HWA CHONG INSTITUTION (HIGH SCHOOL SECTION)

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Topic: A Study on the Effectiveness of Green Spaces in Mitigating Urban Heat Island Effect in Jurong

Slant: Geography

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Declaration

I declare that this assignment is my own work and does not involve plagiarism or collusion. The sources of other people's work have been appropriately referenced, failing which I am willing to accept the necessary disciplinary action(s) to be taken against me.

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Date of Submission:

Chapter 1: Introductory Chapter

1.1. Background

It has long been recognised that Singapore, given its extensive urbanisation to meet its population growth, is a prominent urban heat island (hereafter referred to as “UHI”). A UHI is an urban area that is significantly warmer than its surrounding non-urbanised areas due to human activities, such as those that generate heat, and physical features, like impervious surfaces (Ryu & Baik, 2012). With current projections of climate change showing rising global temperatures (Climate Action Tracker, 2019), the UHI effect is likely to contribute to - and even compound - the warming effects of climate change, doubling the penalty.

To tackle this, most cities, including Singapore, employ the crucial cooling effects that vegetation provides through evapotranspiration (Qiu, Li, Zhang, Chen, Liang & Li, 2013), allocating land for green spaces, like parks, and installing green roofs. However, temperature maps of Singapore reveal that average temperatures at small-scale green spaces (i.e. not nature reserves and rainforests) are not markedly lower than their surrounding urban areas (Meteorological Service Singapore [MSS], 2020; Mughal M. O. & Zhong S., 2018). To address this complication, this paper used Jurong Lake Gardens and the surrounding urban areas in the Jurong district as case studies to evaluate and determine the effectiveness of such green spaces in mitigating the UHI effect and reducing temperatures.

1.2. Rationale

In contemporary Singapore, the severe scarcity of land curtails the implementation of large-scale green spaces to combat rising temperatures (Davison, n.d.). Hence, as an alternative, the extensive application of small-scale (or micro) mitigation methods are heavily relied upon. Unfortunately, when these are (apparently) ineffective, temperatures rise. As a consequence, humans may suffer from thermal discomfort and heat-related maladies (Orimoloye, Mazinyo, Kalumba, Ekundayo & Nel, 2019), while the local ecosystem experiences disruption and changes to the flora and fauna distribution (Roth & Chow, 2012). Considering all this, the need to evaluate - and possibly improve - the effectiveness of micro mitigation methods is urgent and timely.

1.3. Research Questions

I. What factors contribute to the UHI effect in Jurong?
    A. How does the UHI effect vary in intensity throughout the day?
II. How significant are small-scale green spaces in mitigating the UHI effect in Jurong?
III. How can the configuration of green spaces be modified to maximise their effectiveness in mitigating the UHI effect in Jurong?

1.4. Thesis Statement

Small-scale green spaces found amongst urban areas are insignificant in reducing or decelerating the increase in average temperatures caused by the presence of the aforementioned urban spaces in Jurong.

1.5. Scope of Research / Delimitations

Since microclimate conditions are highly dependent on the climate and geography and differ widely from region to region (Wong & Ignatius, 2016), a case study methodology was adopted, whereby Jurong Lake Gardens and its surrounding urban spaces were used as case studies, as previously stated. Observations, measurements and data collection at the aforementioned sites were made largely from May to July.

1.6. Significance of Research / Usefulness

With a better understanding of the effectiveness of small-scale green spaces located amongst urban areas in mitigating the UHI effect, current mitigation strategies can be modified and future solutions can be developed to be more efficacious in reducing temperatures (which would especially benefit Singapore, where large-scale green spaces are few and far between). This ultimately boosts the climate resilience of urban areas, as well as protects and enhances the well-being of Singaporeans in Jurong. Particularly, this research serves to better inform Singaporeans who may hold the misconception that Singapore is “a city in a garden” (Franklin & Chua, 2017) and is thus immune to the effects of the UHI phenomenon.

1.7. Limitations

First and foremost, measurements and observations of the weather at discrete locations could not be recorded simultaneously, diminishing the accuracy of comparisons between data gathered from the chosen sites. To reduce this discrepancy, the travel time between the measurement sites was minimised as far as possible. Next, the COVID-19 situation and the implementation of the “circuit breaker” measures in Singapore restricted outdoor movement, hindering on-site data collection. Additionally, with fewer vehicles on the roads (due to the stay-at-home order), less anthropogenic heat was produced, making the results less representative of the otherwise ordinary circumstances, though it should be noted that some of the data was collected after the “circuit breaker” measures were relaxed (i.e. during Phase One of “Safe Re-opening” and Phase Two of “Safe Transition”) (Ministry of Health [MOH], 2020). Furthermore, the inability to secure interviews with experts in the field who study the UHI effect may have made this research paper less insightful.

Chapter 2: Literature Review

This literature review revolved around current and credible literature regarding the UHI phenomenon and more specifically, the effectiveness of green spaces at mitigating this phenomenon.

Ever since the hypothesis and discovery of the UHI phenomenon by Luke Howard (1853), many studies have been carried out in a bid to define this phenomenon. One such pivotal publication was perhaps Åke Sundborg's (1951), which explained the UHI phenomenon in terms of an "urban energy balance", based on the analysis of incoming and outgoing energy flux from an urban surface system.

