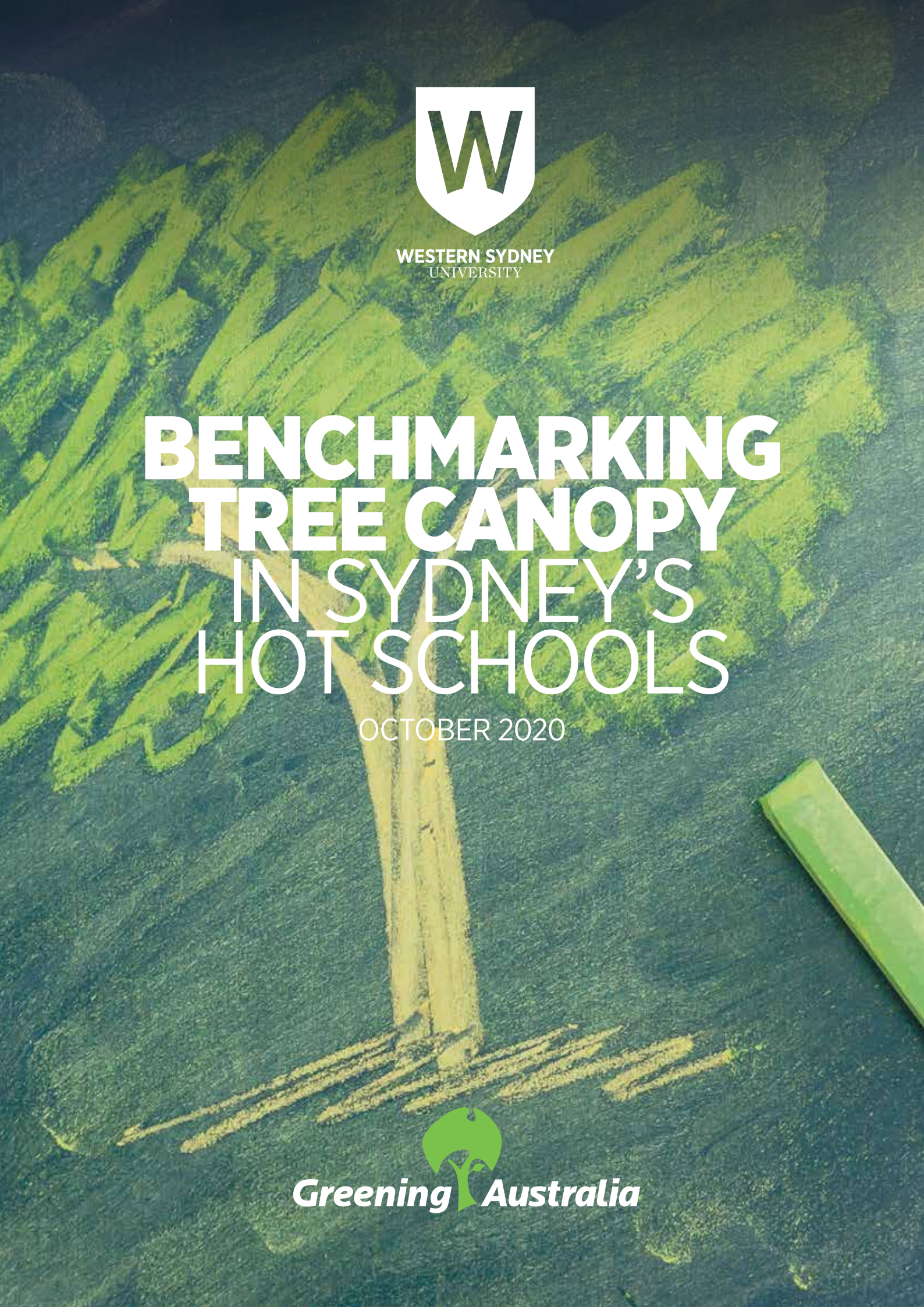

WESTERN SYDNEY UNIVERSITY

BENCHMARKING TREE CANOPY IN SYDNEY'S HOT SCHOOLS

OCTOBER 2020

Greening Australia

AUTHORS

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With respect for Aboriginal cultural protocol and out of recognition that the campuses of Western Sydney University occupy their traditional lands, the Darug, Tharawal (also historically referred to as Dharawal), Gandangara and Wiradjuri people are acknowledged and thanked for permitting this work in their lands (Greater Western Sydney and beyond).

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> **Urban parks and school yards with adequate vegetation, shade, and green space have the potential to provide thermally comfortable environments and help reduce vulnerability to heat stress to those active within or nearby. However, in order to provide this function, outdoor spaces, including parks and schoolyards, must be designed within the context of the prevailing urban climate and projected future climates.**

JENNIFER K. VANOS (ENVIRONMENT INTERNATIONAL, 2015)

SUMMARY

This project identified the 100 most vulnerable schools to heat in Greater Western Sydney using a newly developed *Heat Score*. The *Heat Score* combines socio-economic information that captures exposure, sensitivity and adaptivity of local communities to heat with environmental data related to surface and air temperatures of urban space.

Following the identification of the 100 schools, high-resolution aerial imagery was used to remotely measure a range of attributes at each school. These attributes included the area covered by buildings and open space, as well as the area of tree canopy cover and manmade shade structures. We determined the size of close to 5,000 individual objects to establish a benchmark of shade in Sydney's hot schools.

Key findings:

- Mean area covered by the 100 schools is 23,000 m^2.
- On average 18% of that area is shaded
- Tree canopy cover makes up the majority (15%) of the shaded area.
- Tree canopy cover increases with the area covered by a school.
- Public schools tend to cover larger areas and thus have more tree canopy cover compared to Catholic and independent schools.
- Urban Heat Island effects were reduced when the area of shade was increased.

Additional tree plantings will provide microclimatic benefits. However, the present study reveals that a dual approach is necessary to increase canopy cover among the target schools that differentiates between needs and opportunities.

Catholic and independent schools have the highest need for additional tree canopy cover as their current cover is low. These schools tend to have less open space available for plantings. Successful strategies will require establishing low numbers of carefully selected trees at strategic planting locations to deliver the greatest local shading and cooling benefits.

Public schools offer the greatest opportunities for mass planting of additional trees as they have large areas of open space available. Planting sizeable clusters of trees will provide the greatest cooling benefits not only for the school but generate microclimate and environmental benefits for the surrounding communities.

Analyses provided in this report will assist the development of the most effective tree planting strategies for each of Sydney's 100 hot schools.

CONTENTS

1. BACKGROUND

The climate of New South Wales is changing. A clear long-term trend of increasingly warmer air temperatures is documented in the climate records for this state (Figure 1). The Bureau of Meteorology reported that the 11 hottest years recorded in Australia have all occurred in the past 15 years. The hottest year on record for Australia was 2019 where mean air temperatures were 1.92°C above the long-term mean (1961-1990).

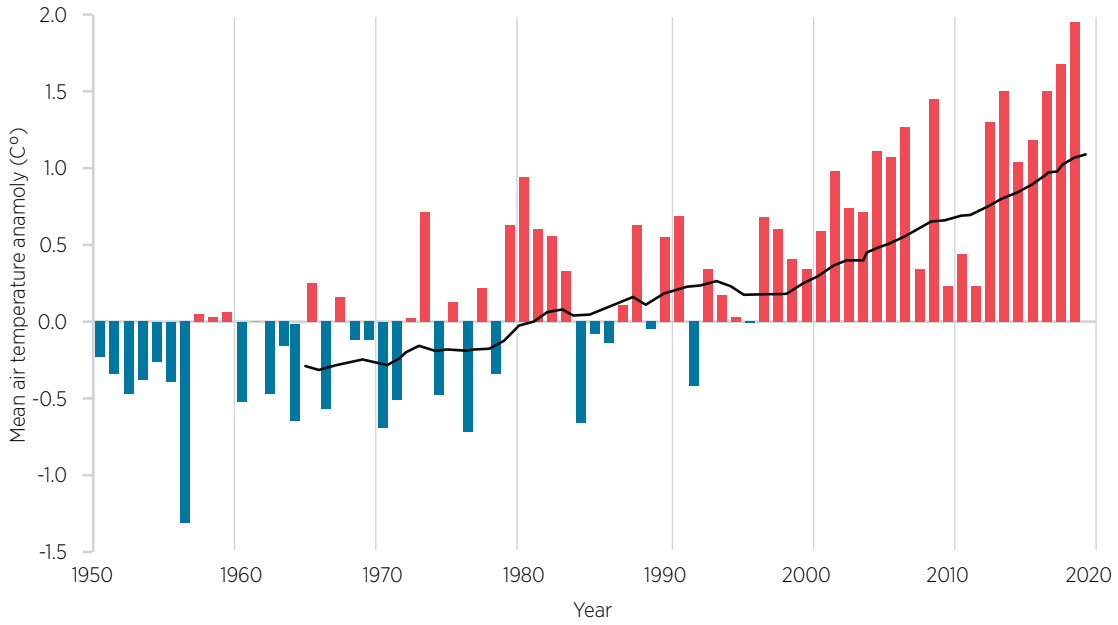


FIGURE 1: Long-term trend in anomalies of air temperatures (i.e., the deviation of the mean annual air temperature from the long-term (1961-1990) mean) in NSW, Australia. Years with cooler than average temperatures are shown in blue, those where average temperatures were warmer are shown in red. The 11 hottest years have been recorded since 2005. The black line shows the 15-year moving mean. Data was downloaded from the Bureau of Meteorology.

Increasing heat will impact the learning outcomes but also the physical health and safety of school children. The clear negative relationship between hot classroom temperatures and learning outcomes has been documented in a number of countries (Seppänen et al., 2006; Wargocki et al., 2010; Goodman et al., 2018). Classroom temperatures can be regulated using air conditioning systems and the 500 million-dollar *'Cooler Classrooms Program'* of the NSW Government (https://www.schoolinfrastructure.nsw.gov.au/programs/cooler-classrooms.html) is a clear indicator that providing optimal learning temperatures inside schools is a key concern of the Department of Education.

The general unpreparedness of schools to deal with climate change effects, especially that of increasing summer heat was highlighted in the *Cool Schools* report from Western Sydney University (Madden et al., 2018) (Figure 2). The report provided a comprehensive overview of current policies and practices around heat and learning in Australia and reviewed building codes, standards, sustainability education and innovative trends in building and landscape design.

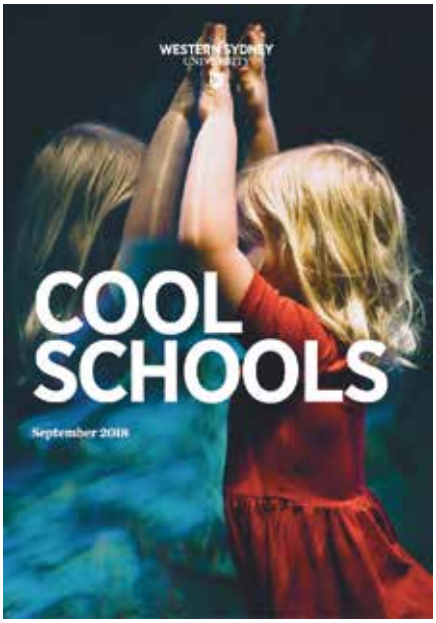


FIGURE 2: The *Cool Schools* report by Madden and colleagues can be downloaded at: https://doi.org/10.26183/5b91d72db0cb7.

The majority of learning takes place inside the classroom. However, a number of key school activities, like sport and play take place outside the classroom. Benefits for the physical, social and emotional wellbeing of school children are generated by outdoor activities during recess (Brockman et al., 2011). For some time now, children in first world countries seem to spend less and less time for physical activity (Ridgers et al., 2013). As a result, morning recess and lunch break at school can comprise 25% of the total daily time where children are physically active (Ridgers et al., 2013). Furthermore, the high value of learning activities in the outdoor space of school environments is increasingly recognised (Harris, 2017).

As a result of rising air temperatures, schools will have to find solutions to deal not only with hot classrooms, but importantly, also develop smart strategies how to provide thermally safe outdoor environments. Yet, lowering outdoor temperature in school environments is far more difficult to achieve than cooling classrooms. Buildings and surfaces that make up school infrastructure are dominated by hard, impervious materials with low albedo (i.e., the reflectivity of the material) and high thermal mass (i.e., the capacity to store solar energy). These materials generally absorb and re-radiate large amounts of solar energy (Ma et al., 2017) leaving unshaded school outdoor environments hot during summer. In contrast, pervious surfaces and green infrastructure, especially well-hydrated lawns, shrubs and trees can provide cooling through evapotranspiration. Tree shade reduces surface temperatures and has been identified as one of the most cost-effective cooling infrastructures in schools (Antoniadis et al., 2016). However, contemporary outdoor school environments can lack these important elements for cooling because they incur maintenance costs and if not managed well, can become health hazards.

Summer temperatures are higher in the western compared to the eastern part of the Sydney Basin. Every summer the number of very hot and extreme air temperatures is far greater in the west. The sea breezes that help cooling the Eastern Suburbs do not reach the western region of the Sydney Basin. This means that schools and their students across Greater Western Sydney have a higher risk of exposure to extreme summer heat. Moreover, given the clear relationship between heat and learning outcomes but also heat and physical health, school children in Greater Western Sydney are disadvantaged in achieving the same academic goals as their peers in the east only because the environmental framework conditions are less favourable.

One strategy to reduce this effect is to increase the canopy cover across the schools of Greater Western Sydney. Yet, there is no available information on canopy cover in schools of the Sydney Basin. This fact makes it extremely difficult to develop strategies and programs that aim to retain and expand canopy cover in schools throughout the region. Which are the most vulnerable schools to heat? Could it be that those schools located in the hottest parts of Greater Western Sydney already have maximum tree canopy cover and thus other means of cooling must be investigated? Could the origin of high vulnerability to heat be a result of socio-economic, rather than purely environmental drivers, or a mix of them? Finding answers to these questions was at the core of the present research.

Here we introduce a new method to rank the schools of Greater Western Sydney according to their vulnerability to heat. This method does not differentiate between public and private, primary or secondary schools. Exposure to increasing summer heat is a shared issue among all schools. Providing thermally adequate and safe outdoor learning environments in schools must not depend on ownership. The clear trend of warming summers and the increasing frequency of extreme air temperatures make it necessary that all schools review their options to provide safe, engaging and heat resilient outdoor environments for their students.

2. STUDY GOALS

The aim of the present project was twofold.

