over 88% of these units in operation for a period of one to six months per year, the resulting noise issues are a serious concern to the Department of Environment and Conservation (DEC) and local governments (Australian Bureau of Statistics, 2006).

In a recent survey conducted by the DEC (2010), local governments reported a total of 295* noise complaints from air conditioner units, with 93* of these reports from evaporative units alone. The total reported noise complaints are consistent with those from previous years, staying relatively steady between 250 and 300 from 2001 through to 2008 (Figure 4). However, the latest survey noted that although air conditioning units represented only 5% of the total noise reports, they were among the most difficult noise complaint for local government to resolve (DEC, 2002). This is likely due to the fact most air conditioning units are installed in a permanent fashion and are designed to operate for long periods of time, thus being a continual disturbance to nearby residences.

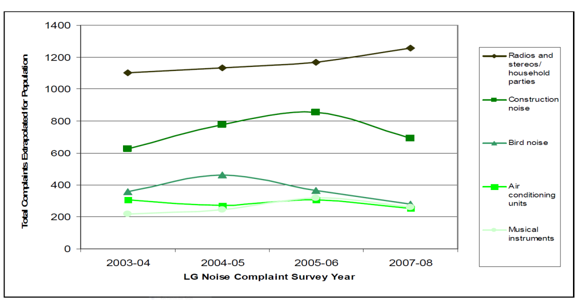

Figure 4. Noise complaints to local governments per year (DEC 2010)

**A few local governments reported noise complaints as a percentage, not a raw number. These results were not included in the totals.*

In this paper, we present the noise and propagation characteristics of four evaporative air conditioning units. The purpose of this preliminary experimental study is to provide the sound power, frequency and directivity properties of these units to assist in the minimization of the environmental noise impact caused by evaporative air conditioners.

MEASUREMENT METHODOLOGY

Noise evaluation has been done on eight evaporative air conditioning units. Since all measurements were conducted in either air conditioner manufactury or residential property, air conditioning units can not be set up in a specific test environment where precision measurement requires. The survey method is used to determine the sound power level of noise sources.

All measurement data has been analysed. However, due to the large amount of data, this paper only presents the measurement set up and analysis of four evaporative air conditioning units. These four units were from two popular brands, Brivis Climate Systems and Cool Breeze, which are commonly used in WA households. The units were tested under different installation conditions. Their photos, models and installation types are all illustrated in Table 1.

Table 1. Photos, models and installation types of air conditioning units.

Photo	Model	Installation
	Cool Breeze D230 15kW (CB1)	Free-standing in an open area
	Brivis-Contour L24 8.9kW (B1)	Free-standing in an open area
	Cool Breeze C205 14.5kW (CB2)	Roof-mounted
	Brivis Contour L54 15.8kW (B2)	Roof-mounted

In this paper, the survey method is employed to determine the sound power levels of the testing units. A hemispherical surface with radius r is used. The surface sound pressure level can be obtained by:

$$\overline{L_p} = 10\log_{10}\left[\frac{1}{N}\sum_{i=1}^{N}10^{0.1L_{pi}}\right] \quad (1),$$

where $\overline{L_p}$ is surface sound pressure level (dB), (Refrence: 20 μPa). L_{pi} is sound pressure level at the ith measurement position, (dB), (Refrence: 20 μPa) and N is total number of measurement positions.

Therefore, sound power level of the source (for measurements outdoors) can be calculated from:

$$SWL = \overline{L_p} + 10\log_{10}\frac{S}{S_0} \quad (2)$$

where SWL is sound power level of the source. S is area of the measurement surface, (m^2) and $S_o = 1\,\text{m}^2$.

To represent different installation conditions, two measurement set-ups were used:

(1) For the two free-standing units, Cool Breeze (named CB1) and Brivis Climate (named B1), measurements were conducted on the ground. There was an open space without any sound reflective surfaces within 8 metres of the measurement area. Two circles were drawn around the units at a radius of 1.5 m and 3 m. Six equally spaced measurement locations were selected around each circle (starting at 0° in Figures 6 and 7).

