Faculty of Science

The impact of trees on thermal comfort at playgrounds in Melbourne, Australia

Therese Carlstein

Degree of Bachelor of Science with a major in Earth Sciences
15 hec

Department of Earth Sciences
University of Gothenburg
2023 B-1223

UNIVERSITY OF GOTHENBURG

UNIVERSITY OF GOTHENBURG
Department of Earth Sciences
Geovetarcentrum/Earth Science Centre

The impact of trees on thermal comfort at playgrounds in Melbourne, Australia

Therese Carlstein

ISSN 1400-3821

B1223
Bachelor of Science thesis
Göteborg 2023

Mailing address	**Address**	**Telephone**	
Geovetarcentrum	Geovetarcentrum	031-786 19 56	Geovetarcentrum
S 405 30 Göteborg	Guldhedsgatan 5A		Göteborg University
			S-405 30 Göteborg
			SWEDEN

Abstract

Climate change causes warmer living conditions, especially in cities due to the urban heat island (UHI) effect. This increases the risk of heat stress, particularly among vulnerable groups like children. Trees have proven to be an effective way to mitigate heat stress, and the City of Melbourne has implemented this by their 'Urban Forest Strategy', developed to increase the number of trees in the city and improve the urban climate. The aim of this study was to investigate how trees impact the thermal comfort at playgrounds in Melbourne by examining i) how much shade was provided at the playgrounds, ii) how often heat stress could be experienced, and iii) how much more frequent it would be without trees. Three playgrounds were selected for the study and two scenarios were modeled during a warm summer day in the SOLWEIG model. One with the current number of trees and one where all the trees were removed. The results showed that the amount of shade was reduced once the trees were removed, which led to higher mean radiant temperatures (T_{mrt}) and thereby increased heat stress. The heat stress was generally higher in the afternoon, which implies that trees are especially important in the later part of the day. The playground located in the open area showed the highest heat stress, especially when the trees were removed, which implies that trees are more important in open areas than in dense areas, as the playground located in an area surrounded by high rise buildings showed no change of heat stress at midday for the two scenarios. However, the heat stress still increased during other parts of the day and trees should therefore not be excluded from densely built areas either. It was also found that the location of the trees is important to be able to provide shade at the right time of day. Two of the playgrounds had high shade cover in the afternoon, which resulted in significantly lower heat stress than at the third playground, which had lower shade cover. As the playgrounds might be more frequently visited in the afternoon, it could be concluded that it might be beneficial to plant more trees in the west. The result from this study can be used for planning more resilient and sustainable cities in the future.

Key words: Urban climate, Thermal comfort, Heath stress, Trees

Sammanfattning

Klimatförändringar bidrar till varmare levnadsförhållanden, speciellt i städer på grund av urban värmeö-effekten (urban heat island effect). Detta ökar risken för värmestress, i synnerhet för riskgrupper så som barn. Träd har bevisats vara effektiva för att mildra värmestress, och the City of Melbourne har implementerat detta genom sin ’Urban Skog Strategi’ (’Urban Forest Strategy’) för att öka antalet träd i staden och förbättra stadsklimatet. Syftet med den här studien har varit att undersöka hur träd påverkar den termiska komforten på lekplatser i Melbourne genom att granska i) hur mycket skugga som finns tillgänglig på lekplatserna, ii) hur ofta värmestress kan upplevas, och iii) hur mycket mer frekvent det skulle vara utan träd. Tre lekplatser valdes för studien och två scenarion modellerades för en varm sommardag i SOLWEIG modellen. Ett med nuvarande antal träd och ett där alla träd togs bort. Resultatet visade att mängden skugga minskade när träden togs bort, vilket ledde till högre mean radiant temperatures (T_{mrt}) och där med ökad värmestress. Värmestressen var generellt högre på eftermiddagen, vilket tyder på att träd är speciellt viktiga under den senare delen av dagen. Lekplatsen som var belägen i en öppen yta visade högst värmestress, speciellt när träden togs bort, vilket tyder på att träd är viktigare i öppna ytor än i tättbebyggda områden, då lekplatsen som var belägen i ett område med höghus inte visade någon förändring av värmestress mitt på dagen mellan de två scenarierna. Dock ökade värmestressen under andra delar av dagen och träd är därav fortfarande viktiga i tätbebyggda områden. Det konstaterades också att placeringen av träden var viktig för att de ska kunna ge skugga vid rätt tid på dagen. Två av lekplatserna hade högt skydd av skugga på eftermiddagen, vilket resulterade i väsentligt lägre värmestress än på den tredje lekplatsen, som hade lägre andel skugga. Eftersom lekplatser kan vara mer besökta på eftermiddagen, kan det konstateras att det skulle kunna vara mer fördelaktigt att plantera mer träd i väster. Resultatet från denna studie kan användas för att planera mer motståndskraftiga och hållbara städer i framtiden.

Nyckelord: Urbant klimat, Termal komfort, Värmestress, Träd

Table of Contents

List of figures and tables

Abbreviations

Artplay – Birrarung Marr Artplay, playground

CDSM – Canopy digital surface model

D – Diffuse irradiance, part of incoming shortwave irradiance that is scattered

DEM – Digital elevation model

DSM – Digital surface model

Flagstaff – Flaggstaff Gardens playground

K – Shortwave radiation,

$K_{\uparrow}$ – Shortwave reflectance

$K_{\downarrow}$ – Shortwave irradiance/mean global irradiance

L – Longwave radiation

NaturePlay – NaturePlay playground Royal Park

Pp – Percentage points

PET – Physiological Equivalent Temperature

QGIS – Geographical information system program, free and open source

S – Direct irradiance, part of shortwave irradiance that comes directly from the sun

SOLWEIG – Solar and Longwave Environmental Irradiance Geometry model, QGIS model within the UMEP plugin

SVF – Sky view factor

T_{mrt} – Mean radiant temperature

UHI – Urban heat island

UMEP – Urban Multi-scale Environmental Predictor, QGIS plugin

WA – Wall aspect

WH – Wall height

1. Introduction

As climate change causes the Earth's climate to get gradually warmer, the need for adapting to the warmer living conditions is rising. Cities are especially affected by climate change due to the urban heat island (UHI) effect, a phenomenon where the cities experience warmer temperatures than the surrounding rural areas, mainly due to the urban infrastructure, like street canyon geometry, and surface materials with high albedo and emissivity (Heaviside et al., 2017; Ward et al., 2016; Mohajerani, 2017). This increases the risk of heat stress, especially among vulnerable groups like children and elderly (Bäcklin et al., 2021).

Children are vulnerable to heat as they experience a quicker rise in core temperature compared to adults, as well as having a weaker thermoregulation, which is mainly affected by their high body surface area to body mass ratio. Children also have lower sweat production than adults and have it harder cooling their bodies through evaporation. The risk of heat stress increases further when participating in physical activity at locations like playgrounds (Vanos et al., 2017), where they also might be exposed to the sun and heat for longer periods of time. According to Wallenberg et al. (2023) heat stress at preschools in Sweden will increase in the future, based on IPCC's climate change scenarios RCP 2.6, 4.5 and 8.5. It is therefore important to study countries with warmer climates to learn what strategies can be used to reduce heat stress.

One way to mitigate the UHI effect and reduce the risk of heat stress is through green infrastructure like trees, as they provide shade and cooling through evapotranspiration (Nuruzzaman, 2015). Trees both absorb and reflect solar radiation and lower the air temperature both under and in proximity of the tree (Coutts et al., 2016; Taleghani, 2018). A study by Vanos et al. (2017) showed that the risk of heat stress among children engaged in active play was significantly reduced in shaded areas of a playground. When adding more shade and vegetation to playgrounds in Wuhan, China, Huang et al. (2016) found that fewer cases of heat stress were reported, people stayed longer at the playground and the number of visitors increased by 80%.

A study by Coutts et al. (2016) showed that street trees could lower heat stress from very strong to strong, in Melbourne, Australia, during a heat event. The city of Melbourne has an 'Urban Forest Strategy' to adapt the city to climate change, where trees and other greening will be used to lower the inner-city temperature and reduce the UHI effect. Among other things, the goal is to increase the tree canopy covers from 22% to 40%, by 2040 (City of Melbourne, nd.).

This study aims to investigate how trees impact the thermal comfort at playgrounds in Melbourne. The change in shadow patterns as well as heat exposure during a warm summer day is modeled using the Solar and Longwave Environmental Irradiance Geometry model (SOLWEIG) to examine i) how much shade is provided at the playgrounds, ii) how often heat stress can be experienced, iii) how much more frequent it would be without trees. The objective is to gain a better understanding of how trees can be implemented when planning more resilient and sustainable cities in the future.

1.1 Radiation and mean radian temperature

One important component when modelling thermal comfort is radiation. The spatial diversity of radiation within an environment, for example the difference between sunlit and shaded places, results in different microclimates. The radiation effecting the microclimates are shortwave radiation (K) from the sun, also referred to as solar radiation, and longwave radiation (L), also known as thermal radiation, which is the radiation emitted within the Earth and atmospheric system (Oke, 2017). In surface radiation balance and microclimate applications, both K and L fluxes are analysed as incoming (↓) or outgoing (↑).