First, we wanted to identify the 100 schools across Greater Western Sydney that are most vulnerable to summer heat. For this task, all schools in the region – primary, secondary, public, private, those with a religious or special needs focus – were included.

Second, the area of tree canopy cover in each of these schools was quantified.

Tree canopy cover in schools provides shading and cooling and is an essential infrastructure asset to prevent school environments from overheating. Understanding the relationships between build and open space and the current tree canopy cover in schools helps fast-tracking programs that aim to effectively cool school outdoor environments. Starting these programs in partnership with the most vulnerable schools will deliver the greatest benefits in the shortest amount of time.

3. METHODOLOGY

3.1 IDENTIFICATION OF 100 HOT SCHOOLS

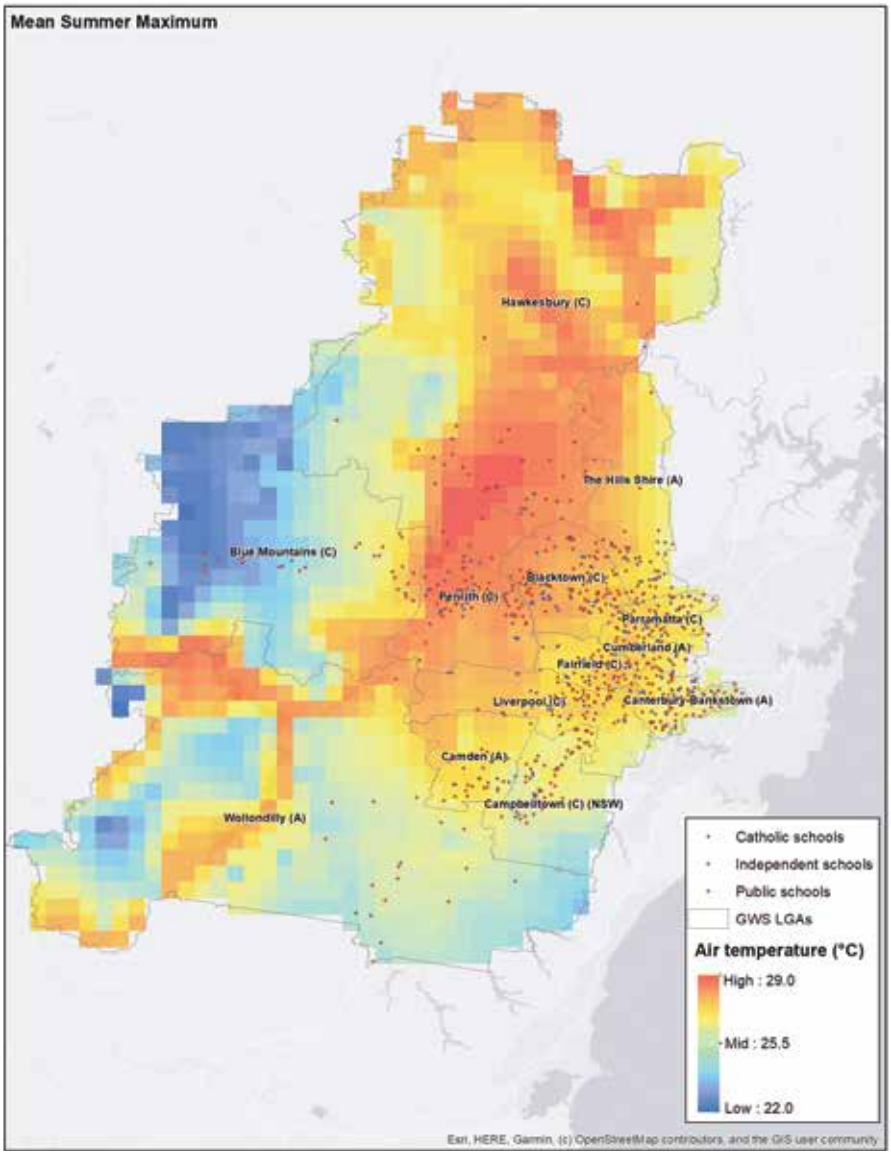
A complete list of all schools across Greater Western Sydney was produced using information available from the New South Wales Education Standards Authority, the Centre for Education Statistics and Evaluation of NSW, the Association of Independent School NSW, Catholic Schools NSW and Wikipedia. Information about each school was tabulated, including the name of the school, its physical location (i.e., street address and suburb), and postcode. A total of 957 schools were identified. Their georeferenced coordinates in degrees latitude and longitude were generated based on the street address and suburb using Batch Geo (www.batchgeo.com). These coordinates were loaded into a geographic information system to generate a shape file containing the locations of all schools.

A shapefile for Greater Western Sydney, based on the definition of the region by the NSW Department of Planning, Industry, and Environment (i.e., based on the boundaries of 13 local government areas: Hawkesbury, Penrith, The Hills, Blue Mountains, Blacktown, Parramatta, Cumberland, Fairfield, Canterbury-Bankstown, Liverpool, Campbelltown, Camden, Wollondilly) was used to eliminate any schools from the list that did not fall into any of these local government areas. This process was necessary as different organisations use different definitions for what constitutes Greater Western Sydney. This procedure resulted in a total of 793 schools for the present study, of which 546 were public schools, 113 Catholic schools and 134 independent schools.

Next, we downloaded data from the Bureau of Meteorology (www.bom.gov.au). The Bureau of Meteorology offers data sets that can be used to visualise long-term climate across Australia. For the present study, we used the mean maximum air temperature (December – February) of the past 30 years (1989/90-2019/20) to create another shape file for the geographic information system. The resulting map (Figure 3) shows a clear 'hot-zone in the central northern section of the Greater Western Sydney between the cities of Penrith, Windsor and Blacktown.

Mean maximum summer temperatures in many local government areas in the eastern part of Greater Western Sydney were 2-3°C cooler compared to this hot zone. When overlaying both shape files, it became clear that many schools of Greater Western Sydney were outside this hot zone yet were likely to suffer from high summer temperatures as a result of other conditions, for example the lack of shade from tree canopies. Also visible in Figure 2 are the generally cooler summer conditions in the foothills and higher elevations in the local government areas of Wollondilly and Blue Mountains.

FIGURE 3: Map of mean summer maximum air temperatures across Greater Western Sydney (GWS). Local government areas are shown as grey lines. Temperature data were calculated for the period between 1989/90 and 2019/20. Data source: Bureau of Meteorology.



Vulnerability to heat is determined by more contributing factors than just mean maximum summer temperatures. These additional factors include environmental and social components that relate for example to vegetation cover or financial means to pay for high electricity costs from air conditioning. To prevent selection bias towards schools from those areas that had hot summer temperatures, we accessed additional data from the central resources for Sharing and Enabling Environmental Data in NSW (www.seed.nsw.gov.au). These data were used to create two additional shape files for the geographic information system.

The first layer was created using the "NSW Urban Heat Island to Modified Mesh Block 2016" data set. This data set contained mesh block information of temperature differences between urban surfaces compared to a reference surface that was entirely vegetated. For example, this reference surface could be a heavily wooded area or an area in a National Park in or around Sydney. The description in SEED states that these data were "derived from the analysis of thermal and infrared data from Landsat satellite, the dataset has been combined with the Australian Bureau of Statistics (ABS) Mesh Block polygon dataset to provide a mean UHI temperature that enables multi-scale spatial analysis of the relationship of heat to green cover." The data were calculated based on measurements during summer 2015/16.

Figure 4 depicts the resulting map with all schools placed into it. The temperature differences for each mesh block are depicted along a continuous colour gradient from 0°C to 12°C. Clearly visible are zones in the local government areas of Fairfield and Liverpool that are subjected to large Urban Heat Island effect. Notably low Urban Heat Island effects are observed in the hot zone shown in Figure 3. Reason for this mismatch is the difference in dominant surface types, which are mostly natural in the zone of high summer maximum temperatures and man-made in the region around Fairfield and Liverpool.

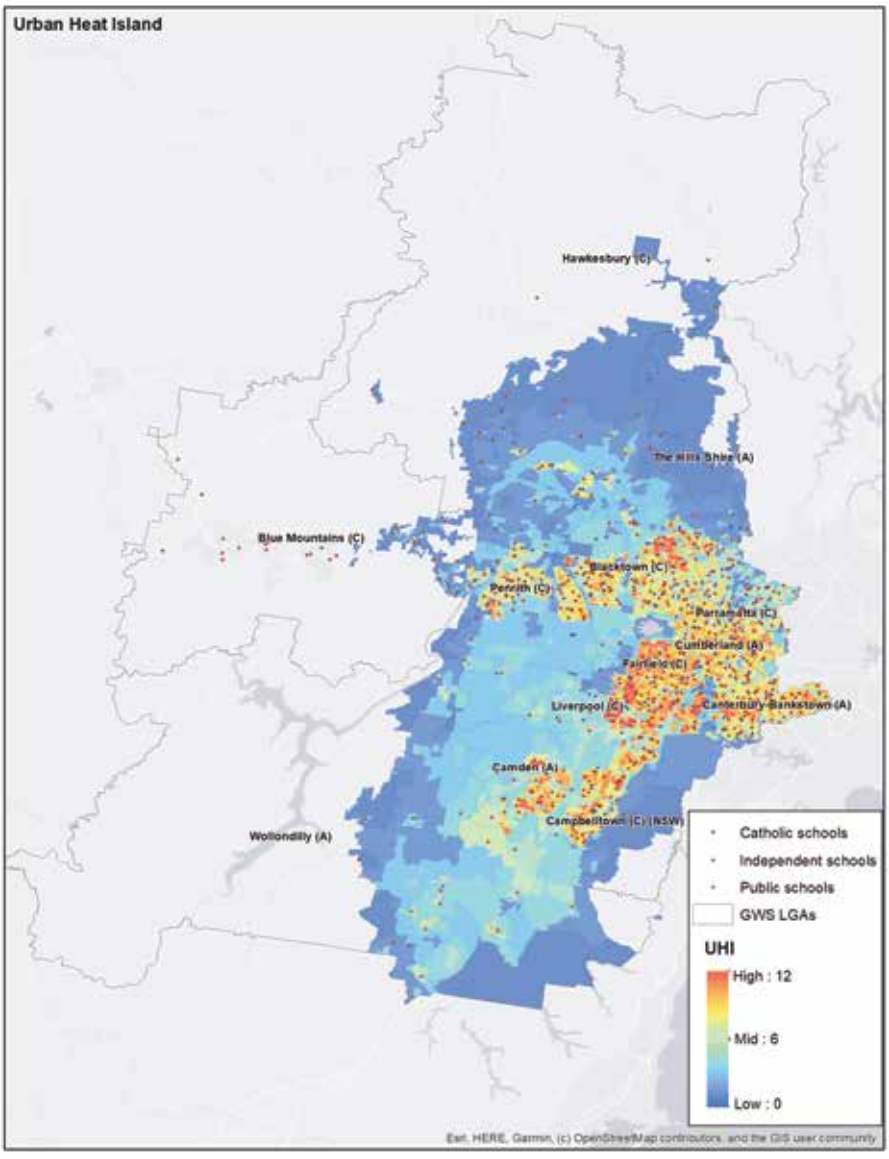


FIGURE 4: Map depicting the Urban Heat Island (UHI) effect across the main urban centres of Greater Western Sydney (GWS). Local government areas are shown as grey lines. The UHI manifests as higher surface temperature of urban compared to a natural surface. This means that colours depicted in the map represent relative temperature differentials between an urban surface compared to a nearby rural surface that is entirely covered by vegetation. Mesh block data were calculated for the summer of 2015/16 and for every Level 1 area of the Australian Bureau of Statistics. Level 1 areas contain a minimum of 200 and a maximum of 800 people. Data source: SEED NSW.

Lastly, we produced a shapefile that depicted the Heat Vulnerability Index (Figure 5). According to information available on SEED, this index is estimated by combining three indicators. First, it determined the apparent exposure to heat using a range of temperature classes. Next, it assesses the sensitivity of an area to heat. This is achieved by measuring the areas covered by vegetation or roads, and looking into population density, the number of elderlies, very young and persons needing care in each mesh block. Lastly, a measure of adaptivity to heat is established by using data from the Australian Bureau of Statistics (Socioeconomic Indexes for Areas (SEIFA) – Index of Relative Socio-Economic Disadvantage (IRSD) and Index of Employment and Education (IEO). The Heat Vulnerability score assigns values from 1 to 5, where an HVI of 5 indicates high exposure, high sensitivity and low adaptive capacity to heat. A score of 1 would mean the opposite. A score of 0 means that no people were living in the area.