(2) For the two roof-mounted units, Cool Breeze CR Series (named CB2) and Brivis Contour (named B2), measurements were conducted on the roof of two residences. Due to the limitations of the roof space, only one circle was drawn around the units at a radius of 1.5 m. Six equally spaced measurement locations were selected around the circle (starting at 0° in Figures 8 and 9).

At each location, the time-domain data of the sound pressure was recorded by a Marantz flash audio recorder for narrow-band spectrum analysis and the one-third octave band spectrum and overall sound pressure level in dB(A) were measured using a B&K 2250 sound level meter.

In addition, the A-weighted sound pressure levels at several locations in the backyards of two residences were recorded to study the noise impact on residential areas.

All measurements were conducted at the maximum work load of the units.

RESULTS AND DISCUSSION

Directivity and characteristics of the sound power

The overall A-weighted sound power levels of each unit were calculated from sound pressure level measured at each measurement positions from eq. (1) and (2) and are shown in Figure 5. These indicate in general, sound power levels of air conditioning units are increased with the increase of their cooling capacity. However, sound power level and cooling capacity are not necessarily maintaining a linear relationship for different units. How much increase in sound power level with cooling capacity depends on specific model, different design of fan blades and fan power.

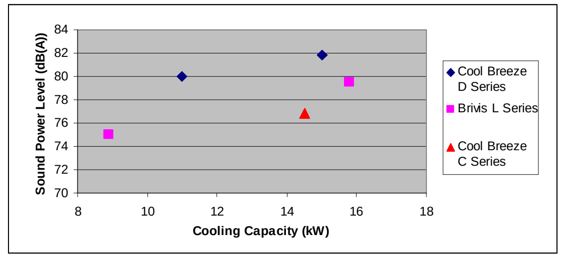

Figure 5. Overall A-weighted sound power levels of the testing units via cooling capacity

The directivity of the sound pressure of the testing units was measured and is shown in Figures 6 to 9.

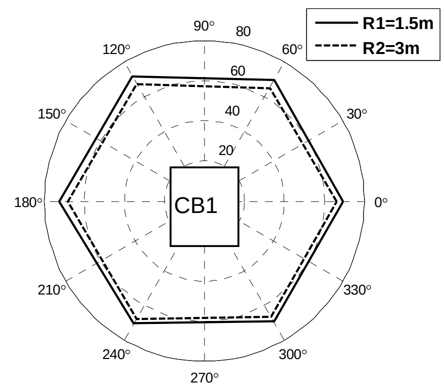

Figure 6. Directional distribution of sound pressure level (dB(A)) from CB1.

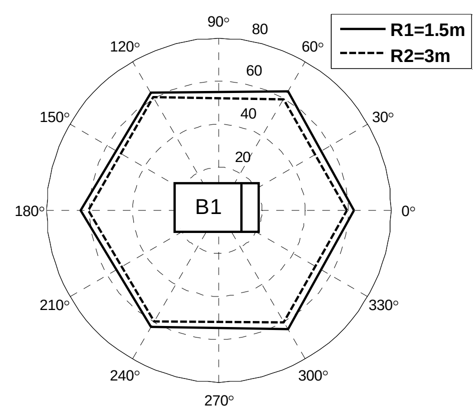

Figure 7. Directional distribution of sound pressure level (dB(A)) from B1*. *: Double lines represent the back side of the roof mounted unit

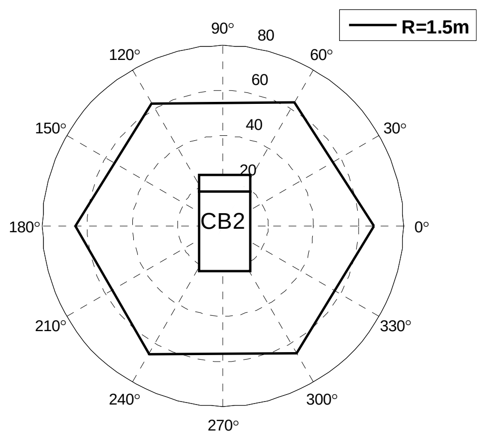

Figure 8. Directional distribution of sound pressure level (dB(A)) from CB2.