K can be described as shortwave irradiance (K↓) and upwelling shortwave flux (K↑). K↑ depends on the reflectance of a surface, while K↓ depends on the position of the sun in the sky in relation to the position on the Earth where an object is located, i.e., the longitude, latitude, and time of the day and year. Other influencing factors are the atmosphere's capacity to transmit and absorb K, and scattering and reflectance of radiation by clouds, sky and surrounding objects. K↓ can be divided into direct irradiance (S), which is the part of the shortwave irradiance that hits a surface directly from the sun, and diffuse irradiance (D), which is scattered in the atmosphere and arrives from all directions (Oke, 2017). The combined amount of direct and diffuse irradiation is referred to as global irradiance (SMHI, 2022).

To summarize the external radiative environment, mean radiant temperature (T_{mrt}) can be used (Oke, 2017). T_{mrt} can be described as the sum of "all long- and shortwave radiation fluxes that the human body is exposed to" (Bäcklin, 2021) and is an important parameter when measuring thermal comfort (Thorsson, 2014). T_{mrt} has a large spatial variation, even over short distances, mainly due to shadow patterns from buildings, trees and topography, but also because of the albedo, emissivity and heat capacity of the surrounding surface materials. T_{mrt} is generally the same as air temperature during the night, as there is no K↓, while during the day the T_{mrt} can be substantially higher than air temperature. At noon and early afternoon, the highest T_{mrt} can be measured in areas close to sunlit walls, due to high incoming S, reflected S and emitted L from the solar exposed surfaces. T_{mrt} can be both monitored or modelled using models like ENVI-met, RayMan or SOLWEIG (Thorsson, 2014).

2. Methods

2.1 Study area

Melbourne is the capital city of Victoria and the second biggest city in Australia, with a population of 4.9 million people. The city is located in the south eastern part of the country and has a temperate climate (Cdf) according to the Köppen-Geiger climate classification, with warm summers and no dry season (Mohammad Harmay et al., 2021; Bureau of Meteorology, nd.b). The warmest month of the year is January, with a mean daily maximum air temperature of 26°C, with a record high of 45.6°C in 1939. Melbourne has on average 7.8 days in January where the daily max temperature is 30°C or above, and 3.6 days where it is 35°C or above (Bureau of Meteorology, 2023). January also has the highest global solar exposure, with a daily mean of 24.3 MJ/m^2, with on average 9 hours of sunshine and an monthly average UV-index between 11 and 12, which is classified as 'extreme' by the Australian Bureau of Meteorology (Bureau of Meterology, nd.b; Bureau of Meteorology, nd.a; Bureau of Meteorology, 2023).

Three playgrounds in Melbourne city were selected for the study: Birrarung Marr Artplay, Flaggstaff Gardens playground and NaturePlay playground in Royal Park. These playgrounds were selected as they were all located in central Melbourne, had a fairly large size, were located different urban environments from each other and had the required data available (see section 2.4.1).

Birrarung Marr Artplay (henceforth in the report called Artplay) has an area of 1824 m^2 and is located by the river close to Flinders Street station, at the edge of the central business district (Figure 1). There are several trees and shade sails in place which cover parts of the playground. It is also located next to a wall of a building in the northern part of the playground (Figure 2A).

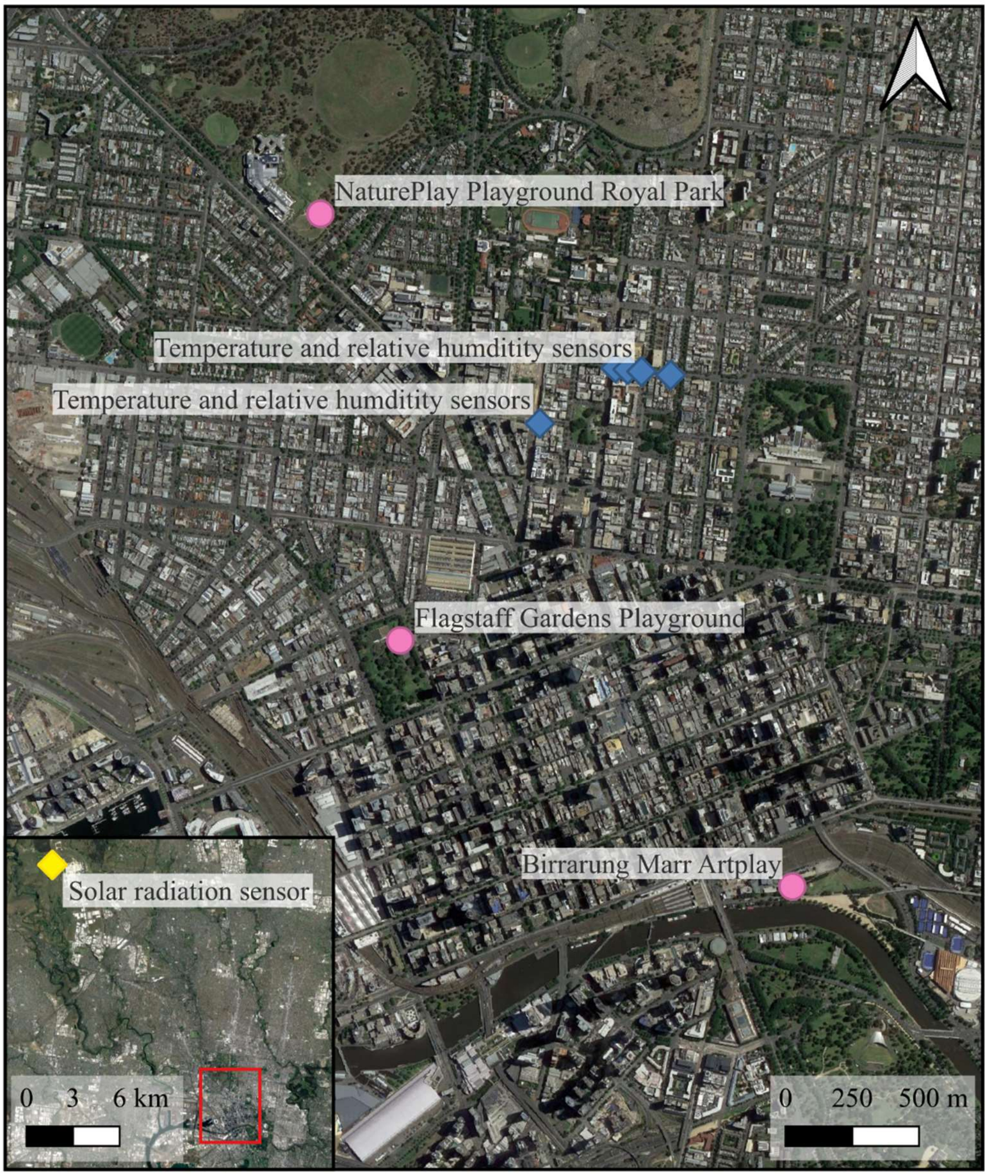

Figure 1. Map of central Melbourne, Australia, including the locations of the playgrounds (pink circles) and meteorological sensors (blue diamonds), as well as the solar radiation sensor location (yellow diamond) in relation to central Melbourne (red box).

Figure 2. Satellite pictures of A) Birrarung Marr Artplay, B) Flaggstaff gardens playground and C) NaturePlay playground Royal Park, with the trees included in the analysis mark in green (basemap Google satellite 2016).

Flaggstaff Gardens playground (henceforth in the report called Flagstaff) is the smallest playground of the study, with an area of 591 m^2. The playground is located in the corner of a park (Flagstaff gardens) in a densely built area in the city centre and is surrounded by several high rise buildings (Figure 1). There are some trees around and a couple covering a small part of the playground area (Figure 2B).

NaturePlay playground Royal Park (henceforth in the report called NaturePlay) is the biggest playground of the study, with an area of 2155 m^2. The playground is located further away from the city centre than the other two playgrounds, in the corner of a large park (Royal Park) next too Royal Children's Hospital (Figure 1). There are several trees surrounding the playground, mostly in the east, and some covering the playground area (Figure 2C).

2.2 Data

2.2.1. Meteorological data

The meteorological data were gathered from Melbourne Data – the City of Melbourne's open data platform. The air temperature and relative humidity data were measured at four stations at Grattan Street and one at Pelham Street (Figure 1), with readings made every 15 minutes. As no radiation data was available from Melbourne Data, the radiation data was gathered from the

Australian Bureau of Meteorology. The solar radiation was measured at a station at Melbourne Airport (Figure 1) and from this station mean global, mean direct and mean diffuse irradiance over one minute were collected.

The radiation data only had a temporal resolution until 2020, hence data from January 2020 was selected to get as recent data as possible from the middle of the summer. As the meteorological and radiation sensors were located at different locations (Figure 1) it was desirable to select a day with clear skies to get consistent readings. The daily mean global, direct and diffuse irradiance was plotted in Microsoft Excel and the 30th of January was then selected, as it was the day with both highest mean global and direct irradiance, and low diffuse irradiance, as can be seen in Figure 3. The air temperature of this day was also plotted to make sure that the radiation readings corresponded with a day with high air temperature. As the 30th of January 2020 had a high air temperature, with almost 40°C in the afternoon, 15:00-17:00 (Figure 4), it was determined that this day was suitable to use in the study.