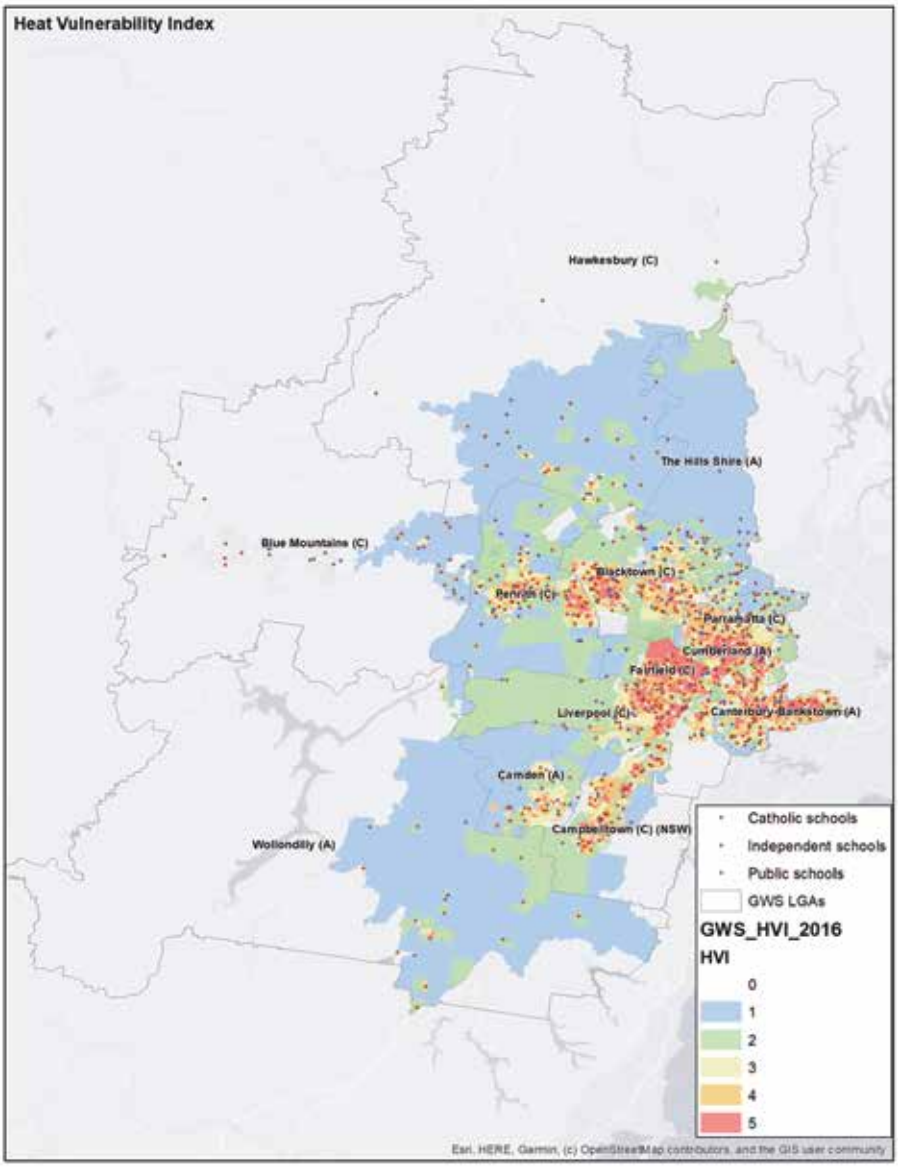


FIGURE 5: Map depicting the Heat Vulnerability Index (HVI) effect across the main urban centres of Greater Western Sydney (GWS). Local government areas are shown as grey lines. The HVI is an indicator of the exposure, sensitivity and the capacity to adapt to heat for individual communities. The HVI is scored from 0 to 5, where 0 mean low exposure, low sensitivity and high adaptability of a community to heat. Please see text for more information about this index. Mesh block data were calculated for the summer of 2015/16 and for every Level 1 area of the Australian Bureau of Statistics. Level 1 areas contain a minimum of 200 and a maximum of 800 people. Data source: SEED NSW.

Location-specific information was extracted for each school from the three shape flies. The following formula was developed for this project to facilitate assign a unique *Heat Score* to schools according to their vulnerability to heat:

Heat Score = HVI ×10 + UHI × 4.5 + T_{air} × 1.5

where HVI is the Heat Vulnerability Index, UHI is the Urban Heat Island Effect and T_{air} is the mean maximum summer air temperature over the past 30 years. Each of the parameters is multiplied by a weighing factor.

In consultation with Greening Australia, it was decided that the Heat Vulnerability Index and Urban Heat Island should receive the highest weight as they captured the most important information about social and environmental characteristics in each unit of analysis (Mesh Block). Moreover, it was expected that planting and maintaining native vegetation by Greening Australia would have a greater impact on local Urban Heat Island effects than lowering mean maximum summer temperatures. Hence, it was decided that T_{air} should have the least weight on selecting the 100 schools to prevent a potential bias towards the observed hot zone. Given that this Index only has a range from 0 to 5, the multiplication factor was set to 10. The Urban Heat Island effect ranged between 0 and 12 °C and a multiplication factor of 4.5 was selected to give this variable appropriate weight. T_{air} was multiplied by a factor of 1.5. Table 1 shows a number of examples of how individual schools scored according to the newly developed formula.

TABLE 1: Example of a school with a low, medium and high *Heat Score*. Parameters used to calculate the Heat Score are also shown. Abbreviations: T_{air} = mean maximum summer air temperature, UHI = Urban Heat Island, HVI = Heat Vulnerability Index.

Operator	School name	T_{air} (°C)	UHI (°C)	HVI (unitless)	Heat Score (unitless)
Public	Kurrajong North Public School	26.5	1.146	1	54.907
Catholic	St Michael's Primary School	27.0	8.018	3	106.582
Independent	Warrakirri College	27.0	9.660	5	133.967

After the Heat Score was calculated for each school, all 793 schools were ranked from a high to low Heat Score. The Heat Score was able to filter out the 100 schools most vulnerable to heat (from here onwards termed 'target schools' for simplicity) according to the combined effects of social, environmental and climatic characteristics (Figure 6). Data for T_{air}, UHI, HVI and the Heat Score for the selected schools can be found in List 1 at the end of this report.

The majority of the target schools had a Heat Vulnerability Index of 5 and no school with a Heat Vulnerability Index lower than 4 was included (Figure 6A). The Urban Heat Island effect of any selected school was high, ranging between 7 and 11 °C (Figure 6B). In contrast, the range of mean maximum summer air temperatures (T_{air}) varied across the target schools, covering a range of a rage of 4.5 °C (24.5-29.0 °C; Figure 6C). The narrow range in Heat Vulnerability Index and Urban Heat Island, juxtaposed by the wide range in T_{air} of the target schools is a clear testament that the formula developed to calculate the Heat Score worked well to rank and identify schools according to their vulnerability to heat.

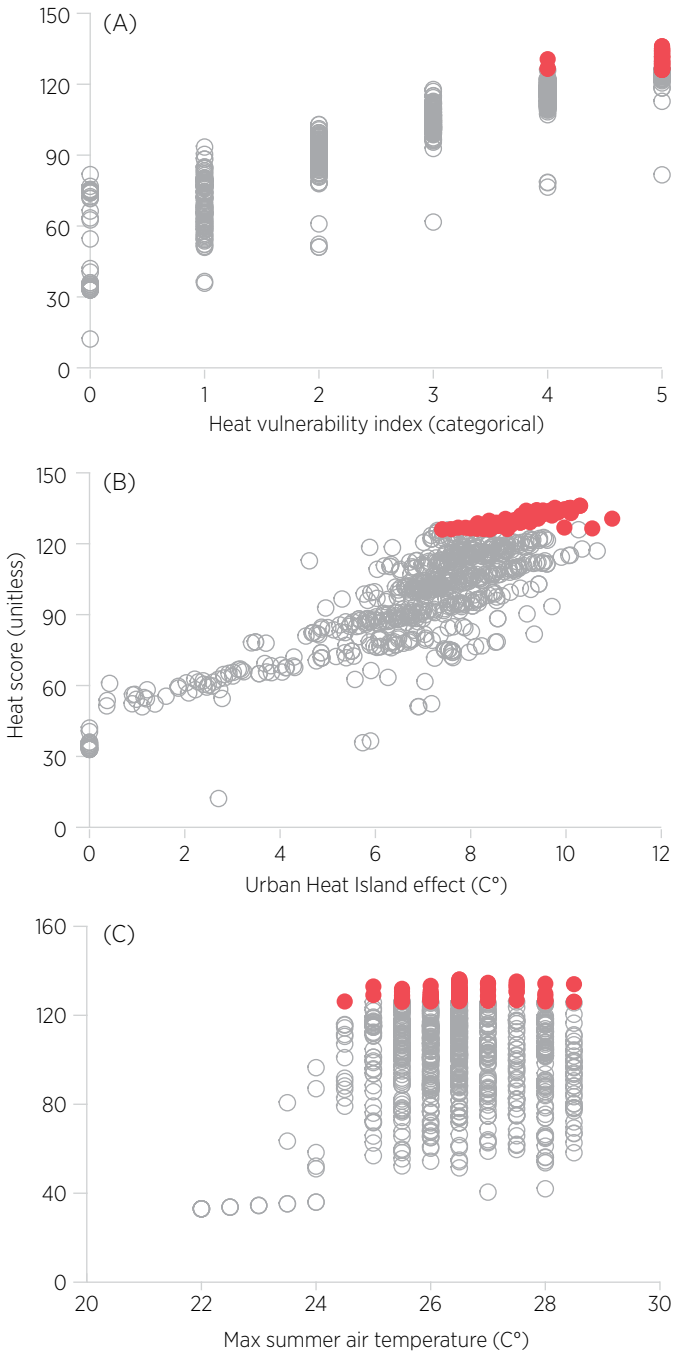


FIGURE 6: Relationships of the Heat Vulnerability Index (A), Urban Heat Island effect (B) and mean maximum summer air temperature (C) with the Heat Score. Dots show data for all public and private schools in Greater Western Sydney (n = 793). Red dots represent the 100 schools that are most vulnerable to heat and were selected for a detailed tree canopy cover analysis.

3.2 TREE CANOPY COVER ANALYSIS

We used Nearmap to analyse the area of tree canopy cover in each of the target schools. This licensed software provides access to high-resolution aerial images that cover Greater Western Sydney. Resolution of the resulting maps is 5.8-7.5 cm per pixel and typically accurate to ±15 cm for distances of up to 200 m. for more information about the quality of these maps, please visit https://docs.nearmap.com/display/ND/Accuracy. The map produced by an overpass in early June 2020 was used for the analyses presented here.

To support a systematic analysis of each target school and generate data sets of equal accuracy and content, a set of categories was developed to guide the identification of boundaries, structures and objects. The following categories were specified:

1. Total area covered by the school
2. Area covered by buildings
3. Area of tree canopy – single and fully inside the school
4. Area of tree canopy – single and not fully inside school
5. Area of tree canopy – cluster and fully inside school
6. Area of tree canopy – cluster and not fully inside school
7. Area of artificial shade structure – not a covered outdoor learning area (COLA)
8. Area of artificial shade structure – covered outdoor learning area (COLA)

The polygon function in Nearmap was used to physically measure the area covered by objects of each category. The area of each polygon in each of the eight categories was documented separately to allow detailed analyses of the absolute and also the relative tree canopy cover. Examples that document the broad variation among the school environments that were assessed in this project are shown in Figure 7, 8 and 9.

Our analyses of the schools produced measurements for 4,913 individual objects covering a total of 3,289,672.83 m^2, or 3.29 km^2 of school infrastructure. The highest number of individual objects were identified at The Ponds High School (n = 117), followed by Rooty Hill High School (n = 111) and Penrith High School. All three schools covered large amounts of space. The lowest number of objects were documented for Warrakirri Collage (n = 2) and the Sydney Adventist School (Auburn). The largest single object was the school grounds of Ambarvale High School, which covered 67,723.39 m^2. The smallest single object covered 0.58 m^2. It was the canopy of a single tree planted in 2019 at St Catherine of Siena Primary School.

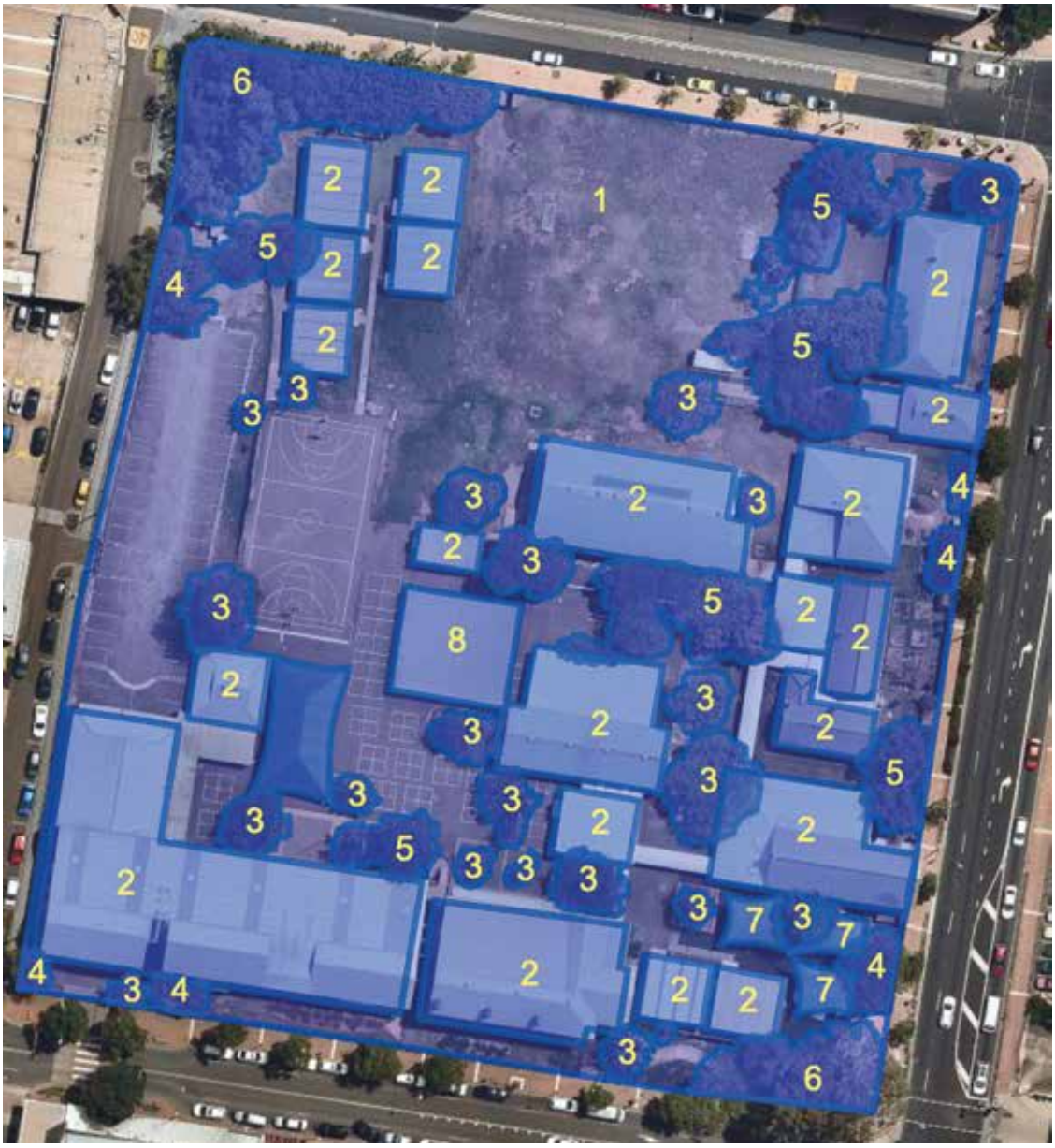


FIGURE 7: A highly heterogeneous school environment with build and open spaces, tree canopy and artificial shade structures. The individual objects belonging to categories 1-8 (see text) are outlined. Measurements for each object were recorded individually and summed for each category. Image © Nearmap.