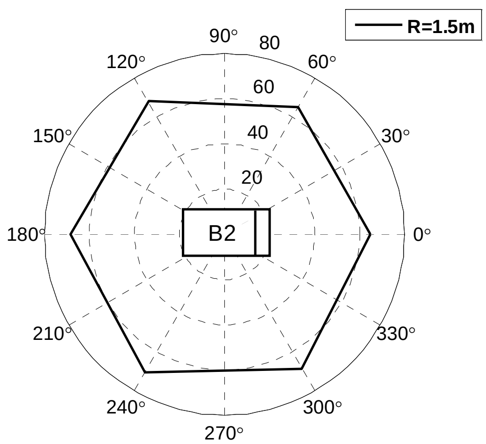

Figure 9. Directional distribution of sound pressure level (dB(A)) from B2.

In summary, the sound pressure level radiated from the units show relatively uniform distribution. The two-roof mounted units have slightly more non-uniform distribution than that of the free-standing units. This might be because both roof-mounted units are installed on the slope of the roof. This would produce sound reflection and cause the non-uniform sound pressure distribution.

To further study the characteristics of the noise source, the power spectra of the four testing units were calculated from the time-domain recordings. They are shown in Figures 10 to 13.

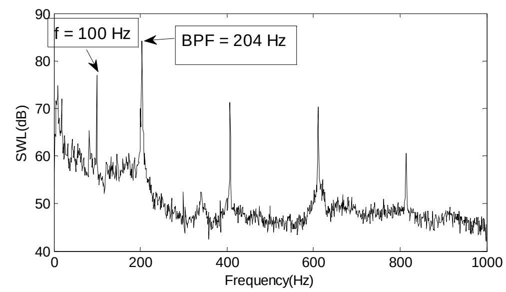

Figure 10. Sound power spectrum of CB1.

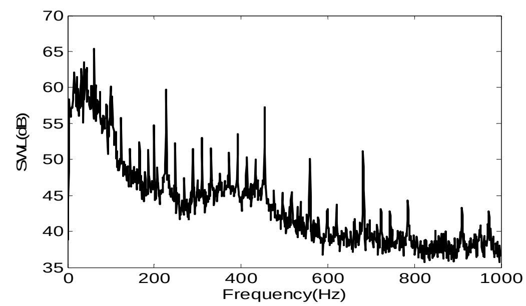

Figure 11. Sound power spectrum of B1.

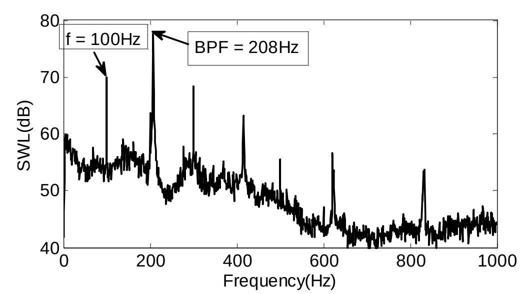

Figure 12. Sound power spectrum of CB2.

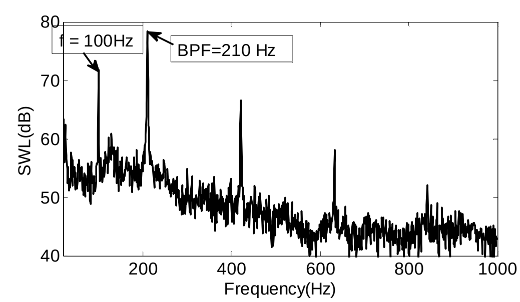

Figure 13. Sound power spectrum of B2.

Two significant frequency peaks can be found in the power spectra of CB1, CB2 and B2. One is at 100 Hz and another is close to 200 Hz. These may be traced to the two mechanical parts (fan and fan motor) which generate the noise and vibration responsible for the measured power spectrum. If the speed of the fan and the number of fan blades are known, then the fan blade noise can be identified by the blade passing frequency (BPF) in Hz, using the following formula:

$$BPF = \frac{N \times RPM}{60}, \quad (2)$$

where N is the number of fan blades and RPM is the fan speed in rpm.