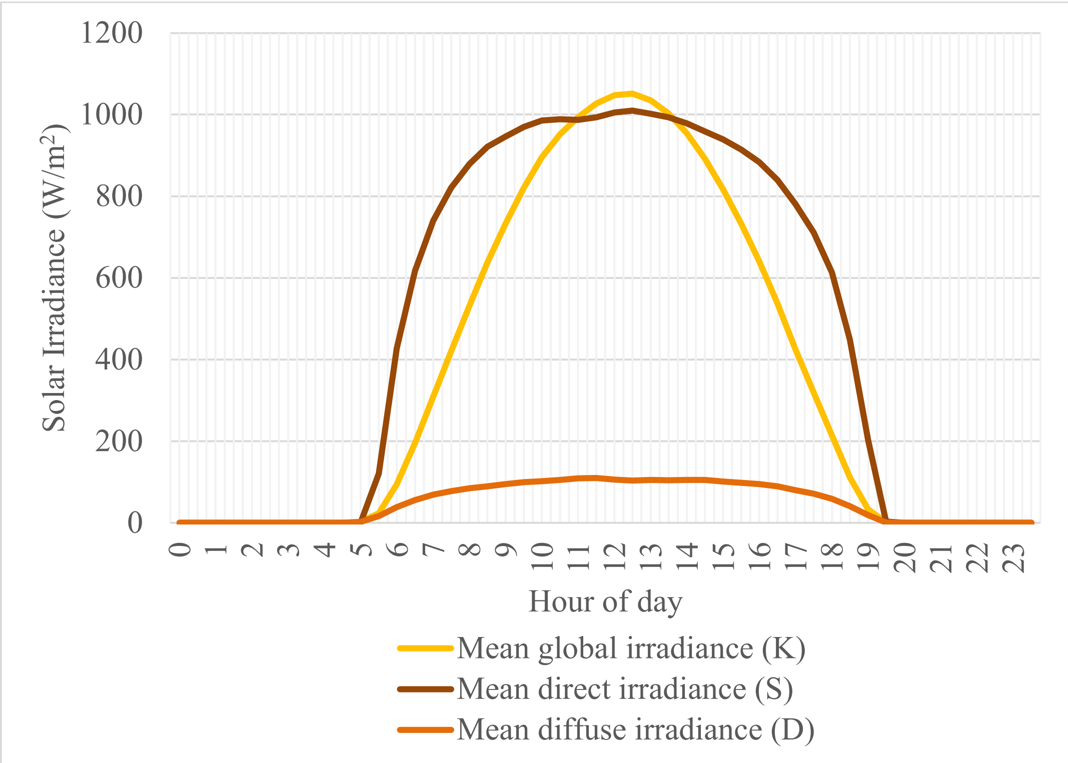

Figure 3. 30 min average of mean global irradiance ($K_{\downarrow}$), direct irradiance (S) and diffuse irradiance (D) for the day with highest radiation in January 2020 (the 30th of January), in Melbourne, Australia.

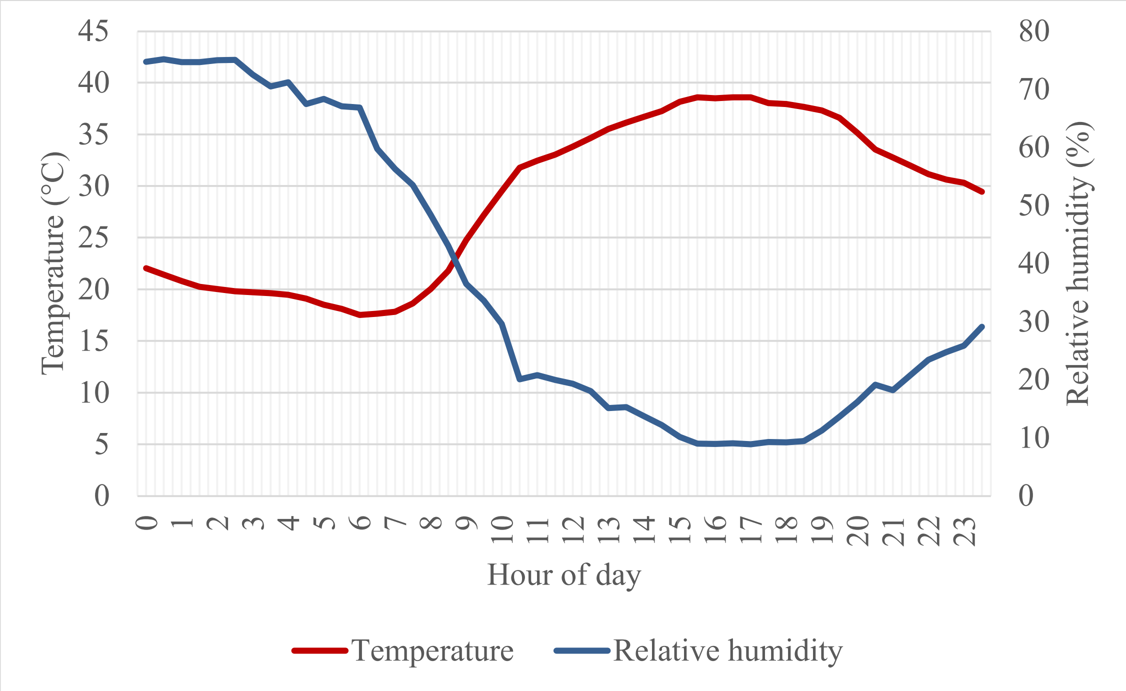

Figure 4. Diurnal profile of air temperature and relative humidity for the day with highest radiation in January 2020 (the 30th of January), based on 30 min mean, in Melbourne, Australia.

30 minute averages of the meteorological and radiation data were calculated in Microsoft Excel. The sunrise in Melbourne City the 30th of January 2020 was at 05:31 and the sunset at 19:36 (Geoscience Australia, nd.) and it was therefore only necessary to analyse the data within this timespan, as no radiation data is available when the sun is not up. Furthermore, only data between 08:00 and 18:00 were selected as it is most likely not many children visiting playgrounds outside these hours.

2.2.2. Spatial data

The spatial data were gathered from Melbourne city Open data. Playground polygons in Melbourne city from 2017, tree canopy polygons from 2019, building footprint polygons from 2020 and a building digital surface model (DSM) over Melbourne from 2018 were used in the analysis.

2.3 Spatial analysis

As the DSM contained both buildings and trees, a new DSM were created by removing the trees in QGIS. This was done using the tree canopy polygons, filling the area covered by the tree polygons with nan-values and then interpolating. A digital elevation model (DEM) was created from the DSM by removing both trees and buildings with tree canopy polygons and building footprint polygons. In the same way, a canopy digital surface model (CDSM) was created by removing buildings from the DSM and height via the DEM. For the polygon layers, a buffer of 2 meters for buildings and 1 meter for trees were used to make sure the polygon data covered all represented values in the DSM file. As the DSM, tree polygons and building polygons were based on data from different years due to lack of same-year databases, some editing of the polygons was done by hand, to make sure that these layers lined up with the DSM.

As no land cover data for the city of Melbourne was available, a land (ground) cover layer was made for each area surrounding the playgrounds, by georeferencing QGIS open street map.

2.4 Thermal comfort modelling

2.4.1. SOLWEIG

Solar and Longwave Environmental Irradiance Geometry model (SOLWEIG) is a model within the Urban Multi-scale Environmental Predictor (UMEP) plugin in QGIS which can be used to model thermal comfort by calculating radiation fluxes in urban settings (Lindberg et al., 2019; Lindberg et al., 2018).

The input data needed for the model is meteorological forcing data (relative humidity, air temperature and shortwave radiation) and spatial data (DSM and ground digital surface/DEM). Some optional data also includes vegetation/CDMS, land (ground) cover data and vegetation cover data. Based on these input data, the model calculates various parameters, most importantly wall height (WH), wall aspect (WA), i.e. geographical direction of the wall, and the sky view factor (SVF), which is the degree of sky visible at a certain point in the study area (Lindberg, 2018; Morakinyo et al., 2020; Azcarate et al., 2021). The output of the model is spatial variations of shadow patterns and T_{mrt} (Lindberg, 2018).

2.4.2. Modelling in UMEP

The meteorological and radiation data were prepared and run through the UMEP meteorological data pre-processor in QGIS, to make it fit the format required for SOLWEIG. The spatial data, DSM and CDSM were used to calculate SVF, WH and WA for the area surrounding the playgrounds. SOLWIEG was then run with the meteorological, radiation and spatial data for each playground to get T_{mrt} and shadow patterns for the selected day and time. To model the difference between scenarios with and without the trees, new SVFs were calculated where the CDSM was removed and SOLWEIG was run a second time for each playground with the new SVF and without the CDSM.

2.4.3 Post processing

UMEP post processing tool SOLWEIG analyser was used to calculate the average T_{mrt} between 08:00 and 18:00, and percent time of the day at which the T_{mrt} was above 56.5°C. Another post processing tool used was zonal statistics in QGIS, which was used to calculate the mean T_{mrt} and the mean shadow cover over the playground areas at the time of day when the global radiation was the highest, 12:30 (Figure 3), as well as four hours before and after, 08:30 and 16:30, to see how the T_{mrt} and shade changed during the day. Zonal statistics were also used to calculate the tree cover for each playground area.

2.5 Heat stress classification

To determine when and how intense heat stress could be experienced, the classification presented by Bäcklin et al. (2022) was used. The classification is based on a grade of physiological stress, measured in Physiological Equivalent Temperature (PET), by Matzarakis et al. (1999). PET is a thermal comfort index which accounts for the human energy balance and is calculated using meteorological parameters (air temperature, wind speed, humidity, T_{mrt}) and personal influencing factors (age, sex, hight, weight, activity, clothing) (Matzarakis et al.,1999; Thorsson et al., 2014; Azcarate et al., 2021). The classification was converted to T_{mrt} using a linear relationship between PET and T_{mrt} described by Lee et al. (2013):

$$\mathrm{PET} = 0.581 \cdot T_{mrt} + 8.2$$

Equation 1.