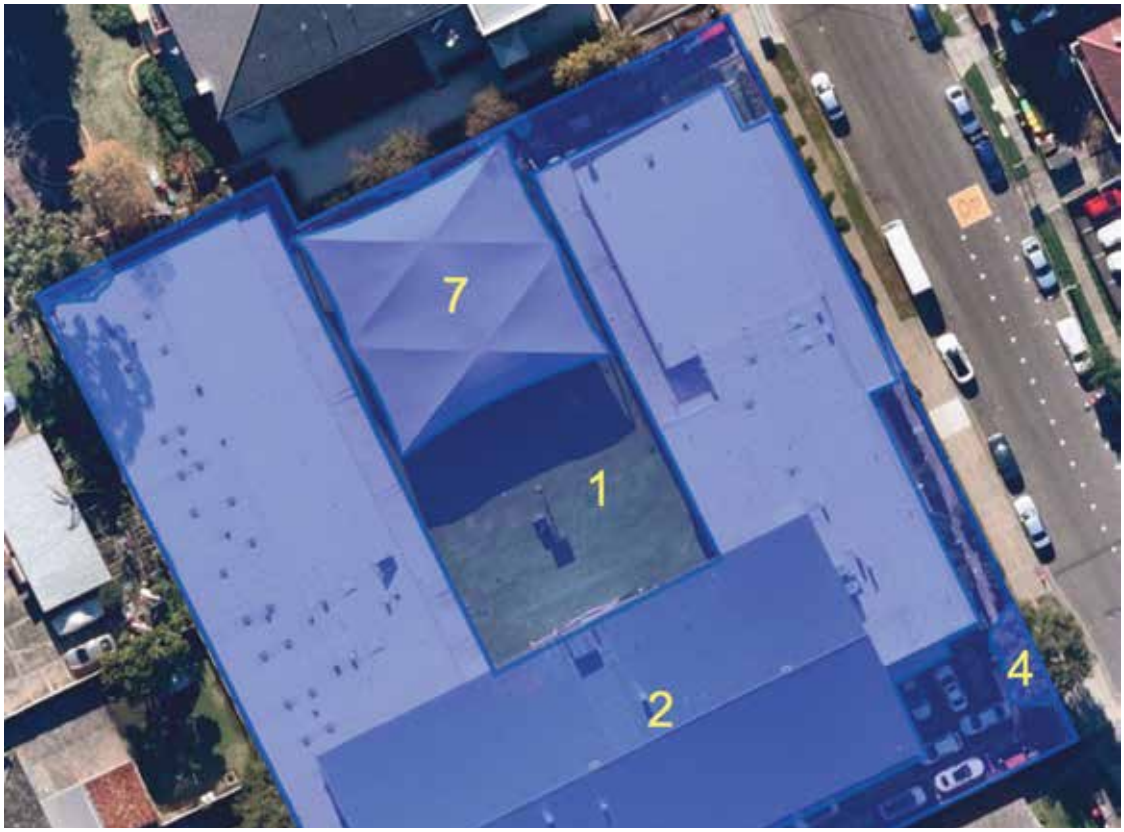


FIGURE 8: A highly uniform school environment, dominated by buildings and a large man-made shade structure that was not a Covered Outdoor Learning Area. The individual objects belonging to categories 1, 2, 4 and 7 (see text) are outlined. Image © Nearmap.

FIGURE 9: Representation of the level of detail applied during the analyses of shade in target schools. Panel A shows outlines around pergolas that shade walkways and shade roofs to shade play spaces. Panel B shows the aerial view of a structure between two adjacent buildings that could be a small building or a tin roof providing shade. Google Street View was used where possible to confirm the nature of structures shown in Panel B. Panel C is an image from Google Street View that helped identify the structure in Panel B as shade roof.

4. RESULTS

The target schools consisted of 65 public schools, 19 Catholic schools and 16 independent schools. The schools were located in 60 different suburbs. The highest number of schools in a single suburb were detected for Liverpool (n = 7), Merrylands (n = 6), Granville (n = 5), Mt Druitt and Fairfield (n = 4). All other suburbs contained between one and three target schools. When sorted by postcodes, 14 target schools fell within the area of 2170, an area around Liverpool in Sydney's south west. The second and third most target schools by postcode fell within the area of 2160 (n = 7) and 2165 (n = 7). These two postcodes mark the area around Merrylands and Fairfield in Sydney's central west.

4.1 AVAILABLE SPACE

The total area taken up by the target schools varied between 1,110 m^2 (St Marys Flexible Learning Centre) and 67,723 m^2 (Ambervale High School) with a mean of around 23,000 m^2. While the largest school grounds were predominately covered by public schools, three Catholic schools were among the 15 schools with the largest ground area (Figure 10). Six independent schools were among the 10 smallest school grounds.

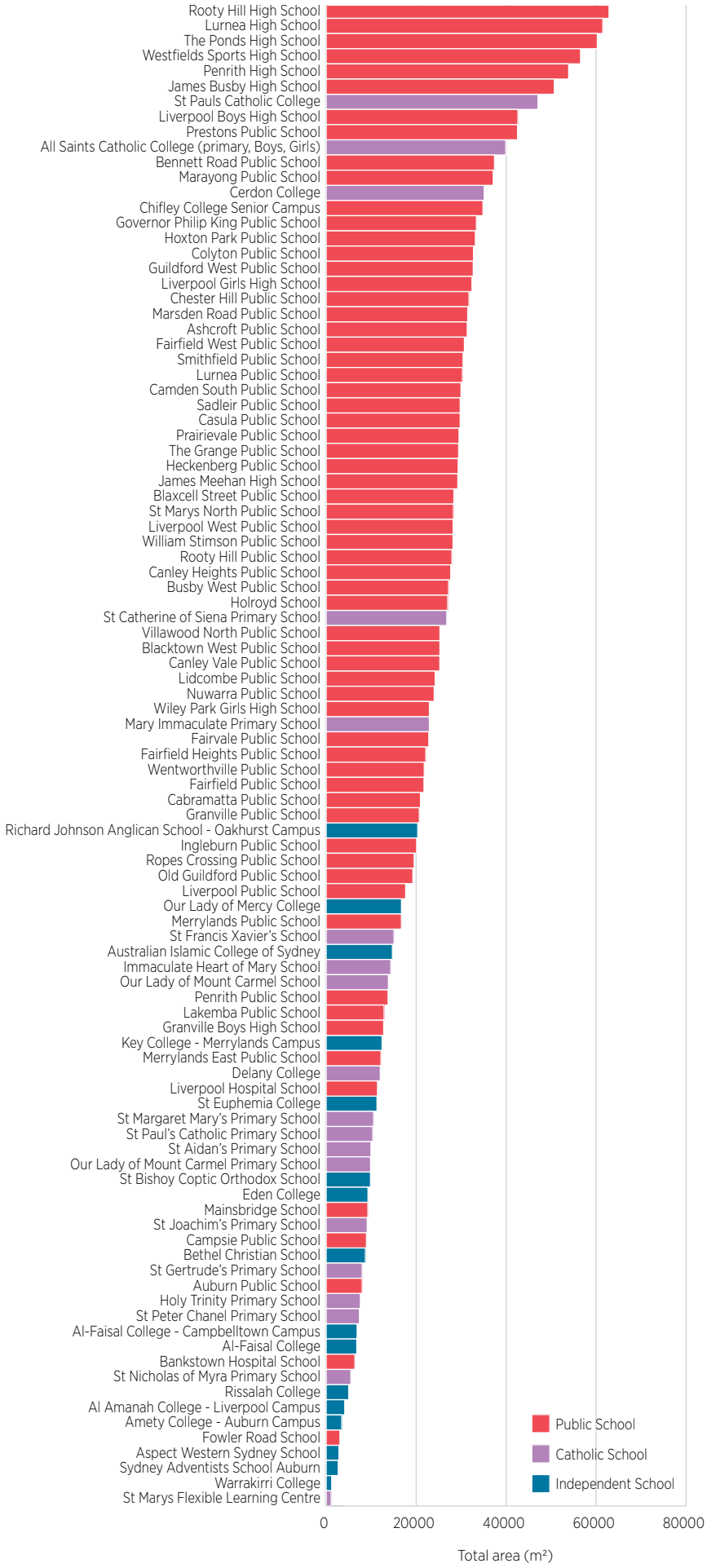


FIGURE 10: Ranking of target schools according to the total ground area covered by each school. The school type is indicated by colour.

The trend of public schools being larger by area is also reflected in the area of buildings that cover these school grounds and the amount of open space that remains. A power function best described the relationship between the total area occupied by the school and its buildings (Figure 11A). This relationship is signified by a rapid increase in the area of buildings at schools that cover less than 10,000 m^2. From there on the area covered by buildings increases less rapidly.

On average, 15,600 m^2 or 63% of the area covered by a school was open space with a large range between 0 and 85%. Only nine target schools provided less than 3000 m^2 of open space. The data showed that schools covering a larger ground area will have more open space available. With increasing ground area, we detected a highly significant linear increase in open space (Figure 11B).

Lurnea Public School had the largest area of open space in both actual and relative size (52,326 m^2 or 85%). However, the schools with high cover of open space in actual square meters were not necessarily those that had a high relative cover of open space. For example, while St Catherine of Sienna Primary School ranked 31st in providing and area of 20,772 m^2 open space, it had the 3rd largest proportion (77%) of open space in relation to its total area. Understanding these relationships will be important when selecting schools for tree planting programs.

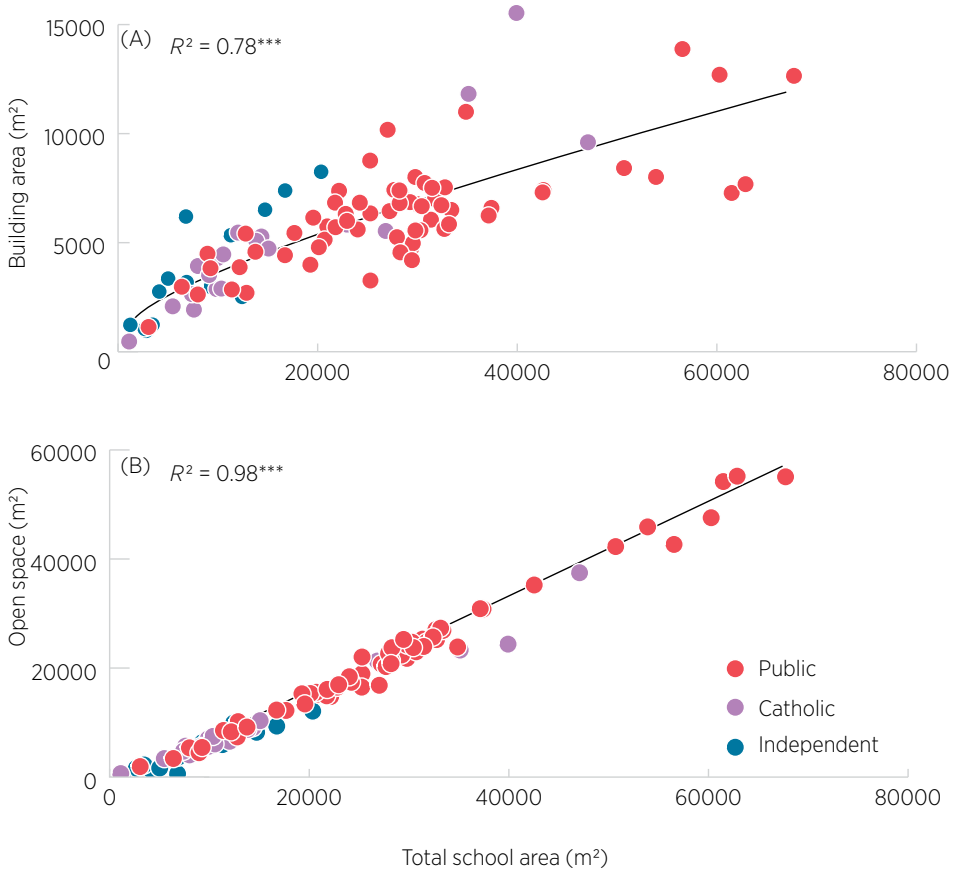


FIGURE 11: Relationship between the total area covered by a school and the area covered by its buildings (A) and the remaining open space (B). Solid lines indicate best-fit functions. The coefficient of determination (R^2) is presented and the statistical strength of the relationship is indicated by asterisks (*** indicate that $p<0.001$). The school type is indicated by colour.

The trends that (1) public schools cover larger areas compared to independent or Catholic schools and (2) that a larger total area will also leave more open space give rise to yet another important observation: Public schools have a smaller relative area covered by buildings compared to Catholic and independent schools (Figure 12). The reverse conclusion of this observation is that the smaller schools, mostly Catholic and independent, have the highest relative coverage of buildings on their school grounds. Figure 10 shows that this is the case. The relationship between the total space occupied by a school and the relative coverage of this area by buildings indicates that more space for additional tree plantings will is available in public compared to Catholic and independent schools. However, the detailed analyses of tree canopy cover will show that Catholic and private schools are those with the greatest need for additional canopy cover.