A tachometer is used to measure the rotational speed of the fan. The fan speed of CB1 was 1353 rpm and its fan consisted of 9 blades. As a result, its blade passing frequency is 203 Hz. Hence, the 204 Hz peak can be identified as the blade passing frequency.

Although it was not practical to measure the fan speeds for the roof-mounted B2 and CB2, their *BPF*s can still be distinguished from their sound power spectra. The testing units CB1, CB2 and B2 also have a common frequency peak at 100 Hz. This is contributed by the fan motor.

Tonality of the noise

There are two common types of noise source, tonal noise and broadband noise. Tonal noise is a steady noise with discrete audible tones and broadband noise is steady noise without discrete frequencies. Tonal noise is caused by rotating components in machines; for example, the fan, engine and pump. Tonal noise is generally more noticeable and more annoying than broadband noise of the same level. Therefore, the *Environmental Protection (Noise) Regulations 1997* (DEC, 2003) state that if a noise level that contains annoying characteristics, such as tonal components, that cannot be practically removed, then the noise level will need to be adjusted by +5 dB(A). According to *Environmental Protection (Noise) Regulations 1997*, the noise is defined as tonal if the A-weighted sound pressure level in any one-third octave band is 3 dB greater than in the average of the neighboring bands.

To study the environmental noise impacts of the evaporative air conditioning units, the tonal characteristics of the noise need to be carefully examined. The A-weighted one-third octave band sound pressure level of each unit was measured at 1.5 m away from the noise source and these are presented in Figures 14 to 17 in order to assess the tonal components of the noise.

They demonstrate that the noise from three out of the four units had significant tonal characteristics in the low-to-middle frequency range. This tonal noise represents the characteristics of the fan and motor noise.

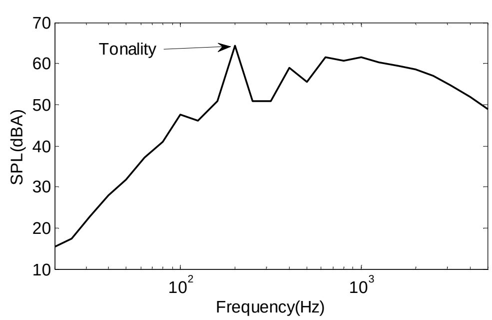

Figure 14. A-weighted one-third octave band spectrum of CB1.

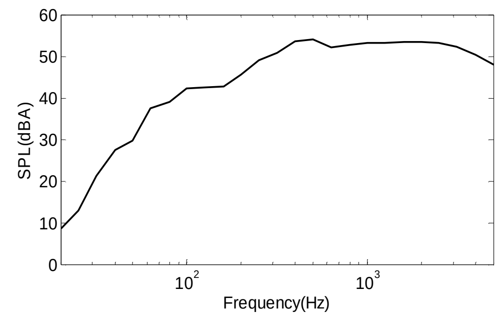

Figure 15. A-weighted one-third octave band spectrum of B1.

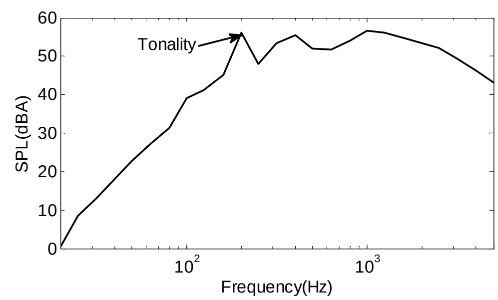

Figure 16. A-weighted one-third octave band spectrum of CB2.

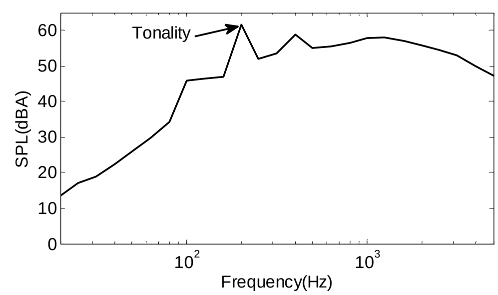

Figure 17. A-weighted one-third octave band spectrum of B2.