This gives the corresponding classifications of slight heat stress when $T_{mrt} > 25.5°C$, moderate heat stress when $T_{mrt} > 35.8°C$, strong heat stress when $T_{mrt} > 46.1°C$ and extreme heat stress when $T_{mrt} > 56.5$.

3. Results

3.1 Shade

All playgrounds showed a varying amount of shade during the day. The shadow patterns move from east to west throughout the day, with longer shadows in the morning and afternoon, and shorter at midday (Figure 5). Artplay was found to be the playground with the highest tree cover (67.4%), and also the playground with the most continuous shade cover throughout the day (Table 1). Flagstaff showed the highest shade cover in the afternoon (Table 1), despite having significantly less tree cover (10.3%) than Artplay. Further on, Flagstaff also had the lowest shading of the playgrounds during midday, with only 12.8% cover (Table 1). NaturePlay showed an opposite result, with the highest shading in the morning and the lowest in the afternoon (Table 1). Despite having the lowest tree cover among the playgrounds (3.6%), 29.9% of the playground was shaded at midday (Table 1).

Table 1. Average shading (%) at each playground during the morning, midday and afternoon, with and without trees. ΔShade is change in shade (percentage points, pp) when the trees are removed.

	ARTPLAY			**FLAGSTAFF**			**NATUREPLAY**		
TIME OF DAY	With trees	Without trees	ΔShade	With trees	Without trees	ΔShade	With trees	Without trees	ΔShade
08:30	75.5	15.8	-59.7	54.4	9.8	-44.6	84.8	3.8	-81.0
12:30	66.7	9.6	-57.1	12.8	0	-12.8	29.9	0.2	-29.6
16:30	87.6	22.1	-65.5	87.0	55.7	-31.3	20.4	3.1	-17.3

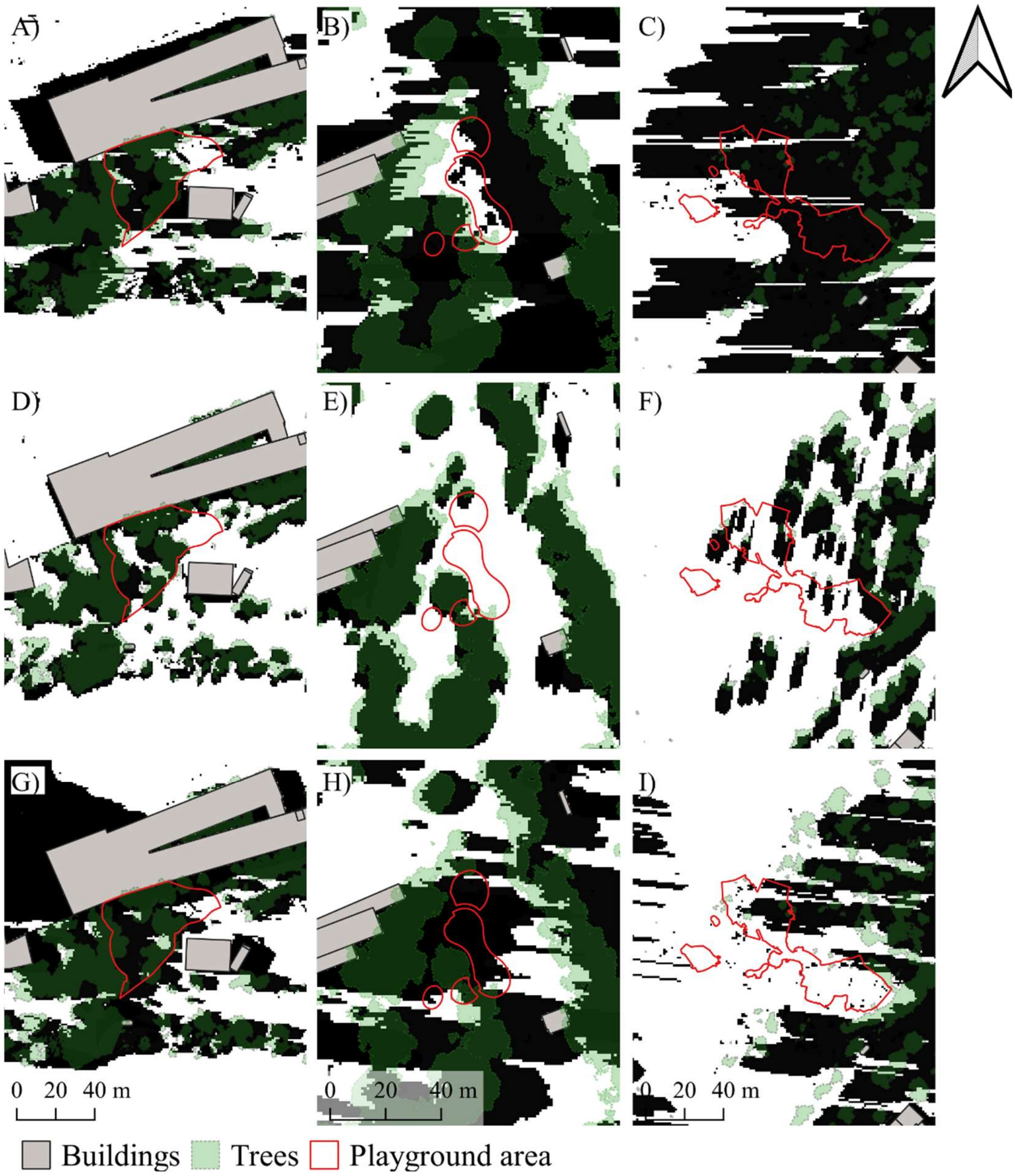

Figure 5. Shadow patterns (in black) at 08:30 (top row), 12:30 (middle row) and 16:30 (bottom row), at Birrarung Marr Artplay (left column), Flagstaff Gardens Playground (middle column) and NaturePlay Playground Royal Park (right column).

In the modelling scenario with all the trees removed, the shade cover was reduced at all playgrounds, visualized in Figure 6. The lowest shade cover was seen at midday, were Flagstaff and NaturePlay had an absence or almost complete absence of shade (Table 1). The biggest reduction of shade could be seen at NaturePlay in the morning, with 81 percentage points (pp) less shading (Table 1). NaturePlay was the playground that had the least amount of shade once the trees were removed, with around 3% shade both in the morning and in the afternoon, and 0.2% at midday (Table 1). Artplay was the playground which showed the biggest continuous reduction in shade in the scenario were the trees was removed, throughout all three times of day, but was still the playground with the highest amount of shade throughout all three times of day, except in the evening when Flagstaff had over half the playground area shaded (Table 1).

Even with the trees removed there was still over 55% shade at Flagstaff in the afternoon (Table 1), due to the building located northwest of the playground which provided shade in the afternoon (Figure 6H). Similarly, Artplay has a building located adjacent to the playground in the north to northwest (Figure 6G). Even though this building is closer to the playground than the one at Flagstaff, the shade cover was about 30% less in comparison (Table 1). This is due to the building at Flagstaff is higher (about 37 m high) than the one at Artplay (about 20 m high).