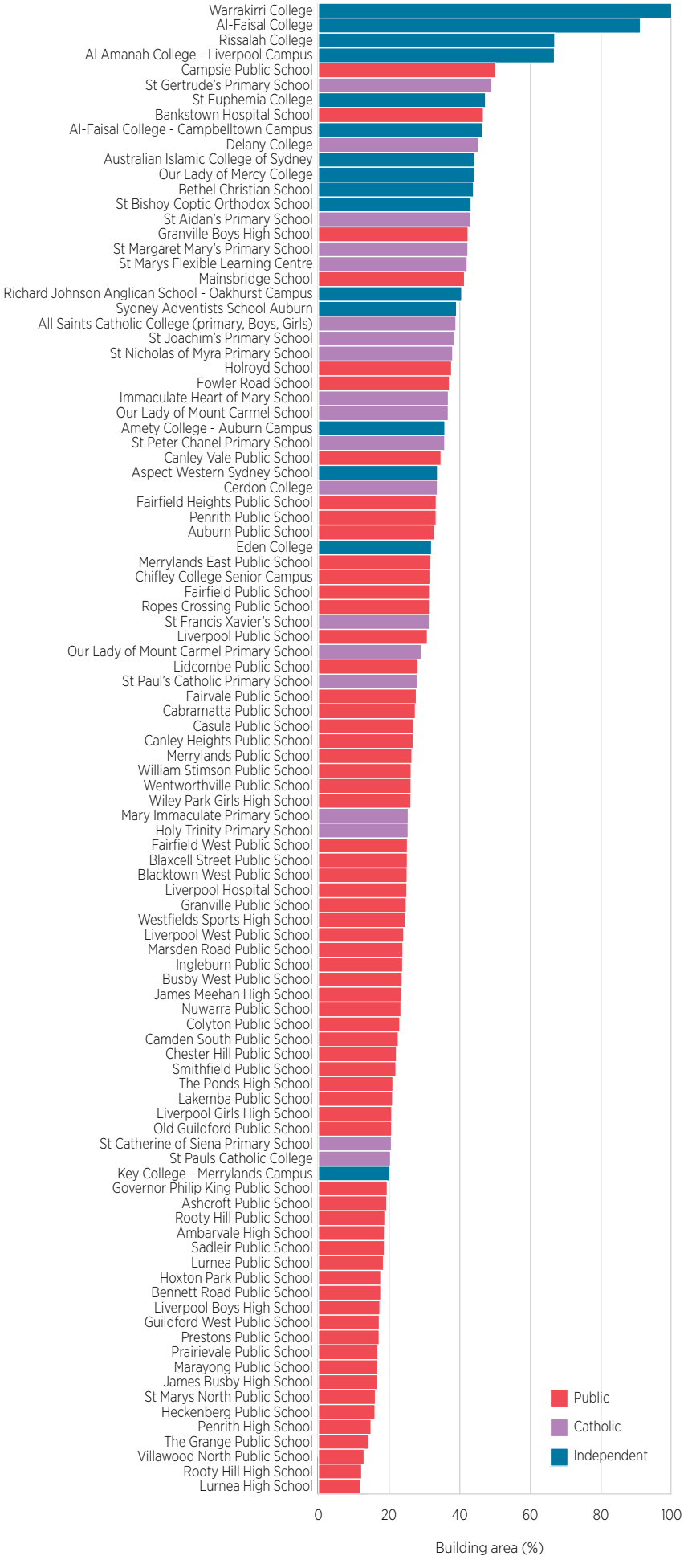


FIGURE 12: Ranking of target schools according to the relative area of buildings taken up as proportion of the entire area of the school. The school type is indicated by colour.

4.2 **SHADE IN SCHOOLS**

Two of the identified 100 schools did not have any open space and consequently were not providing any shade. The shade provided by the remaining 98 schools was largely dependent on the amount of open space. On average the mean school area (23,000 m^2) had a total relative area of 18% under shade. Of this area, 12.2 % was shaded by tree clusters, 2.4% by individual trees and 3.1 % by other manmade structures. In relative terms, the Merrylands campus of the Key College had the largest cover of shade. While this school has a relatively small ground area of 12,400 m^2 it has only 20% of this area covered by buildings (see Figure 13). Surprisingly, the lowest relative cover of shade of all schools was found in a public school with a large ground area. At The Ponds High School, just 2.4% of 60,270 m^2 were shaded (Figure 13).

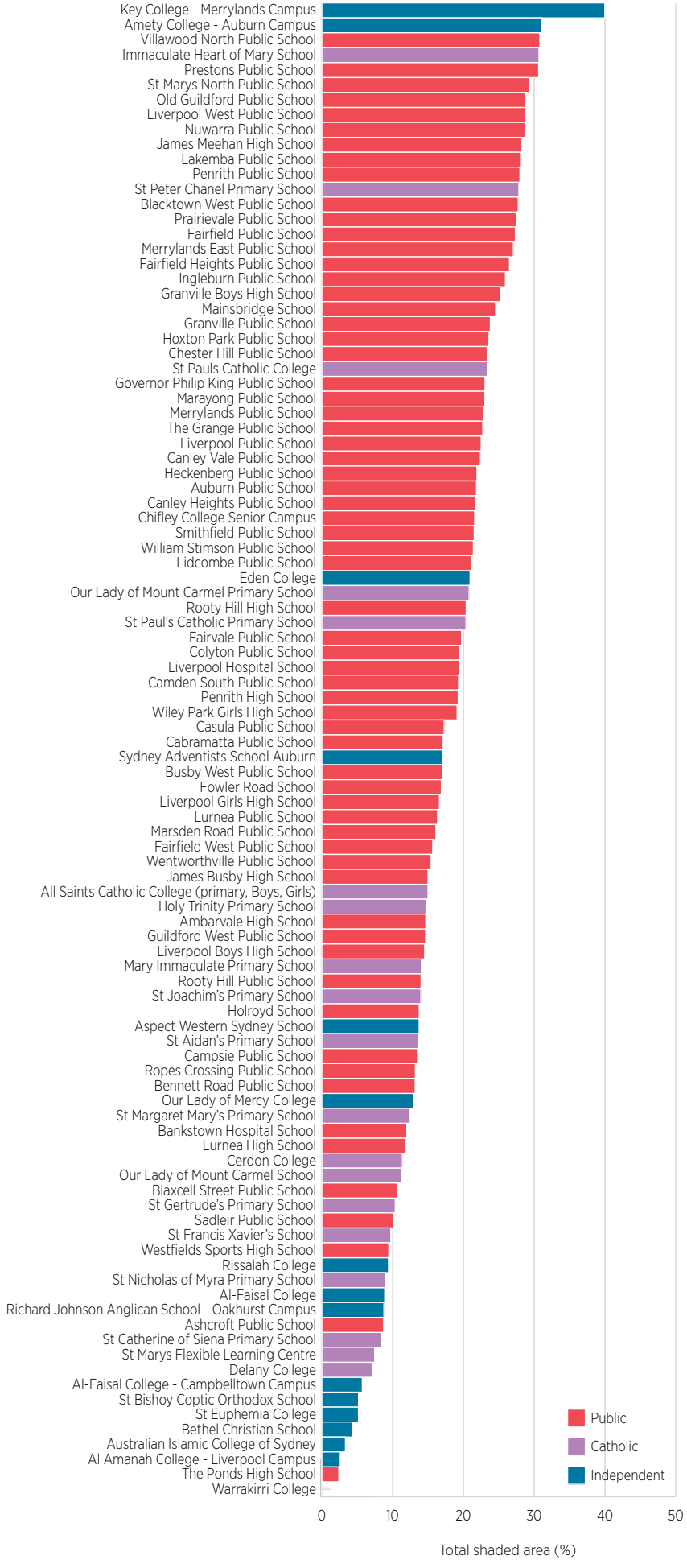


FIGURE 13: Ranking of target schools according to the relative area of shade as proportion of the entire area of the school. For this ranking, the area covered by shade was calculated as the sum of all shade structures measured (i.e., sum of categories 3-8). The school type is indicated by colour.

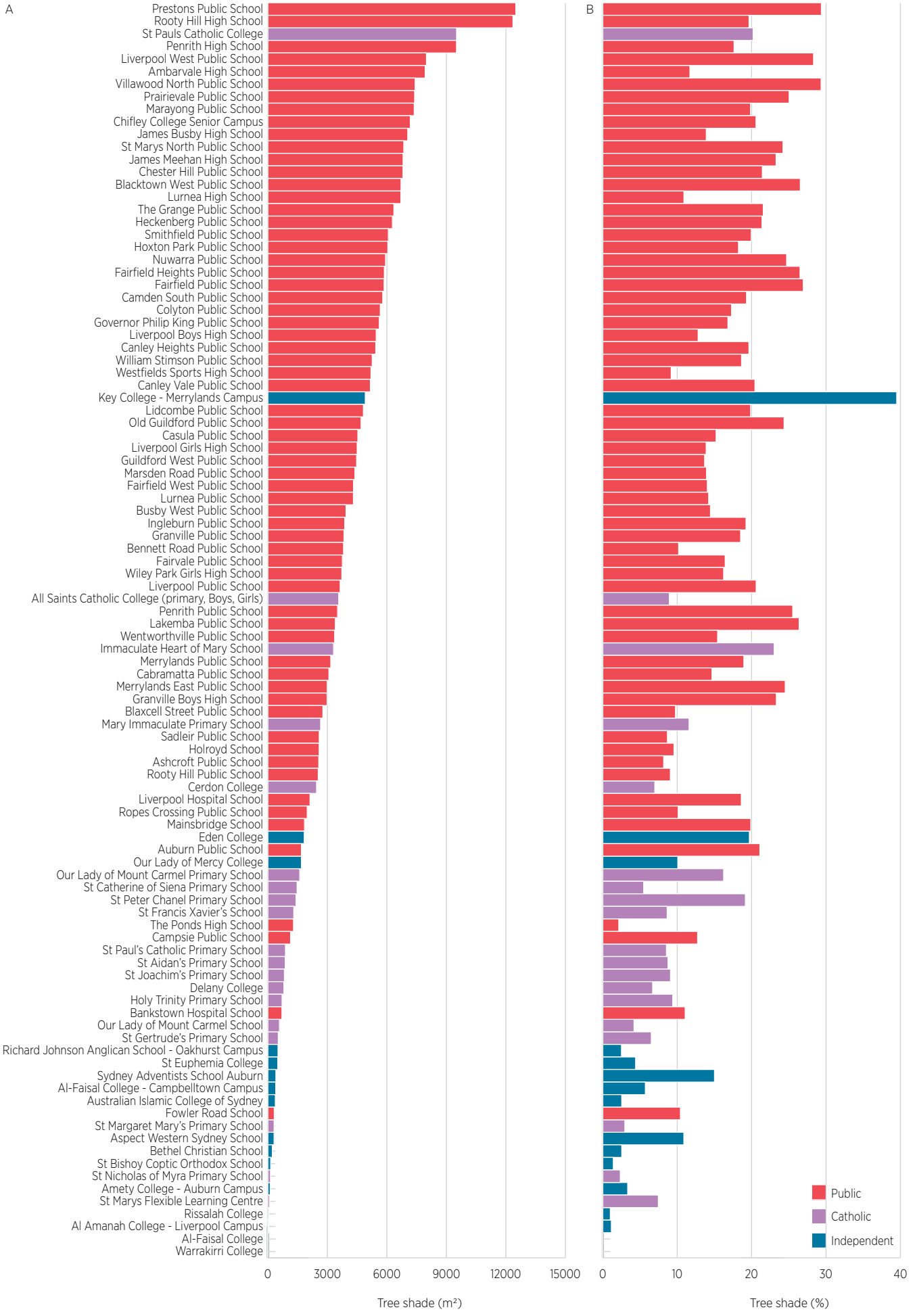
When separated by the major categories of tree canopy clusters, individual trees and manmade shade structures, the largest area of shade provided by clusters of trees was 11,690 m^2 at Prestons Public School, representing 27.5% of the total school area. Rooty Hill High School had the largest area shaded by individual trees (3170 m^2). The largest area covered by manmade shade, including COLAs, shade sails and other structures was 2,420 m^2 at All Saints Catholic College. The relative proportions of shade provided by the three categories can be determined for every school using data provided in List 2 at the end of this report.

4.3 **TREE CANOPY COVER**

All except two target schools had at least one tree or cluster of trees that partially provided shade on their grounds. While the relative coverage of tree canopy among the target schools was 15% or 3600 m^2, this percentage varied widely from 0% to 40 %, and accordingly from around 50 m^2 to 12,500 m^2 (Figure 14). Here, total tree canopy cover is the sum of all measurements collected in categories 3-6, including individual trees and tree clusters that are partially or fully cover open space or buildings or other structures inside schools. Among the 30 target schools with the largest tree canopy cover was only one Catholic and no independent school. This fact highlights the importance of having large school grounds with open space available to provide a healthy and extensive tree canopy.

We found that 13 target schools had less than ten individual or groups of trees that provided shade. Of these, eight were independent schools, four Catholic and one public. As mentioned previously, independent and Catholic schools had generally less total ground space and as consequence also less open space available compared to public schools. Thus, our finding that tree canopy area is generally lower in independent and Catholic compared to public schools is to a large part owed to a lack of space.

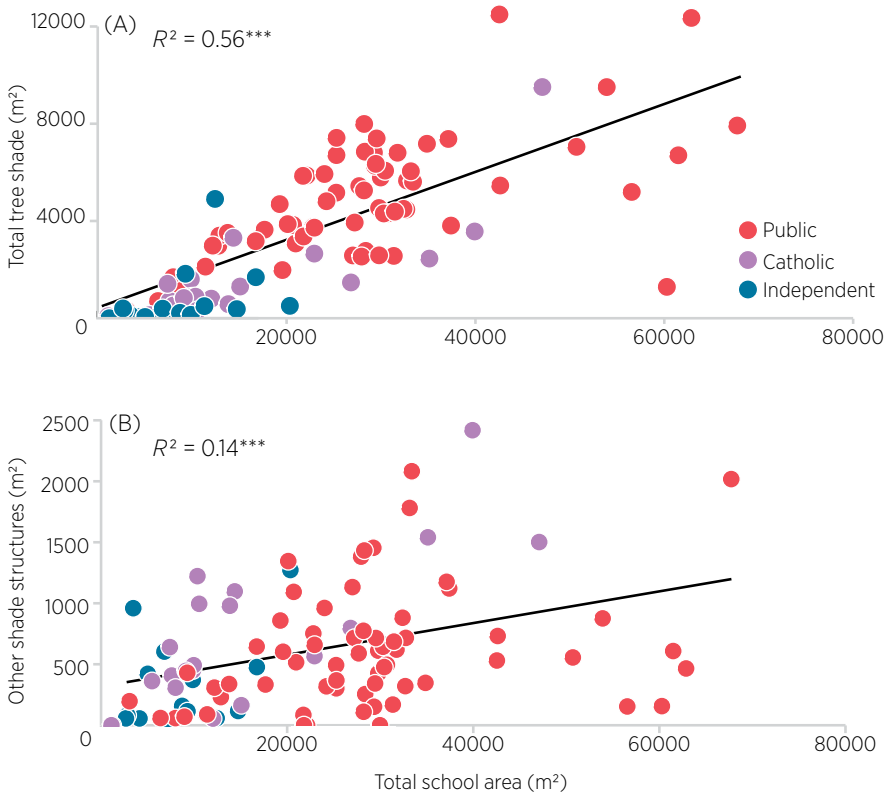
The importance to consider both, total existing canopy area in square meters and the relative area of tree canopy in a school becomes obvious when looking at both panels of Figure