Noise impact on the neighbouring community

Although the number of noise complaints due to evaporative air conditioning units are lower (37%) than those from reverse-cycle air conditioning units (63%) in WA (DEC, 2002), they are still a significant noise issue for the community. It is important to study the noise impact on residential areas. Two residential properties were selected for this study. Both were located in quiet streets in the western suburbs of Perth in WA. Residential property no. 1 was a single-storey house, its land area was approximately 450 m^2 and air conditioning unit CB2 was installed on its roof. Its background noise was measured at 34 dB(A). In contrast, residential property no. 2 was a two-storey house, its land area was approximately 950 m^2 and air conditioning unit B2 was installed on its roof. Its background noise was 37 dB(A). Several locations close to the boundaries of each residential property were selected to record the overall A-weighed sound pressure level. Then, noise contour plots for each residential property were obtained by interpolating the sound pressure level of the measurement points and presented in Figures 18 and 19.

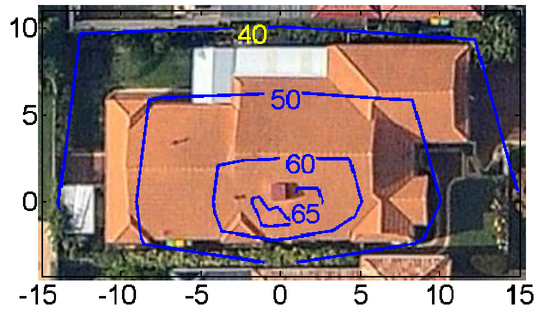

Figure 18. Noise contour plot of residence no. 1.

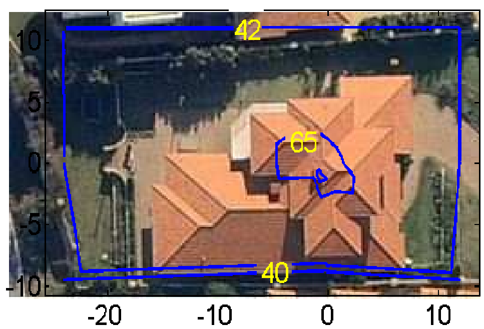

Figure 19. Noise contour plot of residence no. 2.

The noise level of CB2 in residential property no. 1 was lower than that of B2 in residential property no. 2, but the noise level on the right-hand-side of the building was about 50 dB(A). By taking into account sound decay in the neighbouring property and the penalty for tonal noise, the noise level may still be above the assigned daytime noise level (45 dB(A)) in the *Environmental Protection (Noise) Regulations 1997* and thus cause concerns and complaints.

On the other hand, although the noise level of B2 in residential property no. 2 was relatively higher, the greater land area allowed more sound decay and less sound emission into the neighbour's property. Consequently, this potentially reduces the number of noise complaints. This also suggests that quieter air conditioning units need to be considered for installation in small-block residential properties.

CONCLUSION AND FUTURE STUDIES

In conclusion, roof-mounted evaporative air conditioning units installed in residential properties often cause concerns and complaints from the community. In order to evaluate the noise emissions from these units, the noise levels of four evaporative air conditioning units have been measured. Based on the measurement data, the sound power of each unit was calculated and the fan noise and motor noise were identified as two major noise sources of these units. The noise emission is approximately omni-directional, but such directivity is affected by the installation conditions. In addition, tonality was also discovered in the noise sources. By comparing the noise levels close to the boundaries of the residential properties, it was shown that the sound levels in a small block are much higher than in a large block and are more likely to cause complaints.

This study is a preliminary evaluation of noise emissions from evaporative air conditioning units. Only eight units were tested. A greater number of samples, in terms of different brands and different models, need to be investigated in order to draw conclusions with statistical significance, particularly regarding cooling capacity and sound power. Furthermore, a more detailed yet simple prediction method is required to provide guide for practical installations.

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