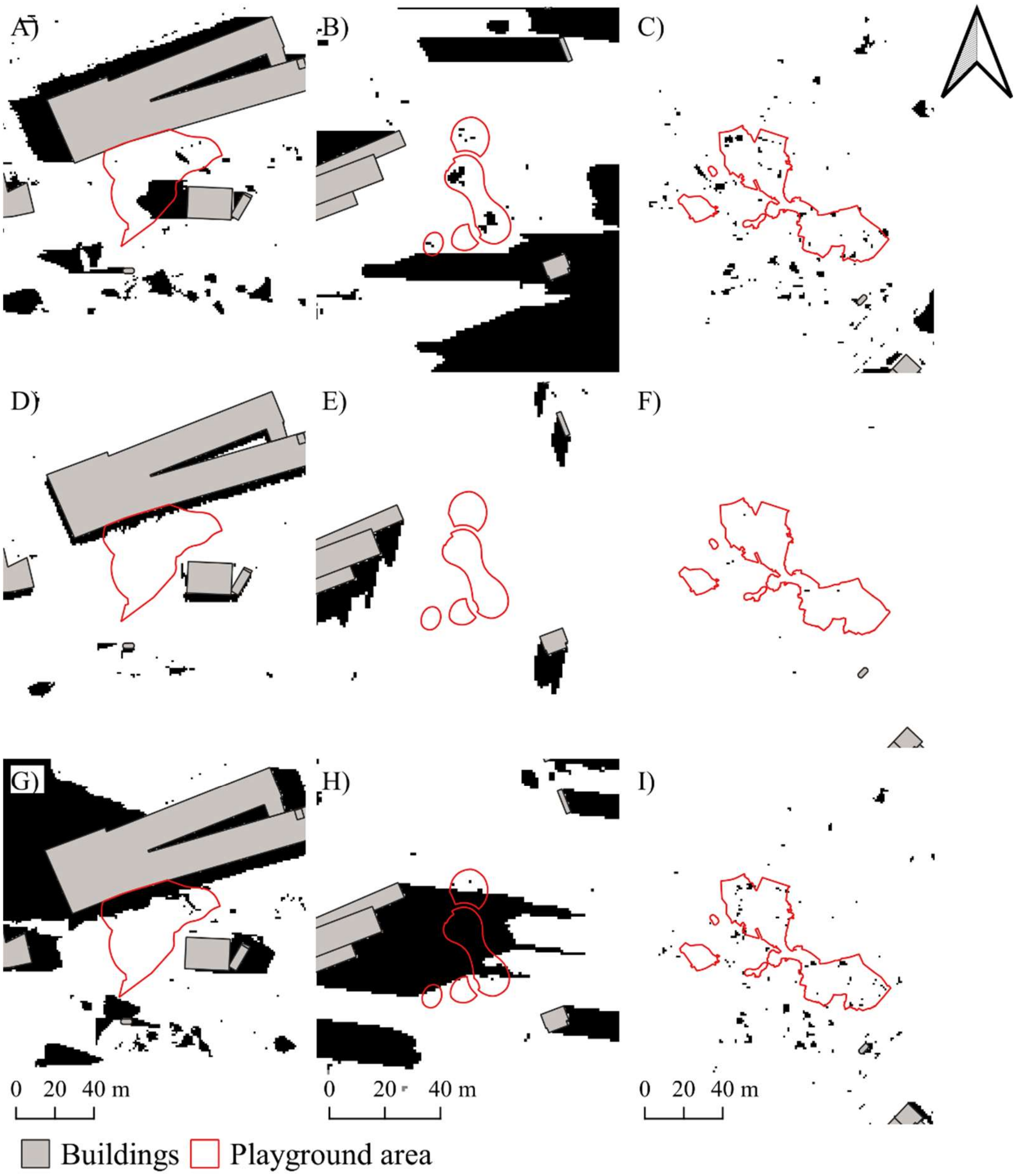

Figure 6. Shadow patterns (in black) with trees removed, at 08:30 (top row), 12:30 (middle row) and 16:30 (bottom row), at Birrarung Marr Artplay (left column), Flagstaff Gardens Playground (middle column) and NaturePlay Playground Royal Park (right column).

3.2 Mean radiant temperature

The general pattern for the T_{mrt} was the lowest temperatures in the morning and highest in the afternoon, with no relation to the amount of shading. For example, at NaturePlay the amount of shade without trees was about 3% in both the morning and afternoon (Table 1), while the T_{mrt} increased from 57.0°C to 68.0°C (Table 2). A similar result could be seen at Flagstaff in the simulation with trees, where the shade cover was lower in the morning than in the afternoon (Table 1), while the T_{mrt} increased by 11°C from morning to afternoon (Table 2). Flagstaff was also the only playground which showed the highest temperature at midday instead of in the afternoon (Table 2).

Slight heat stress (T_{mrt} > 25.6°C) could be experienced at all playgrounds in the morning. At Artplay the heat stress rose to moderate (T_{mrt} > 35.9°C) during midday and afternoon. At Flagstaff and NaturePlay, strong heat stress could be experienced (T_{mrt} > 46.2°C) at midday (Table 2). The T_{mrt} then decreased slightly at Flagstaff to moderate heat stress, while it continued to rise at NaturePlay and extreme heat stress (T_{mrt} >= 56.6°C) could be experienced in the afternoon (Table 2).

Table 2. Average T_{mrt} (°C) at each playground during the morning, midday and afternoon, with and without trees. ΔT_{mrt} is change in T_{mrt} (°C) when the trees are removed.

	ARTPLAY			FLAGSTAFF			NATUREPLAY		
TIME OF DAY	With trees	Trees removed	ΔT_{mrt}	With trees	Trees removed	ΔT_{mrt}	With trees	Trees removed	ΔT_{mrt}
08:30	30.1	49.0	18.9	35.1	50.4	15.4	26.4	57.0	30.6
12:30	40.7	54.8	14.1	51.2	55.9	4.7	48.1	60.6	12.5
16:30	41.6	58.4	16.8	40.0	49.8	9.8	57.0	68.0	11.0

When the trees were removed from the model, the T_{mrt} increased at all playgrounds, with the biggest change observed in the morning, when the T_{mrt} increased with around 15-30°C (Table 2). This was due to that the reduction of shade also was highest in the morning, with around 44-80 pp less shade, with exception for Artplay with had slightly higher reduction in the afternoon (Table 1).

The biggest difference of T_{mrt} could be seen at NaturePlay with over 30°C higher T_{mrt} at 08:30 (Table 2). NaturePlay also showed the highest T_{mrt} throughout the day, with extreme heat stress at all three times of day (Table 2). Artplay showed continuing rising T_{mrt} throughout the day, with strong heat stress in the morning to midday, and extreme heat stress in the afternoon.

Even though the shade cover was reduced to 0% once the trees were removed (table 1), Flagstaff was the playground which showed the smallest difference in T_{mrt} between the trees and no trees simulations of all playgrounds and time of day (Table 2). Strong heat stress could be experienced during all three times when the trees were removed (Table 2). Hence, there was no increase in heat stress at midday between the scenarios. There was only a slight increase in

T_{mrt} from 51.2°C to 55.9°C (Table 2), which is most likely explained by that there was a low percent of shade even before the trees were removed (12.8%) (Table 1).

NaturePlay was the playground which showed the highest T_{mrt} of all playgrounds both with and without trees, with exception from in the morning with trees, when it instead was the lowest T_{mrt}, which is most likely explained by the high shade cover (84.8%) at this time of day (Table 1). It was the only playground that experienced extreme heat stress in the scenario with trees (Table 2) and, when the trees were removed, showed extreme heat stress throughout the whole day. This could partly be due to the lack of shade, for example NaturePlay had the least amount of shade of the playgrounds in the afternoon in the scenario with trees. However, at midday when the trees were removed, both NaturePlay and Flagstaff had no or almost no shade (Table 1), but NaturePlay had almost 5°C higher T_{mrt} (Table 2), which resulted in strong heat stress at Flagstaff while NaturePlay had extreme heat stress.

3.3 Spatial variation of mean radiant temperature and heat stress

In case of the spatial variation of the daily average T_{mrt}, Artplay and NaturePlay showed the biggest difference between the scenarios. At Artplay in the scenario with trees, moderate heat stress (T_{mrt} around 35.9-46.1°C) and slight heat stress (T_{mrt} around 25.6-35.8°C) could be experienced at most parts of the playground, and only strong heat stress (T_{mrt} around 46.2°C-56.5°C) could be experienced in the most eastern part of the playground (Figure 7D). In the scenario without trees, extreme heat stress (T_{mrt} >=56.5°C) could be experienced at a majority of the playground area, and T_{mrt} did not go below 35.9°C (moderate heat stress) (Figure 7G).

At about half of NarturePlay moderate heat stress could be experienced, and at most of the other areas strong heat stress, with only the isolated area in the west that showed T_{mrt} above 56.6°C (extreme heat stress), could be experienced (Figure 7F). When the trees were removed, extreme heat stress could be experienced at most of the playground area (Figure 7I). Flagstaff showed slightly less change between the scenarios. The biggest change could be seen in the most northern part as well as the southern part of the playground area, were the T_{mrt} increased from around 35.9-46.1°C (moderate heat stress) to >=56.6°C (extreme heat stress) (Figure 7F & 7I).