A
B
Prestons Public School
Rooty Hill High School
St Pauls Catholic College
Penrith High School
Liverpool West Public School
Ambarvale High School
Villawood North Public School
Prairievale Public School
Marayong Public School
Chifley College Senior Campus
James Busby High School
St Marys North Public School
James Meehan High School
Chester Hill Public School
Blacktown West Public School
Lurnea High School
The Grange Public School
Heckenberg Public School
Smithfield Public School
Hoxton Park Public School
Nuwarra Public School
Fairfield Heights Public School
Fairfield Public School
Camden South Public School
Colyton Public School
Governor Philip King Public School
Liverpool Boys High School
Canley Heights Public School
William Stimson Public School
Westfields Sports High School
Canley Vale Public School
Key College - Merrylands Campus
Lidcombe Public School
Old Guildford Public School
Casula Public School
Liverpool Girls High School
Guildford West Public School
Marsden Road Public School
Fairfield West Public School
Lurnea Public School
Busby West Public School
Ingleburn Public School
Granville Public School
Bennett Road Public School
Fairvale Public School
Wiley Park Girls High School
Liverpool Public School
All Saints Catholic College (primary, Boys, Girls)
Penrith Public School
Lakemba Public School
Wentworthville Public School
Immaculate Heart of Mary School
Merrylands Public School
Cabramatta Public School
Merrylands East Public School
Granville Boys High School
Blaxcell Street Public School
Mary Immaculate Primary School
Sadleir Public School
Holroyd School
Ashcroft Public School
Rooty Hill Public School
Cerdon College
Liverpool Hospital School
Ropes Crossing Public School
Mainsbridge School
Eden College
Auburn Public School
Our Lady of Mercy College
Our Lady of Mount Carmel Primary School
St Catherine of Siena Primary School
St Peter Chanel Primary School
St Francis Xavier's School
The Ponds High School
Campsie Public School
St Paul's Catholic Primary School
St Aidan's Primary School
St Joachim's Primary School
Delany College
Holy Trinity Primary School
Bankstown Hospital School
Our Lady of Mount Carmel School
St Gertrude's Primary School
Richard Johnson Anglican School - Oakhurst Campus
St Euphemia College
Sydney Adventists School Auburn
Al-Faisal College - Campbelltown Campus
Australian Islamic College of Sydney
Fowler Road School
St Margaret Mary's Primary School
Aspect Western Sydney School
Bethel Christian School
St Bishoy Coptic Orthodox School
St Nicholas of Myra Primary School
Amety College - Auburn Campus
St Marys Flexible Learning Centre
Rissalah College
Al Amanah College - Liverpool Campus
Al-Faisal College
Warrakirri College
0
3000
6000
9000
12000
15000
Tree shade (m²)
0
10
20
30
40
Tree shade (%)
Public
Catholic
Independent

14. While the ranking of schools according to their total tree canopy cover is clear, the side-to-side comparison with the relative area covered by tree canopy brings out the fact that ranking low for total canopy area can still mean that 20% or more of the total area covered by the school is under canopy.

Similar to the relationship between the area covered by a school and the open space within that area, also the relationship between the area covered by a school and its total tree canopy cover was positive and statistically highly significant ($p < 0.001$) (Figure 15A). However, as depicted in Figure 15, the majority of Catholic and independent schools had a lower total tree canopy area than predicted – all, except three schools fall below the predicted relationship of the dependent (tree canopy) and independent (school area) variables. As shown in Figure 11, the total area of a school was a very strong predictor for the amount of open space, hence the area of tree canopy was also significantly and positively related to the area of open space ($R^2 = 0.53$, $p < 0.001$, figure not shown).

A clear exception to the general trend was The Ponds High School where tree canopy cover was very low (1,289 m^2) compared to the total area covered by the school (60,269 m^2). With 2.14 % tree canopy cover, this school is far below the average of 15% among all target schools. It is reasonable to expect that tree canopy cover is expanding over time as this school is relatively new (opened in 2015). We identified 84 individual trees at this school, representing the second highest number in this category. Only Rooty Hill High School had more individual trees (n = 90). However, with 5 tree clusters, the amount of tree groups at The Ponds High School was very low.



Although statistically highly significant, the relationship between the total area covered by a school and the area covered by other shade structures within school was quite weak (Figure 15B). This observation indicates that the amount of shade provided by manmade structures does not necessarily depend on the ground area of schools, whereas the area covered by trees does.

FIGURE 15: Relationship between the total area covered by a school and the total area of tree canopies providing shade (A) and the area covered by non-tree shade structures (B). Solid lines indicate best-fit functions. The coefficient of determination (R^2) is presented and the statistical strength of the relationship is indicated by asterisks (*** indicate that $p<0.001$). The school type is indicated by colour.

FIGURE 14 (opposite page): Ranking of target schools according to the total area of tree canopy cover (Panel A). Also shown is the relative total tree canopy cover, which represents the proportion of area covered by tree canopies of the total area of the school ground (Panel B). The school type is indicated by colour.

Analyses of partial canopy cover revealed that once the area of a school decreases, the relative proportion of partial tree canopy cover will increase (Figure 16). The strong positive relationship between the area covered by a school and available open space (see Figure 11) helps explaining this result. As the area of available open space declines, it becomes increasingly likely that trees will be pushed towards the outer boundary of schools. Planting trees along fence lines is one strategy to retain some open space for school yards, sports fields or playgrounds that receive direct sunshine. However, trees planted near fence lines have a greater risk of removal due to physical damage of fences, conflicts with other build infrastructure, power lines, public safety or other issues. For smaller schools, this means that any existing tree canopy cover is at greater risk of being lost compared to larger schools that can plant and grow trees further away from fence lines.

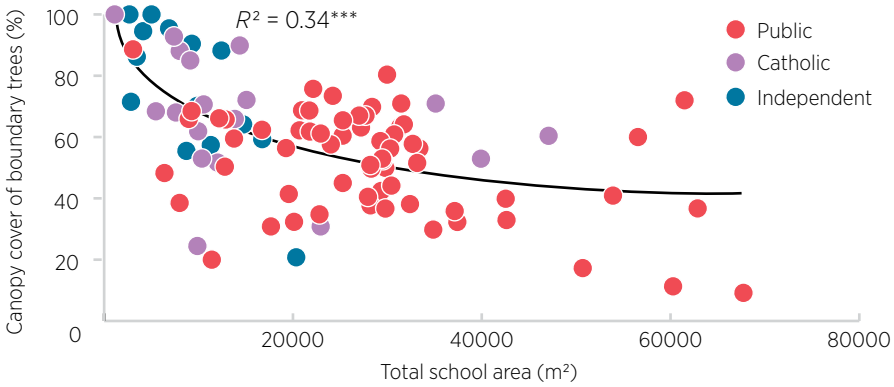


FIGURE 16: Relationship between the total area covered by a school and its proportion of tree canopy that only partially covers the school grounds. Partial canopy cover was calculated as sum of partial canopy cover of individual trees and that of tree clusters. The solid line indicates the best-fit function. The coefficient of determination (R^2) is presented and the statistical strength of the relationship is indicated by asterisks (*** indicate that $p<0.001$). The school type is indicated by colour.

We found no clear relationship between tree canopy cover and the Heat Score for the target schools (Figure 17A). This was not surprising as the Heat Score was calculated using parameters that were not directly related to individual schools, rather than entire surrounding suburbs and their communities. However, the data indicate that there is a 'cap effect' of tree canopy cover. The black line in Figure 17A indicates this effect, where more than 90% of target schools fall below this line and only a very small number of schools remain above the line. The capping effect indicates that it is very unlikely for a school with a large canopy area to also have a high Heat Score.

The six schools above this line had higher tree canopy cover than anticipated for their Heat Score. Five of these schools were in the Liverpool area (postcode 2170) and one in Fairfield (postcode 2165). Both areas were previously identified as those with high vulnerability to heat (see Figures 3 and 4). The general trend among these six schools remain, indicating that schools with higher tree canopy cover will have a lower Heat Score. No relationship between the Heat Score and the relative tree canopy area was found (Figure 17B).

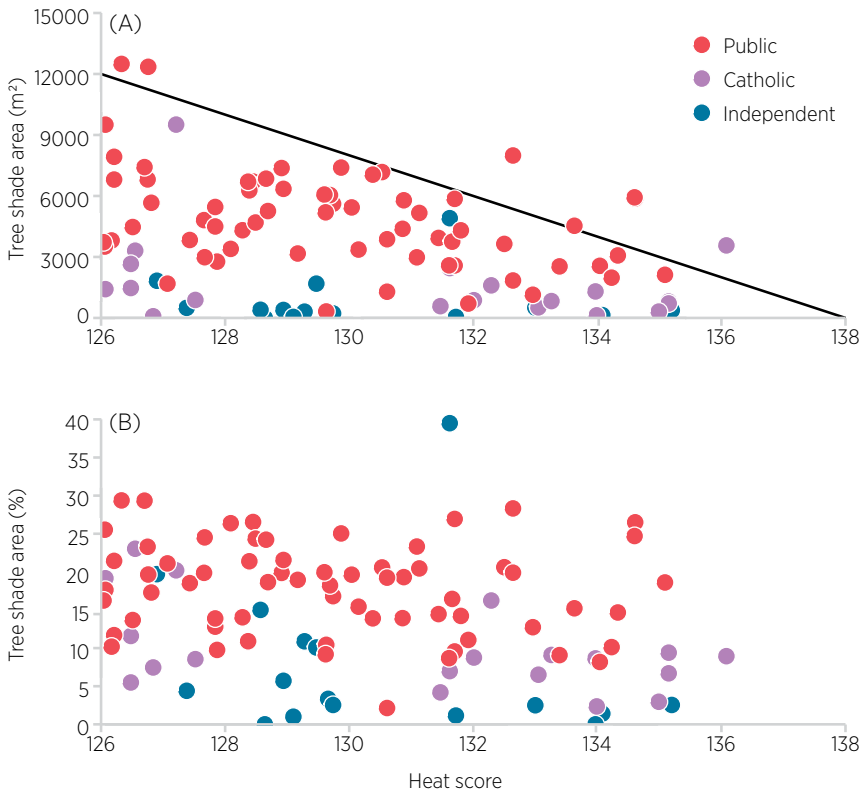


FIGURE 17: Relationship between the Heat Score and tree shade area in square meters (Panel A) and the relative area covered by trees in relation to the total area of the school (Panel B). The black line in Panel A indicates a 'capping effect' of tree canopy on the Heat Score – the tendency of higher tree canopy resulting in a lower Heat Score. The school type is indicated by colour.

A complete correlation analysis was done to identify if any of the heat-related environmental and socio-economic parameters used to identify the target schools (T_{air}, UHI, Heat Score) could be used to explain the variation in the measured categories 3-8 individually or in combination. The three dependent variables and 11 independent variables for this analysis are shown in Table 2.

TABLE 2: List of independent and dependent variables used in the correlation analyses.

VARIABLE #	INDEPENDENT VARIABLE	DEPENDENT VARIABLE
1	Area of complete canopies	T_{air}
2	Area of incomplete tree canopies	UHI
3	Area of complete tree clusters	Heat Score
4	Area of incomplete tree clusters	
5	Area covered by manmade structures (non-COLA)	
6	Area covered by COLA	
7	Sum of all tree canopies	
8	Sum of all tree clusters	
9	Sum of all canopies	
10	Sum of all manmade shade structures	
11	Sum of all shade structures	

The resulting 33 relationships did not yield very strong correlation coefficients. The highest coefficients were around 0.2, indicating that the dependent variable helped explaining 20% of the variation in the independent variable. However, the three highest scoring correlations were those between variables 7, 8 and 11 and the UHI, indicating that indeed a greater tree canopy cover and more shade can reduce the Urban Heat Island effect at a local level. All three correlations were negative and highly significant ($p < 0.001$).

23 of the 33 relationships had correlation coefficients smaller than 0.1, yielding very weak or no relationships at all. Although it is remarkable that the cooling effect of shade and tree canopy cover on UHI is detectable at this scale, results of the analysis clearly showed that there was not a strong relationship between the apparent summer temperatures or vulnerability to heat and the area of any type of shade cover provided in the target schools. This result clearly documents that in the target schools, shade management is currently not related to predominant environmental conditions during summer and does not reflect the high vulnerability of local communities to heat. This can certainly be improved, providing immediate cooling benefits to schools, but also thermal and biodiversity improvements to the surrounding landscape.

5. CONCLUSIONS AND RECOMMENDATIONS

The intention of this project was to identify the 100 schools in Greater Western Sydney with the greatest vulnerability to heat and to determine their cover of tree canopy. The results of our remote analysis provides an improved level of understanding how much and in what form shade is provided in school across this region.

Tree canopy cover in the target schools varied widely between 0 and 40%. On average, schools provided 3,600 m^2 tree canopy cover, which represents 15% of the area covered by the school. Only two of the 100 schools did not have an open area and thus no tree canopy. The majority (58%) of tree canopy was provided by the canopies of individual or groups of trees that were only partially covering the school grounds. Among Catholic and independent schools, this area of shade provided by these 'boundary trees' increased to 78%, while at public schools it declined to 52%. These observations indicate that it is more likely to have large mature and complete tree canopies that can provide maximum shade and cooling in public schools.

The most schools with high vulnerability to heat were located in the Local Government Areas of Liverpool, Fairfield and Cumberland Councils in Sydney's central and south western region. Within that region, the schools with the least tree canopy cover were both Catholic and independent schools. We were able to establish a causal relationship between the area covered by a school and the area within the school being covered by trees. While effective tree canopy cover increases simultaneously with the area covered by the school, the relative area covered by trees will be higher in schools that cover less ground area. Correlation analyses provided strong evidence that an increase of tree canopy cover will help reduce local Heat Island effects.

5.1 SMALL SCHOOLS

Importantly, once a school area decreases, trees are predominately growing along (inside or outside) the outer boundary of schools. In this location, canopy cover provided by individual trees or groups of trees will only provide partial shade cover for the school. Any shade provided by trees along fence lines, walls or other boundary structures are at greater risk of being removed, compared to individual and groups of trees that grow entirely inside the boundary of schools. The greater risk arises from conflicts specific to these locations and can include mitigation of property damage, provision of public safety, development outside the school, and so on. Careful assessment of each individual situation in those schools with a high number of boundary trees are necessary to develop effective strategies to increase their tree canopy cover.

Successful strategies must incorporate tree height and canopy architecture at maturity, tendency to develop surface roots and tolerance of shade. The latter will be particularly important when young trees are planted among mature trees to form a subdominant canopy layer that over time will grow into the dominant canopy layer. This process is supported by gradually opening up the overstorey canopy through incremental removal of mature and over-mature trees. This approach will provide the greatest chance to retain a continuous canopy cover and valuable shade to schools that cover a small area and have a high dependency on boundary trees due to limited availability of open space.

5.2 LARGE SCHOOLS

As the area covered by a school increases, so does the area of open space. From a tree planting perspective, this means greater opportunity. However, open space at schools may already be assigned to uses that will not allow introducing new trees. Examples are sport fields, tennis courts or carparks. However, it is necessary to note that spacious schools tend to have more tree canopy already, with the exception of The Ponds High School. This is shown in the positive relationship in Figure 15A.

In reality the amount of tree canopy cover in larger schools, arbitrarily defined here as those that cover more than 20,000 m^2, is better assessed using relative cover, rather than effective size. Reason for this is that the area covered by large schools can vary enormously from 2 to more than 6 hectares. An example clarifies the need for this approach. Ambarvale High School and Prairievale Public School have 7,900 and 7,400 m^2 tree canopy cover, respectively. While this represents a high 25% tree canopy cover at Prairievale which covers 28,000 m^2 ground, it only represents around 12% at Ambarvale with covers 67,000 m^2. Consequently, successful canopy expansion strategies for both schools will vary as opportunity – the available area for additional planting – will markedly differ.

We recommend that tree plantings at larger schools follow a dual approach:

1. Predominately plant new trees in clusters inside the school grounds
2. Infill planting of boundary trees

This approach will provide the greatest cooling and shading benefits on school grounds that were previously unshaded. The effectiveness of a single tree cluster compared to several individual trees is greater, and so are biodiversity and habitat benefits. Also, growing tree groves (or for that matter also individual trees) that are fully contained within the boundary of the school will minimise the risk of tree removal as result of activities outside the boundary or damage to infrastructure. However, if ornamental trees like *Eucalyptus caesia* (native) or Jacaranda (exotic) is planted, line or row plantings instead of clusters will offer shading but also aesthetic benefits. Infill plantings of boundary trees should follow the same principles as outlined above for small schools.

5.3 GENERAL REMARKS

In previous research, we showed that shading reduced surface temperatures in a schoolyard covered by bitumen by more than 20°C during summer (Pfautsch et al., 2020). Shading other surface materials decreased their temperature by 10-15°C. Shading reduces the amount of radiant heat which will generally increase human thermal comfort. It follows that the more surface area of a school is shaded,

especially where hard surfaces dominate, the more will the risk of heat-related illnesses and incidents during summer decline.
Many scientific studies have shown that trees help improve human thermal comfort (Sanusi et al., 2017), particularly when protecting hard surfaces from direct sunlight (Gillner et al., 2015). Introducing advanced trees into an unshaded school environment will provide the greatest cooling benefits over time (Antoniadis et al., 2016, 2018). Given the high frequentation of these areas within schools, it is necessary to select tree species that represent minimal risk of dropping green limbs, produce allergenic or poisonous materials, are free of thorns and spikes. Using a custom-designed tree species selection tool in a previous study (Pfautsch et al., 2020), we found that Jacaranda and Sweetgum as tall trees and Lilly Pilly, bottlebrushes, Queensland Brush Box or paperbarks as shorter trees worked well to meet a range of these criteria. In addition, and depending on the planting location, their crown architecture, water use, aesthetic appeal and educational value (e.g., deciduousness can be used to talk about seasons in the classroom) should be considered during the selection process.
Newly planted, but also existing trees should be watered/irrigated for best cooling benefits. Sufficient access to water will promote expansion of the canopy and shade over a larger area in less time. It will also support high rates of transpiration and associated air cooling. The required water can be provided from rainwater tanks that collect roof run-off. Smart, web-based technology can be used to optimise rainwater storage and water supply for trees. Tree watering activities can be a fun and educative activity that is incorporated in curricular activities or becomes part of tree adoption programs.
Every additional tree in schools of Greater Western Sydney (or any other school) will provide cooling benefits for our children in a warmer future. We owe the coming generations of school children access to heat- and UV-smart outdoor environments to support their capacity for learning and safe play.

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7. SCHOOL DATA

List 1: Target schools with their physical addresses, school type, mean maximum summer temperature (December-February 1989-2019; T_{summer}), urban heat island effect (UHI), Heat Vulnerability Index (HVI) and the Heat Score. Schools are listed alphabetically.

School name	Street	Suburb	Postcode	School type	T_{summer} (°C)	UHI (°C)	HVI (unitless)	Heat Score (unitless)
Al Amanah College - Liverpool Campus	55 Speed St	Liverpool	2170	Independent	26.50	9.33	5	131.7
Al-Faisal College	149 Auburn Rd	Auburn	2144	Independent	26.00	8.81	5	128.6
Al-Faisal College - Campbelltown Campus	10 Benham Rd	Minto	2566	Independent	25.50	9.04	5	128.9
All Saints Catholic College	53 Bigge St	Liverpool	2170	Catholic	26.50	10.29	5	136.1
Ambarvale High School	Thomas Rose Drive	Rosemeadow	2560	Public	24.50	8.77	5	126.2
Amety College - Auburn Campus	28 Kerr Parade	Auburn	2144	Independent	26.00	9.04	5	129.7
Ashcroft Public School	Sheriff St	Ashcroft	2168	Public	26.50	9.84	5	134.0
Aspect Western Sydney School	295 Victoria St	Wetherill Park	2164	Independent	26.50	8.78	5	129.3
Auburn Public School	Auburn Rd & Beatrice St	Auburn	2144	Public	26.00	8.46	5	127.1
Australian Islamic College of Sydney	33 Headcorn St	Mount Druitt	2770	Independent	27.50	9.77	5	135.2
Bankstown Hospital School	Paediatric Unit Gallipoli St	Bankstown	2200	Public	25.50	9.71	5	131.9
Bennett Road Public School	100-114 Bennett Rd	Colyton	2760	Public	28.00	7.59	5	126.2
Bethel Christian School	114 Mount Druitt Rd	Mount Druitt	2770	Independent	28.00	8.39	5	129.7
Blacktown West Public School	Lancaster St	Blacktown	2148	Public	27.00	8.43	5	128.5
Blaxcell Street Public School	352 Blaxcell Street	Granville	2142	Public	26.00	8.64	5	127.9
Busby West Public School	Starling St	Green Valley	2168	Public	26.50	9.26	5	131.4
Cabramatta Public School	Levuka St	Cabramatta	2166	Public	27.00	9.74	5	134.3
Camden South Public School	Hume Hwy	Camden	2570	Public	26.00	9.31	5	130.9
Campsie Public School	Evaline St	Campsie	2194	Public	25.00	10.10	5	133.0
Canley Heights Public School	Cambridge St	Canley Heights	2166	Public	26.50	8.95	5	130.0
Canley Vale Public School	Canley Vale Rd	Canley Vale	2166	Public	27.00	9.03	5	131.1
Casula Public School	De Meyrick Ave	Casula	2170	Public	26.50	9.75	5	133.6
Cerdon College	74 Sherwood Rd	Merrylands West	2160	Catholic	26.50	9.30	5	131.6
Chester Hill Public School	Proctor Pde	Chester Hill	2162	Public	26.00	8.27	5	126.2
Chifley College Senior Campus	67 North Parade	Mount Druitt	2770	Public	27.50	8.73	5	130.5
Colyton Public School	Nelson St	Mount Druitt	2770	Public	28.00	7.74	5	126.8
Delany College	40 Grimwood St	Granville	2142	Catholic	26.50	10.09	5	135.2
Eden College	63 Harold St	Macquarie Fields	2564	Independent	26.00	8.42	5	126.9
Fairfield Heights Public School	Station St	Fairfield	2165	Public	27.00	9.80	5	134.6
Fairfield Public School	68-82 Smart St	Fairfield	2165	Public	27.00	9.15	5	131.7
Fairfield West Public School	Palmerston Rd	Fairfield West	2165	Public	26.50	8.56	5	128.3
Fairvale Public School	Wolseley St	Fairfield	2165	Public	27.00	9.15	5	131.7

School name	Street	Suburb	Postcode	School type	T_{summer} (°C)	UHI (°C)	HVI (unitless)	Heat Score (unitless)
Fowler Road School	Cnr Fowler Rd & Matthew St	Merrylands	2160	Public	26.50	8.86	5	129.6
Governor Philip King Public School	Allambie Rd	Edensor Park	2176	Public	26.00	9.05	5	129.7
Granville Boys High School	14 Mary St	Granville	2142	Public	26.50	9.19	5	131.1
Granville Public School	Lena St	Granville	2142	Public	26.50	8.37	5	127.4
Guildford West Public School	Palmer St	Guildford West	2161	Public	26.50	8.17	5	126.5
Heckenberg Public School	Jindabyne St	Heckenberg	2168	Public	26.50	8.59	5	128.4
Holroyd School	Willara Ave	Merrylands	2160	Public	26.50	9.32	5	131.7
Holy Trinity Primary School	40 Grimwood St	Granville	2142	Catholic	26.50	10.09	5	135.2
Hoxton Park Public School	99 Pacific Palms Circuit	Hoxton Park	2171	Public	26.50	8.87	5	129.7
Immaculate Heart of Mary School	30 Proctor Parade	Sefton	2162	Catholic	26.00	8.34	5	126.6
Ingleburn Public School	Oxford Rd	Ingleburn	2565	Public	25.50	9.41	5	130.6
James Busby High School	Brolga Cresc	Green Valley	2168	Public	26.50	9.03	5	130.4
James Meehan High School	Harold St	Macquarie Fields	2564	Public	26.00	8.39	5	126.8
Key College - Merrylands Campus	98 Kenyons Rd	Merrylands	2160	Independent	26.50	9.30	5	131.6
Lakemba Public School	Alice St	Lakemba	2195	Public	25.50	8.85	5	128.1
Lidcombe Public School	Mills Street	Lidcombe	2141	Public	26.00	8.59	5	127.7
Liverpool Boys High School	18 Forbes Street	Liverpool	2170	Public	26.50	8.47	5	127.8
Liverpool Girls High School	Forbes St	Liverpool	2170	Public	26.50	8.47	5	127.8
Liverpool Hospital School	Elizabeth St	Liverpool	2170	Public	26.50	10.07	5	135.1
Liverpool Public School	Railway Street	Liverpool	2170	Public	26.50	9.50	5	132.5
Liverpool West Public School	79-81 Hoxton Park Rd	Liverpool	2170	Public	26.50	9.53	5	132.6
Lurnea High School	2 Hillview Parade	Lurnea	2170	Public	26.50	8.58	5	128.4
Lurnea Public School	West & Reilly Sts	Lurnea	2170	Public	26.50	9.34	5	131.8
Mainsbridge School	Flowerdale Rd	Liverpool	2170	Public	26.50	9.53	5	132.6
Marayong Public School	Davis Rd	Blacktown	2148	Public	27.00	8.54	5	128.9
Marsden Road Public School	363 Garfield Road West	Marsden Park	2765	Public	26.50	9.13	5	130.9
Mary Immaculate Primary School	50 Emerald Dr	Eagle Vale	2558	Catholic	27.00	8.00	5	126.5
Merrylands East Public School	Myee St	Merrylands	2160	Public	26.50	8.43	5	127.7
Merrylands Public School	Fowler Rd	Merrylands	2160	Public	26.50	8.76	5	129.2
Nuwarra Public School	McKay Ave	Moorebank	2170	Public	26.50	9.97	5	134.6
Old Guildford Public School	Woodville Rd	Guildford	2161	Public	26.50	8.61	5	128.5
Our Lady of Mercy College	6 Victoria Rd	Parramatta	2150	Independent	26.50	8.83	5	129.5
Our Lady of Mount Carmel Primary School	4 Bennett St	Wentworthville	2145	Catholic	26.50	9.45	5	132.3
Our Lady of Mount Carmel School	230 Humphries Rd	Bonnyrigg	2177	Catholic	26.50	9.27	5	131.5
Penrith High School	158-240 High St	Penrith	2750	Public	28.50	7.40	5	126.1

School name	Street	Suburb	Postcode	School type	T_{summer} (°C)	UHI (°C)	HVI (unitless)	Heat Score (unitless)
Penrith Public School	51 High St	Penrith	2750	Public	28.50	7.40	5	126.1

School name	Street	Suburb	Postcode	School type	T_{summer} (°C)	UHI (°C)	HVI (unitless)	Heat Score (unitless)
Prairievale Public School	Prairievale & Mimosa Rds	Bossley Park	2176	Public	26.50	8.92	5	129.9
Prestons Public School	Kurrajong & Box Rds	Prestons	2170	Public	26.50	8.13	5	126.3
Richard Johnson Anglican School - Oakhurst Campus	93 Hyatts Rd	Oakhurst	2761	Independent	27.50	9.28	5	133.0
Rissalah College	72 Hampden Rd	Lakemba	2195	Independent	25.00	9.24	5	129.1
Rooty Hill High School	54 North Parade	Rooty Hill	2766	Public	27.50	7.89	5	126.8
Rooty Hill Public School	Westminster St	Rooty Hill	2766	Public	27.50	9.37	5	133.4
Ropes Crossing Public School	Pulley Drive	Ropes Crossing	2760	Public	28.00	9.39	5	134.2
Sadleir Public School	Insignia St	Sadleir	2168	Public	26.50	9.30	5	131.6
Smithfield Public School	O Connell St	Smithfield	2164	Public	26.50	8.86	5	129.6
St Aidan's Primary School	5 Adelaide St	Rooty Hill	2766	Catholic	27.50	9.06	5	132.0
St Bishoy Coptic Orthodox School	59 Methven St	Mount Druitt	2770	Independent	27.50	9.52	5	134.1
St Catherine of Siena Primary School	58 Dalmeny Dr	Prestons	2170	Catholic	26.00	10.55	4	126.5
St Euphemia College	202 Stacey St	Bankstown	2200	Independent	25.50	8.69	5	127.4
St Francis Xavier's School	71 Webster Rd	Lurnea	2179	Catholic	26.50	9.83	5	134.0
St Gertrude's Primary School	11 Justin St	Smithfield	2164	Catholic	26.50	9.62	5	133.1
St Joachim's Primary School	7 Mary St	Lidcombe	2141	Catholic	26.00	9.84	5	133.3
St Margaret Mary's Primary School	7 Chetwynd Rd	Merrylands	2160	Catholic	26.50	10.05	5	135.0
St Marys Flexible Learning Centre	63 Forrester Rd	St Marys	2760	Catholic	28.00	9.97	4	126.8
St Marys North Public School	24-40 Willow Road	North St Marys	2760	Public	28.00	8.15	5	128.7
St Nicholas of Myra Primary School	28 Higgins St	Penrith	2750	Catholic	28.50	9.16	5	134.0
St Paul's Catholic Primary School	20 Mitchell St	Camden	2570	Catholic	26.00	8.56	5	127.5
St Pauls Catholic College	198 Old Prospect Rd	Greystanes	2145	Catholic	26.50	8.32	5	127.2
St Peter Chanel Primary School	43 Regent St	Regents Park	2143	Catholic	25.50	8.40	5	126.1
Sydney Adventists School Auburn	3 Macquarie Rd	Auburn	2144	Independent	26.00	8.79	5	128.6
The Grange Public School	8 Benham Road	Minto	2566	Public	25.50	9.04	5	128.9
The Ponds High School	180 Riverbank Drive	The Ponds	2769	Public	27.50	10.97	4	130.6
Villawood North Public School	Bligh St	Fairfield East	2165	Public	26.50	8.21	5	126.7
Warrakirri College	3 Hamilton Rd	Fairfield	2165	Independent	27.00	9.66	5	134.0
Wentworthville Public School	70-100 Fullagar Road	Wentworthville	2145	Public	26.50	8.98	5	130.2
Westfields Sports High School	406A Hamilton Road	Fairfield West	2165	Public	26.50	8.86	5	129.6
Wiley Park Girls High School	The Boulevarde	Punchbowl	2196	Public	25.50	8.40	5	126.0
William Stimson Public School	Lily St	Wetherill Park	2164	Public	26.50	8.65	5	128.7

LIST 2: Target schools and their total area, the area covered by buildings, open space, all shade structures, manmade shade structures, the total area of tree canopies, that of tree clusters and individual trees. Schools are listed alphabetically.