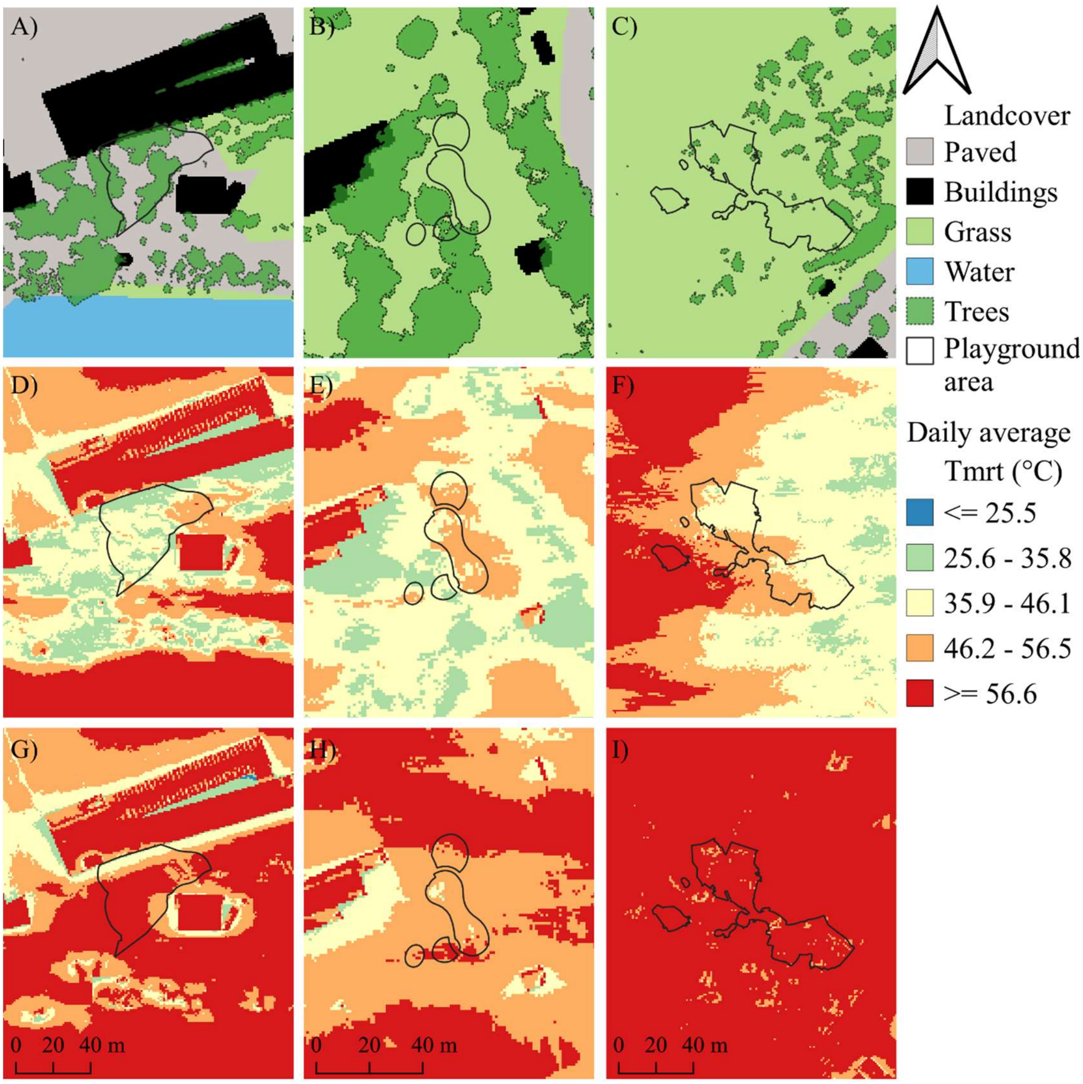

Figure 7. Landcover with outline for trees (top row) and spatial variation of average mean radiant temperature (T_{mrt}) between 08:00 and 18:00 with trees (middle row) and with trees removed (bottom row) at Birrarung Marr Artplay (left column), Flagstaff Gardens Playground (middle column) and NaturePlay Playground Royal Park (right column).

Figure 8 shows the percent of time the T_{mrt} was above 56.5°C, which corresponds to extreme heat stress. Even before the trees were removed extreme heat stress could be experienced at least 1-20% time of the day at all playgrounds (Figure 8A, 8C & 8E). Once the trees were removed, the time above 56.5°C increased at all playgrounds (Figure 8B, 8D & 8F), where NaturePlay experienced extreme heat stress 81-100% of the time for almost the entire playground area (Figure 8F). Artplay also showed a large increase in the central to southwestern part, with changed from 0-20% to 81-100% (Figure 8B). At Flagstaff the change was not quite as pronounced, but extreme heat stress could still be experienced at a majority of the playground area for about half the day or more, 41-80% (Figure 8D).

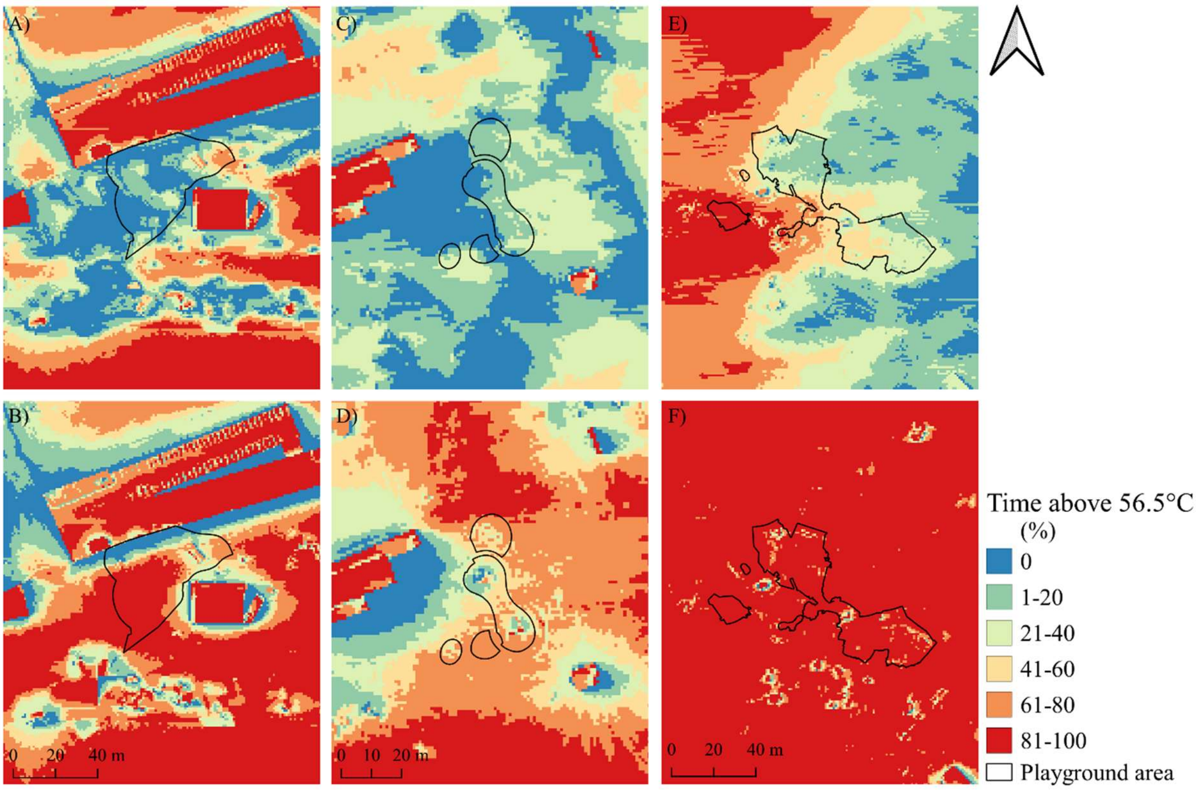

Figure 8. Percent time of the day (08:00-18:00) the mean radiant temperature (T_{mrt}) is above 56.5°C with trees (top row) and with trees removed (bottom row) at Birrarung Marr Artplay (left column), Flagstaff Gardens Playground (middle column) and NaturePlay Playground Royal Park (right column).

4. Discussion

4.1 Connection between shade, mean radiant temperature and heat stress

A connection between amount of shade and T_{mrt} could be found, where reduced shade, in the scenario without trees, resulted in higher temperatures and consequently higher heat stress. Previous studies on trees' impact on the thermal comfort show similar results. Bäcklin et al. (2021) found, through SOLWEIG modelling, that trees were an effective way to lower T_{mrt} and consequently mitigating heat stress at preschool yards in Gothenburg, Sweden. A study by Guo et al. (2023) showed that by planting trees using SOLWEIGs tree planter tool, the average T_{mrt} could be lowered by 3.5-7.7°C at different squares in Dalian, China, which also lowered the risk of heat exposure. Similarly, the daytime average T_{mrt} was lowered by 1.7-5.1°C by using SOLWEIGs tree planter tool to position street trees in Adelaide, Australia (Thom et al., 2016). A different model, ENVI-met, showed that the T_{mrt} could be reduced by up to 31°C at an urban schoolyard in Volos, Greece, under tree canopies (Antoniadis et al., 2018).

The connection between shade and T_{mrt} can also be seen when looking at the spatial variation of the daily T_{mrt}, where the lowest T_{mrt} seemed to appear in the places with the highest tree cover (Figure 7A-F). Similar results were shown in Adelaide, Australia, by Thom et al. (2016), where the larges reduction in T_{mrt} were found directly under tree canopies, and a cluster of trees could reduce the T_{mrt} with 14.1-18.7 °C. Furthermore, even though the trees did not directly cover the playground area, they still had a cooling effect on the T_{mrt}, as the daily average was lower in the areas in close proximity to the trees, due to the shading (Figure 7A-F). This was especially visible at NaturePlay, which for the most part of the playground area had daily average T_{mrt} equal to moderate to strong heat stress when there were trees around (Figure 7F) and daily average T_{mrt} equal to extreme heat stress over the entire study area when the trees were removed (Figure 7I). It can therefore be concluded that trees are an important mitigation of heat stress at the playgrounds and are important for the thermal comfort.

However, the T_{mrt} increased in the afternoon, with exception for at Flagstaff, with no relation to trees or no trees scenario, or to the amount of shading. This is most likely due to absorption of radiation during the day. A similar pattern can be seen in the diurnal profile of air temperature, which is lower in the morning and higher in the afternoon (Figure 4). The coldest time of the day is just before sunrise as no radiation has hit earth during the night, hence the T_{mrt} is lower in the morning as the ground and surrounding surfaces has less absorbed radiation than compared to later in the day. Hence, trees are more important for the thermal comfort later in the day than in the morning. Ren et al. (2022) found that street trees in Changchung city, China, were most effective at reducing heat stress between 13:00 and 15:00. Similarly, Milosevic et al. (2017) found that the thermal comfort was most improved in the afternoon when changing trees to more favourable locations at parking lots in the City of Novi Sad (Serbia). However, based on the results of this study, as the heat stress increased in the morning when the trees were removed (Table 2), it is important to note that trees are an important factor for mitigating heat stress during all times of the day.

4.2 Importance of trees in different urban environments

Flagstaff showed the smallest difference in T_{mrt} between the trees and no trees scenarios, and was the only playground where extreme heat stress was not experienced when the trees were removed (Table 2). This is most likely due to the playground, although being located in a small park, is in a densely built area and surrounded by high rise buildings. Thom et al. (2016) showed for their SOLWEIG simulation of five different sites in Adelaide, Australia, that the high density area had lowest T_{mrt}, as the shade from the buildings prevented direct radiation from reaching the ground, causing less heat absorption in the morning and afternoon. As seen in Figure 6B and 6H, the playground and surrounding area was shaded by buildings both in the morning and afternoon, which therefore affected the absorption of direct radiation and lowered the T_{mrt}. This implies that trees are less important in densely built urban areas.

However, even though the daily average T_{mrt} for Flagstaff only showed strong heat stress for the majority of the playground area when the trees were removed (Figure 7H), extreme heat stress could still be experience at 41-80% of the day (Figure 8D). Trees should therefore not be completely excluded in densely built areas, as they still act as a mitigating factor for heat stress during the times of day when the playground is not shaded by buildings and other surrounding objects. Moreover, a study by Morakinyo et al. (2020) showed that trees in street canyons in Hong Kong can have a cooling effect on both daytime and night time air temperature. As the shading effect of building competes with that of trees, both SVF in different urban canyons and tree species needs to be considered to get the best heat reduction potential. High foliage trees are in general better at mitigating heat, but sparse foliage trees performed better in dense areas with high SVF (Morakinyo et al., 2020). Therefore, not only the implementation of trees at playgrounds, but also what type of trees should be discussed.

NaturePlay was the playground that experienced highest T_{mrt} and heat stress among the playgrounds, which is most likely due to that the playground is located in a big, open park. Thom et al. (2016) got similar results, where the open landscapes showed highest daytime T_{mrt}. The lack of shading from other geometric structures results in intense exposure to shortwave radiation, which cause high absorption and reflectance (Thom et al., 2016). This implies that trees are, although not unimportant in dense urban areas as discussed above, more important for the thermal comfort in open areas than in densely built areas. It also states that, even though the T_{mrt} was lower in the mornings, trees are important in open areas in the morning as well, as they reduced T_{mrt} by 30°C and mitigated heat stress from extreme to slight heat stress at NaturePlay (Table 2). Based on the results of Morakinyo et al., 2020, mentioned above, the §most beneficial trees for open areas like NaturePlay, would be high foliage trees.

4.3 Location of trees in relation to the playgrounds

NaturePlay had the lowest tree cover (3.6%), but still showed the highest amount of shade in the morning and more than twice as much shade as Flagstaff during midday (Table 1), although Flagstaff had higher tree cover (10.3%). In Figure 7C several trees can be seen north to west of the playground. These have not been accounted for when calculating the tree coverage as they do not directly cover the playground area, but still provided shading at the playground during the morning and midday hours (Figure 5C & 5F). This is especially visible when the trees were removed, as the shading decreased by 81 pp in the morning and by 29.6 pp at midday (Table 1), which resulted in close to no shade at the playground (Figure 6C & 6F).

Not only does this emphasize that trees are an important provider of shade, but also that the location of the trees matters. Even though there were several trees surrounding Flagstaff they did not provide as much shade midday as at NaturePlay due to their position (Figure 5E). A study by Langenheim et al. (2020) showed that factors like solar geometry, physical characteristics of the tree and peak pedestrian use-times can be used to place street trees in the most effective positions. It is therefore also important to consider which time of the day the playground is most used when positioning the trees. For example, on weekdays the playground might be more frequently visited in the afternoon when children finish school and their accompanying adults finish work.

As mentioned, the T_{mrt} was generally highest in the afternoon. Both Artplay and Flaggstaff had shade cover around 87% at 16:30 (Table 1) and only moderate heat stress could be experienced, compared to NaturePlay where extreme heat stress could be experienced (Table 2), as there were barely any trees located west of the playground (Figure 7C) and only 20.4% shade was provided (Table 1). Hence, it might be beneficial for the thermal comfort to implement more trees in the west.

4.4 Limitations

The focus in this study was the effects of trees on the thermal comfort. Although the shade from buildings and other structures included in the DSM were used for the analysis, the study has not accounted for shade sails and other shading playground features, which were not included in the DSM. However, although shade sails have proven to lower the T_{mrt}, they are not as effective as trees, which provides cooling both through shade and evapotranspiration (Vanos et al., 2016).

As the meteorological sensors are not located directly at the playgrounds (Figure 1) there is a slight margin of error for the modelled T_{mrt} at the playgrounds, as the meteorological variables might vary slightly at the playgrounds compared to the sensor locations. However, these variations are considered to be negligible and not have any major affects on the result of the study due to a lower spatial variation of air temperature. Furthermore, the solar radiation sensor is located outside central Melbourne, at Melbourne airport (Figure 1), which also might contribute to a margin of error. However, this was accounted for, as mentioned in section 2.2.1, as a day with clear skies were selected for the study, to get consistent readings.

The classification of heat stress in this study is based on a linear relationship between T_{mrt} and PET. However, it is not always a linear relationship, as there are other factors, like wind speed, which also influence thermal comfort (Shashua-Bar et al., 2012). Trees can have a negative impact on the thermal comfort, as they can both reduce wind speed and block wind, and thereby affect ventilation in urban areas (De Abreu-Harbich et al., 2015; Zheng et al., 2020; He et al., 2019).

It is also important to note that the classification is based on a European perception of heat stress. The perception of heat stress varies among people and while the classification used in this study is based on studies in Germany, people in Australia might be more acclimatized to a warmer climate than people in central Europe and thereby be able to withstand higher temperatures before heat stress can be experienced.

Furthermore, other studies use different classifications for heat stress than the one used in this report. For example, Thom et al. (2016), Lau et al. (2016) and Lau et al. (2015) classifies moderate heat stress as T_{mrt} 55-60°C and extreme heat stress as T_{mrt} above 60°C, based on a study by Thorsson et al. (2014). However, as this classification is based on heat related mortality among elderly people, it was considered less suitable for this study, as the target group for playgrounds is children.

5. Conclusion

This study has investigated how trees impact the thermal comfort at three playgrounds in Melbourne, Australia. Two scenarios have been investigated via SOLWEIG modeling, one with the current number of trees and one where all the trees were removed. The result showed a connection between amount of shade and T_{mrt}, where the amount of shade was reduced once the trees were removed, which resulted in higher T_{mrt} and thereby increased heat stress. The intensity of heat stress was lowest in the morning, as the T_{mrt} were generally higher in the afternoon, which implies that trees are especially important in the later part of the day. The spatial variation showed lowest daily average T_{mrt} in areas with highest tree cover. The T_{mrt} was also reduced in areas surrounding the trees due to the shadow patterns.

Furthermore, higher intensity of heat stress could be experienced at the playground located in an open area than at the one located in a densely built area, surrounded by high rise buildings, especially once the trees were removed, which implies that trees are more important in open areas. However, as the heat stress increased at both playgrounds once the trees were removed, trees are still important in densely built areas and rather what type of trees is best suited for each location should be considered.

Lastly, it was also found that the location of the trees matters, as it results in different shadow patterns during different times of day. As two of the playgrounds had high shade cover in the afternoon, which resulted in significantly lower heat stress than at the third playground which had lower shade cover, combined with that the playgrounds might be more frequently visited in the afternoon, it can be concluded that it might be beneficial for the thermal comfort to implement more trees in the west.

With this in mind, it would in future studies be interesting to use SOLWEIGs tree planting tool to investigate the impact on the T_{mrt} and heat stress if trees were planted in these locations. Furthermore, a greater number of playgrounds should be included to get a broader and more accurate representation of the results. Other indices for describing thermal comfort can also be used, like PET or Universal Thermal Climate Index (UTCI), to get a more accurate perception of heat stress and thermal comfort.

The results of this study show how trees can be implemented for better thermal comfort at playgrounds, which will be particularly important in the future, as climate change will cause warmer living conditions, especially in urban areas. As a warm summer day with calm conditions were modeled, the result can hint how thermal comfort will be affected by these warmer climate conditions. The result from this study, complimented by the suggested future studies, should therefore be considered when planning more resilient and sustainable cities in the future, as an adaptation to climate change.

6. Acknowledgement

I would like to thank my supervisor, Janina Konarska. You have been an ideal supervisor and I am really grateful for your presence and support throughout the thesis work. Thank you for providing project ideas, for always being available for questions and feedback, and for the constructive criticism on how to improve my thesis.

A big thank you also goes out to Oscar Bäcklin for your pedagogical explanation of SOLWEIG and continuous help with QGIS and SOLWEIG. I really appreciate all the time you spent to help me, and for always being quick to respond and available for questions. Without your help I'm not sure I would have gotten any results for this study.

Finally, I would like to thank Mark D. Johnson, both for leading the Bachelor thesis course and for all the interesting lectures and excursions during the Earth science bachelor program. Grattis 'Till' pensionen! I wish you a happy retirement.

7. References

Antoniadis, D., Katsoulas, N., & Kittas, C. (2018). Simulation of schoolyard's microclimate and human thermal comfort under Mediterranean climate conditions: Effects of trees and green structures. *International Journal of Biometeorology, 62*, p. 2025-2036. https://doi.org/10.1007/s00484-018-1612-5

Azcarate, I., Acero, J., Garmendia, L., & Rojí, E. (2021). Tree layout methodology for shading pedestrian zones: Thermal comfort study in Bilbao (Northern Iberian Peninsula). *Sustainable Cities and Society, 72*, p. 102996. https://doi.org/10.1016/j.scs.2021.102996

Bureau of Meteorology. (2023). *Climate statistics for Australian locations.* http://www.bom.gov.au/climate/averages/tables/cw_086071_All.shtml Retrieved 2023-04-21.

Bureau of Meteorology. (nd.a). *Average solar ultraviolet (UV) Index.* http://www.bom.gov.au/climate/maps/averages/uv-index/?period=jan Retrieved 2023-04-21.