School name	School area (m^2)	Building area (m^2)	Open space (m^2)	Total shade (m^2)	Manmade shade (m^2)	Total tree shade (m^2)	Tree clusters (m^2)	Individual trees (m^2)
Al Amanah College - Liverpool Campus	4129.4	2757.9	1369.0	103.2	55.9	47.3	7.8	39.6
Al-Faisal College	6801.8	6197.9	603.8	603.7	603.7	0.0	0.0	0.0
Al-Faisal College - Campbelltown Campus	6873.8	3191.2	3664.7	392.8	0.0	392.8	299.5	93.3
All Saints Catholic College (primary, Boys, Girls)	39916.1	15531.8	22705.1	5986.7	2418.6	3568.1	3094.0	474.1
Ambarvale High School	67723.4	12649.7	47874.8	9943.8	2018.0	7925.8	7129.6	796.3
Amety College - Auburn Campus	3458.1	1237.2	2204.9	1075.1	959.6	115.5	99.6	15.9
Ashcroft Public School	31351.5	6053.4	24356.7	2733.1	169.4	2563.7	1769.4	794.3
Aspect Western Sydney School	2839.7	956.8	1794.8	390.2	81.0	309.2	230.0	79.3
Auburn Public School	7993.4	2624.2	4331.8	1745.5	58.4	1687.1	1552.3	134.8
Australian Islamic College of Sydney	14725.8	6511.2	8080.4	490.8	116.8	374.0	273.9	100.1
Bankstown Hospital School	6385.6	2979.9	3040.0	766.1	59.3	706.8	526.5	180.2
Bennett Road Public School	37411.7	6595.5	28236.0	4932.4	1121.4	3811.0	3262.0	549.0
Bethel Christian School	8710.8	3823.6	4788.7	380.0	158.6	221.4	135.2	86.2
Blacktown West Public School	25277.7	6342.4	15245.7	7012.5	302.7	6709.9	6322.1	387.8
Blaxcell Street Public School	28381.4	7139.6	20405.8	3026.4	255.5	2770.9	2742.5	28.3
Busby West Public School	27208.9	6445.9	19312.0	4651.6	716.1	3935.5	3840.5	94.9
Cabramatta Public School	20961.3	5746.6	14253.5	3590.4	516.2	3074.2	2979.2	95.0
Camden South Public School	29969.3	6768.1	22064.9	5787.1	0.0	5787.1	5616.5	170.6
Campsie Public School	8960.1	4492.2	4079.0	1211.4	70.1	1141.4	1078.0	63.4
Canley Heights Public School	27685.1	7418.1	18473.4	6025.1	589.2	5435.9	5435.9	0.0
Canley Vale Public School	25258.3	8763.0	14452.7	5657.8	493.0	5164.7	4904.1	260.6
Casula Public School	29784.4	8009.8	19506.3	5145.5	611.5	4534.0	4370.5	163.4
Cerdon College	35120.7	11822.8	22584.8	3993.4	1540.6	2452.8	2108.6	344.2
Chester Hill Public School	31748.7	6997.3	22310.3	7426.4	619.9	6806.4	6639.1	167.3
Chifley College Senior Campus	34861.5	11000.2	18824.8	7523.3	347.4	7176.0	6961.4	214.6
Colyton Public School	32752.9	7537.8	22823.9	6380.5	716.2	5664.4	5485.1	179.3
Delany College	12029.0	5462.3	6177.4	859.9	54.7	805.2	742.3	62.9
Eden College	9288.5	2972.0	6141.4	1944.1	114.6	1829.5	1722.4	107.1
Fairfield Heights Public School	22143.1	7379.2	13338.8	5868.7	0.0	5868.7	5735.0	133.6
Fairfield Public School	21740.0	6834.5	13069.5	5941.5	84.9	5856.6	5726.3	130.2
Fairfield West Public School	30719.8	7736.0	21294.6	4809.6	495.9	4313.7	3953.8	359.9
Fairvale Public School	22810.5	6319.5	14044.6	4503.8	752.5	3751.3	3674.3	77.0
Fowler Road School	3057.6	1132.6	1888.6	516.1	197.3	318.9	305.7	13.2
Governor Philip King Public School	33390.4	6500.9	24434.9	7696.9	2082.5	5614.4	5294.8	319.5
Granville Boys High School	12785.6	5415.6	5888.8	3223.1	241.3	2981.9	2748.6	233.2
Granville Public School	20699.1	5139.8	14109.7	4927.2	1093.4	3833.8	3677.5	156.3
Guildford West Public School	32692.6	5629.1	25175.2	4792.4	320.6	4471.8	4448.2	23.6
Heckenberg Public School	29337.8	4693.1	21031.0	6426.6	151.5	6275.0	6184.8	90.2
Holroyd School	27012.5	10176.7	15983.9	3714.6	1132.5	2582.1	2248.0	334.2
Holy Trinity Primary School	7600.3	1928.8	5443.0	1121.7	407.4	714.2	485.8	228.5
Hoxton Park Public School	33159.5	5846.9	24384.4	7826.7	1781.4	6045.3	5831.0	214.3

School name	School area (m^2)	Building area (m^2)	Open space (m^2)	Total shade (m^2)	Manmade shade (m^2)	Total tree shade (m^2)	Tree clusters (m^2)	Individual trees (m^2)
Immaculate Heart of Mary School	14363.3	5281.7	8746.5	4405.7	1097.4	3308.3	3166.7	141.6
Ingleburn Public School	20115.8	4791.0	12705.6	5216.9	1345.7	3871.2	3036.2	834.9
James Busby High School	50698.4	8420.4	36445.2	7604.6	555.7	7048.8	5067.5	1981.3
James Meehan High School	29260.1	6858.8	19585.9	8268.3	1454.7	6813.6	5591.0	1222.6
Key College - Merrylands Campus	12422.3	2513.3	9330.8	4965.4	58.0	4907.4	4660.9	246.4
Lakemba Public School	12872.9	2700.6	9007.9	3627.0	230.5	3396.5	3190.0	206.5
Lidcombe Public School	24221.4	6833.7	16110.3	5131.1	319.1	4812.0	3880.1	931.9
Liverpool Boys High School	42622.0	7411.6	31549.5	6189.8	731.6	5458.3	4023.5	1434.8
Liverpool Girls High School	32397.5	6717.5	22896.7	5380.2	881.3	4499.0	3414.2	1084.8
Liverpool Hospital School	11403.8	2854.6	6851.2	2211.4	89.0	2122.4	1092.4	1030.0
Liverpool Public School	17667.8	5445.3	9704.3	3975.1	333.7	3641.3	2369.8	1271.5
Liverpool West Public School	28214.4	6811.8	16424.9	8101.2	110.3	7990.9	7162.6	828.4
Lurnea High School	61482.5	7278.9	52326.3	7310.2	608.3	6701.8	6165.2	536.7
Lurnea Public School	30296.9	5567.8	22842.8	4952.3	643.5	4308.8	2671.7	1637.1
Mainsbridge School	9261.0	3828.6	4851.4	2272.2	430.2	1842.1	1200.8	641.3
Marayong Public School	37130.9	6245.3	26155.8	8549.6	1175.9	7373.7	5892.3	1481.4
Marsden Road Public School	31469.5	7514.4	22681.3	5069.4	685.5	4383.9	3307.5	1076.4
Mary Immaculate Primary School	22932.5	5828.2	15266.4	3224.0	566.6	2657.4	1293.5	1364.0
Merrylands East Public School	12181.0	3875.9	7293.2	3294.9	308.5	2986.4	2310.2	676.2
Merrylands Public School	16722.2	4424.6	11105.2	3813.8	644.9	3168.9	2043.5	1125.4
Nuwarra Public School	24010.3	5605.3	15889.7	6892.9	961.4	5931.5	5289.8	641.7
Old Guildford Public School	19267.2	3988.9	13231.8	5552.4	858.4	4694.0	3910.6	783.4
Our Lady of Mercy College	16739.5	7389.7	8663.3	2163.8	476.7	1687.1	912.6	774.5
Our Lady of Mount Carmel Primary School	9872.5	2874.0	5787.6	2053.3	450.3	1603.0	1245.3	357.7
Our Lady of Mount Carmel School	13839.0	5085.0	8556.5	1559.2	979.6	579.5	420.9	158.7
Penrith High School	53901.7	8013.5	40269.4	10383.1	875.9	9507.2	7921.8	1585.4
Penrith Public School	13759.3	4582.5	7754.9	3850.2	338.0	3512.2	2168.7	1343.5
Prairievale Public School	29534.2	4972.3	21046.4	8110.8	715.1	7395.7	6442.4	953.4
Prestons Public School	42536.8	7305.4	27719.9	13025.3	530.7	12494.6	11689.3	805.3
Richard Johnson Anglican School - Oakhurst Campus	20345.4	8250.4	11691.8	1781.4	1272.5	508.9	59.2	449.7
Rissalah College	5014.8	3353.7	1661.1	471.7	421.5	50.2	0.0	50.2
Rooty Hill High School	62870.6	7682.6	47372.1	12817.4	465.4	12352.0	9184.9	3167.1
Rooty Hill Public School	27943.4	5251.5	21183.0	3918.1	1382.2	2535.9	1199.2	1336.7
Ropes Crossing Public School	19558.7	6145.8	12252.7	2583.5	602.6	1981.0	1515.4	465.6
Sadleir Public School	29793.0	5559.6	22595.1	3013.0	426.3	2586.7	1050.2	1536.5
Smithfield Public School	30427.8	6673.4	20365.0	6546.9	477.0	6069.8	4092.4	1977.4
St Aidan's Primary School	9956.2	4288.7	5335.3	1363.8	492.0	871.8	514.1	357.8
St Bishoy Coptic Orthodox School	9852.8	4256.3	5555.1	510.5	371.7	138.8	26.9	111.9
St Catherine of Siena Primary School	26818.3	5536.2	20772.1	2268.5	797.1	1471.5	967.0	504.5
St Euphemia College	11294.2	5341.3	5741.1	583.9	86.8	497.2	211.6	285.6
St Francis Xavier's School	15076.6	4729.8	9983.2	1467.8	164.4	1303.4	899.0	404.4
St Gertrude's Primary School	8002.2	3928.9	4011.3	829.0	307.8	521.2	353.2	168.0

School name	School area (m^2)	Building area (m^2)	Open space (m^2)	Total shade (m^2)	Manmade shade (m^2)	Total tree shade (m^2)	Tree clusters (m^2)	Individual trees (m^2)
St Joachim's Primary School	9119.4	3517.5	5477.3	1274.9	445.4	829.4	652.1	177.4
St Margaret Mary's Primary School	10542.9	4461.1	5990.2	1307.3	995.4	311.9	0.0	311.9
St Marys Flexible Learning Centre	1109.9	467.0	642.9	82.8	0.0	82.8	45.5	37.2
St Marys North Public School	28288.4	4555.3	20287.2	8283.0	1432.4	6850.6	5779.2	1071.4
St Nicholas of Myra Primary School	5477.1	2081.2	3355.3	490.3	361.8	128.5	23.1	105.4
St Paul's Catholic Primary School	10354.2	2895.3	7042.8	2107.4	1222.3	885.1	392.9	492.2
St Pauls Catholic College	47081.5	9603.4	33712.6	11011.9	1501.9	9510.0	8276.1	1233.9
St Peter Chanel Primary School	7392.0	2641.6	4648.2	2056.9	640.7	1416.2	1341.6	74.6
Sydney Adventists School Auburn	2675.8	1045.8	1630.0	457.6	56.0	401.6	361.9	39.7
The Grange Public School	29446.8	4198.2	22261.3	6692.0	342.6	6349.5	4896.8	1452.7
The Ponds High School	60269.3	12699.8	46425.9	1446.1	156.8	1289.3	168.0	1121.3
Villawood North Public School	25288.6	3264.6	19461.0	7787.3	367.8	7419.5	6958.0	461.4
Warrakirri College	1230.6	1230.6	0.0	0.0	0.0	0.0	0.0	0.0
Wentworthville Public School	21795.4	5709.3	14801.1	3362.8	0.0	3362.8	3050.2	312.6
Westfields Sports High School	56548.8	13878.3	40592.5	5348.6	153.9	5194.7	4281.3	913.4
Wiley Park Girls High School	22943.7	5997.4	15498.9	4384.3	659.3	3725.0	2847.0	878.0
William Stimson Public School	28196.3	7395.5	18218.9	6032.7	774.5	5258.2	4368.6	889.6

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