Bureau of Meteorology. (nd.b). *Climate classification maps.* http://www.bom.gov.au/climate/maps/averages/climate-classification/?maptype=kpn Retrieved 2023-04-21.

Bäcklin, O., Lindberg, F., Thorsson, S., Rayner, D. & Wallenberg, N. (2021). Outdoor heat stress at preschools during an extreme summer in Gothenburg, Sweden - Preschool teachers' experiences contextualized by radiation modelling. *Sustainable Cities and Society, 75,* p. 103324. https://doi.org/10.1016/j.scs.2021.103324

City of Melbourne. (nd.). *Urban Forest strategy.* https://www.melbourne.vic.gov.au/community/greening-the-city/urban-forest/pages/urban-forest-strategy.aspx Retrieved 2023-05-05.

Coutts, A., White, E., Tapper, N., Beringer, J., & Livesley, S. (2016). Erratum to: Temperature and human thermal comfort effects of street trees across three contrasting street canyon environments. *Theoretical and Applied Climatology, 124*, p. 55-68. https://doi.org/10.1007/s00704-015-1409-y

De Abreu-Harbich, L., Labaki, L., & Matzarakis, A. (2015). Effect of tree planting design and tree species on human thermal comfort in the tropics. *Landscape and Urban Planning, 138*, p. 99-109. https://doi.org/10.1016/j.landurbplan.2015.02.008

Geoscience Australia. (nd). *Sunrise. Sunrise & Twilight Times.* Geodetic Calculators. https://geodesyapps.ga.gov.au/sunrise

Guo, F., Guo, R., Zhang, H., Dong, J., & Zhao, J. (2023). A canopy shading-based approach to heat exposure risk mitigation in small squares. *Urban Climate, 49*, p. 101495. https://doi.org/10.1016/j.uclim.2023.101495

He, B., Ding, L., & Prasad, D. (2019). Enhancing urban ventilation performance through the development of precinct ventilation zones: A case study based on the Greater Sydney, Australia. *Sustainable Cities and Society, 47*, p. 101472. https://doi.org/10.1016/j.scs.2019.101472

Heaviside, C., Macintyre, H. & Vardoulakis, S. (2017). The Urban Heat Island: Implications for Health in a Changing Environment. *Current environmental health reports, 4*, p. 296-305. https://doi.org/10.1007/s40572-017-0150-3

Huang, J., Zhou, C., Zhuo, Y., Xu, L., & Jiang, Y. (2016). Outdoor thermal environments and activities in open space: An experiment study in humid subtropical climates. *Building and Environment, 103*, p. 238-249. http://dx.doi.org/10.1016/j.buildenv.2016.03.029

Langenheim, N., White, M., Tapper, N., Livesley, S., & Ramirez-Lovering, D. (2020). Right tree, right place, right time: A visual-functional design approach to select and place trees for optimal shade benefit to commuting pedestrians. *Sustainable Cities and Society, 52*, p. 101816. https://doi.org/10.1016/j.scs.2019.101816

Lau, K., Lindberg, F., Rayner, D., & Thorsson, S. (2015). The effect of urban geometry on mean radiant temperature under future climate change: A study of three European cities. *International Journal of Biometeorology, 59*, p. 799-814. https://doi.org/10.1007/s00484-014-0898-1

Lau, K., Ren, C., Ho, J., & Ng, E. (2016). Numerical modelling of mean radiant temperature in high-density sub-tropical urban environment. *Energy and Buildings, 114*, p. 80-86. http://dx.doi.org/10.1016/j.enbuild.2015.06.035

Lee, H., Holst, J., & Mayer, H. (2013). Modification of Human-Biometeorologically Significant Radiant Flux Densities by Shading as Local Method to Mitigate Heat Stress in Summer within Urban Street Canyons. *Advances in Meteorology, 2013*, p. 1-13. https://doi.org/10.1155/2013/312572

Lindberg, F., Grimmond, C. S. B., Gabey, A., Jarvi, L., Kent, C. W., Krave, N., Sun, T., Wallenberg, N. & Ward, H. C. (2019). *Urban Multi-scale Environmental Predictor (UMEP) Manual*. https://umep-docs.readthedocs.io/ Retrieved 2023-04-10.

Lindberg, F., Grimmond, C. S. B., Gabey, A., Jarvi, L., Kent, C. W., Krave, N., Sun T., Wallenberg, N. & Ward, H. C. (2018). *Thermal Comfort – Introduction to SOLWEIG.* https://umep-docs.readthedocs.io/projects/tutorial/en/latest/Tutorials/IntroductionToSolweig.html#objectives Retrieved 2023-04-10.

Matzarakis, A., Mayer, H., & Iziomon, M. (1999). Applications of a universal thermal index: Physiological equivalent temperature. *International Journal of Biometeorology, 43*, p. 76-84. https://doi-org.ezproxy.ub.gu.se/10.1007/s004840050119

Milosevic, D., Bajsanski, I., & Savic, S. (2017). Influence of changing trees locations on thermal comfort on street parking lot and footways. *Urban Forestry & Urban Greening, 23*, p. 113-124. https://doi.org/10.1016/j.ufug.2017.03.011

Mohajerani, A., Bakaric, J., & Jeffrey-Bailey, T. (2017). The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete. *Journal of Environmental Management, 197*, p. 522-538. https://doi-org.ezproxy.ub.gu.se/10.1016/j.jenvman.2017.03.095

Mohammad Harmay, N. S., Kim, D., & Choi, M. (2021). Urban Heat Island associated with Land Use/Land Cover and climate variations in Melbourne, Australia. *Sustainable Cities and Society, 69*, p. 102861. https://doi-org.ezproxy.ub.gu.se/10.1016/j.scs.2021.102861

Morakinyo, T., Ouyang, W., Lau, K., Ren, C., & Ng, E. (2020). Right tree, right place (urban canyon): Tree species selection approach for optimum urban heat mitigation - development and evaluation. *The Science of the Total Environment, 719*, p. 137461. https://doi.org/10.1016/j.scitotenv.2020.137461

Nuruzzaman, Md. (2015). Urban Heat Island: Causes, Effects and Mitigation Measures - A Review. *International Journal of Environmental Monitoring and Analysis, 3*(2), p. 67-73. doi: 10.11648/j.ijema.20150302.15

Oke, T. R., Mills, G., Christen, A. & Voogt, J. A. (2017). *Urban climates.* Cambridge University press. DOI: 10.1017/9781139016476

Ren, Z., Zhao, H., Fu, Y., Xiao, L., & Dong, Y. (2022). Effects of urban street trees on human thermal comfort and physiological indices: A case study in Changchun city, China. *Journal of Forestry Research, 33*, p. 911-922. https://doi.org/10.1007/s11676-021-01361-5

Shashua-Bar, L., Tsiros, I., & Hoffman, M. (2012). Passive cooling design options to ameliorate thermal comfort in urban streets of a Mediterranean climate (Athens) under hot summer conditions. *Building and Environment, 57*, p. 110-119. https://doi.org/10.1016/j.buildenv.2012.04.019

SMHI. (2022). *Climate indicator – Global radiation.* https://www.smhi.se/en/climate/climate-indicators/climate-indicators-global-radiation-1.91484 Retrieved 2023-04-17.

Taleghani, M. (2018). Outdoor thermal comfort by different heat mitigation strategies- A review. *Renewable & Sustainable Energy Reviews, 81*, p. 2011-2018. https://doi.org/10.1016/j.rser.2017.06.010

Thom, J., Coutts, A., Broadbent, A., & Tapper, N. (2016). The influence of increasing tree cover on mean radiant temperature across a mixed development suburb in Adelaide, Australia. *Urban Forestry & Urban Greening, 20*, p. 233-242. https://doi.org/10.1016/j.ufug.2016.08.016

Thorsson, S., Rocklöv, J., Konarska, J., Lindberg, F., Holmer, B., Dousset, B., & Rayner, D. (2014). Mean radiant temperature - A predictor of heat related mortality. *Urban Climate, 10*(2). https://doi.org/10.1016/j.uclim.2014.01.004

Vanos, J., Herdt, A., & Lochbaum, M. (2017). Effects of physical activity and shade on the heat balance and thermal perceptions of children in a playground microclimate. *Building and Environment, 126*, p. 119-131. https://doi.org/10.1016/j.buildenv.2017.09.026

Vanos, J., Middel, A., McKercher, G., Kuras, E., & Ruddell, B. (2016). Hot playgrounds and children's health: A multiscale analysis of surface temperatures in Arizona, USA. *Landscape and Urban Planning, 146*, p. 29-42. https://doi.org/10.1016/j.landurbplan.2015.10.007

Wallenberg, N., Rayner, D., Lindberg, F., & Thorsson, S. (2023). Present and future heat stress of preschoolers in five Swedish cities. *Climate Risk Management, 40*, p. 100508. https://doi.org/10.1016/j.crm.2023.100508

Ward, K., Lauf, S., Kleinschmit, B. & Endlicher, W. (2016). Heat waves and urban heat islands in Europe: A review of relevant drivers. *Science of The Total Environment, 569-570,* p. 527-539. https://doi.org/10.1016/j.scitotenv.2016.06.119

Zheng, S., Guldmann, J., Liu, Z., Zhao, L., Wang, J., Pan, X., & Zhao, D. (2020). Predicting the influence of subtropical trees on urban wind through wind tunnel tests and numerical simulations. *Sustainable Cities and Society, 57*, p. 102116. https://doi-org.ezproxy.ub.gu.se/10.1016/j.scs.2020.102116