However, recent studies have diverted their focus towards the driving forces, magnitude and overall extent of the UHI effect. In 2007, Watkins, Palmer and Kolokotroni published a rather influential study that evaluated the impact that different urban landscapes' characteristics have on humans' thermal comfort level. Amongst other UHI factors, they demonstrated that vegetation had significant cooling effects through evapotranspiration and providing shade, evidenced by the cooling effect of the studied park that influenced areas 200m to 400m away from the park itself. This paper adopted a comprehensive research approach, considering not only the air temperature - which many UHI studies are limited to - but also the radiant temperature field, solar radiation, wind speed and humidity. Following Watkins et al., several scholars have instead assumed more specialised and contextualised research methods, narrowing their focus to a single UHI factor for more specialised analysis. Amongst such studies, an overwhelming majority of researchers investigating the role of vegetation and greenery in the UHI effect proposed that they alleviate the adverse effects of the UHI phenomenon (Li & Norford, 2016; Ruan, 2016; Trihamdani, Kubota, Lee, Sumida & Phuong, 2017). While there were disagreements over the exact extent of this alleviation, this was most likely due to the widely differing climates of the chosen measurement sites.

Yet, Singapore's temperature maps (MSS, 2020) directly contradicts the aforementioned, deeply established belief. To resolve this problem, viewpoints from other studies were taken into account. Murphy, Hall, Hall, Heisler, Stehman & Anselmi-Molina (2011) revealed that the presence of grass-covered green space does not impede the daytime warming effects of a UHI and suggested that greening efforts instead focus on increasing tree cover. Additionally, Gunawardena, Wells & Kershaw (2017) concluded that blue spaces - areas dominated by surface water bodies or water courses - may exacerbate heat stress under oppressive conditions due to decreased evaporation. As a partially grass-covered green space surrounding a lake, Jurong Lake Gardens may potentially provide decreased cooling effects due to the aforesaid findings. Hence, with these added insights, this paper aims to address and resolve the perplexing contradiction in literature surrounding the effectiveness of green spaces in mitigating the adverse effects of the UHI phenomenon.

Also, studying the UHI effect requires a clear understanding and classification of urban and rural areas. Pizzoli (2007) suggested that to classify the rural and the urban, a multidimensional approach should be adopted, taking into account the economic activities, geographical dimensions and population density of the area. However, due to Singapore's small geographical size and high extent of urbanisation, there is no distinct borderline between the said "urban" and "rural" areas (Wong & Yu, 2005), so the aforementioned, dichotomous urban-rural classification framework is not very applicable to Singapore's unique case. Therefore, this study determined the extent of urbanisation of an area by the number of urban buildings and extent of human activities present there.

Chapter 3: Methodology

Basic weather elements - namely air temperature, relative humidity and wind speed - were recorded at the chosen data collection sites using a Kestrel 5000 weather pocket, to allow for a micro perspective on the issue of the effectiveness of green spaces at mitigating the UHI effect (i.e. even small temperature differences between sites are accounted for, unlike weather satellites). Observations about rainfall, cloud coverage, physical and human features of the sites will also be made. These measurements were split into two categories according to their time of recording: morning (07:00 - 12:00) and afternoon / evening (12:00 - 19:00).

To investigate the factors which contribute to the UHI effect nearby Jurong Lake Gardens, the data collection sites were chosen according to their land use. The type of surface at the site, including tree and grass cover, was also taken into consideration. On the other hand, to evaluate the effectiveness of Jurong Lake Gardens in mitigating the UHI effect, sites with similar number of urban buildings (e.g. Site 3 and Site 2) were chosen to vary in their distance from Jurong Lake Gardens, so that it can be deduced how the distance from Jurong Lake Gardens affects its cooling effect, thereby determining how extensive, far-reaching and significant this cooling effect is.

The chosen data collection sites are shown below:

Site	*Land use(s)*	*General classification*	*Trees within 900m²*	*Grass within 900m² / %*	*Detailed description*
1	MRT station Park	Suburban	9 medium 8 small	~50	2m wide walkway linking Chinese Garden MRT station to Jurong Lake Gardens, located just south of Chinese Garden MRT station.
2	Park	Suburban	4 medium 1 small	~80	2m wide walkway linking Chinese Garden MRT station to Jurong Lake Gardens, located roughly 100m southwest of Chinese Garden MRT station.
3	Park Large lake	Suburban	8 medium 8 small	~80	2m wide walkway circling around Jurong Lake Gardens, located just beside large lake, east of Jurong Lake Gardens, roughly 300m south of Chinese Garden MRT station.
4	MRT station Roadway	Suburban	3 medium 8 small	~10	Boon Lay Way, located just north of Chinese Garden MRT station and Chinese Garden Station bus stop. Two three-lane roads.
5	Commercial Vacant space	Suburban	2 medium	~50	Undeveloped grass field of roughly 18,000m², located southeast of Yuhua Place, roughly 200m northwest of Chinese Garden MRT station. Small multi-storey car park.
6	Vacant space	Suburban	3 medium 5 small	~20	Undeveloped grass field, located roughly 150m southeast of Chinese Garden MRT station.
7	Park	Suburban	12 medium 8 small	~80	2m wide walkway circling around Jurong Lake Gardens, located just beside large lake, east of Jurong Lake Gardens, roughly 200m southwest of Chinese Garden MRT station.
8	Commercial	Suburban	4 small	0	10m wide walkway located just north of JCube, between JCube and another commercial building.
9	MRT station Bus terminal Roadway	Suburban	10 medium 3 small	~30	Jurong Gateway Road, located just northeast of JCube, roughly 150m northwest of Jurong East MRT station. Signalised pedestrian crossing across two three-lane roads. Heavy road and pedestrian traffic throughout the day.

Table 1. Chosen data collection sites

Chapter 4: Discussion and Analysis

4.1. General data and findings

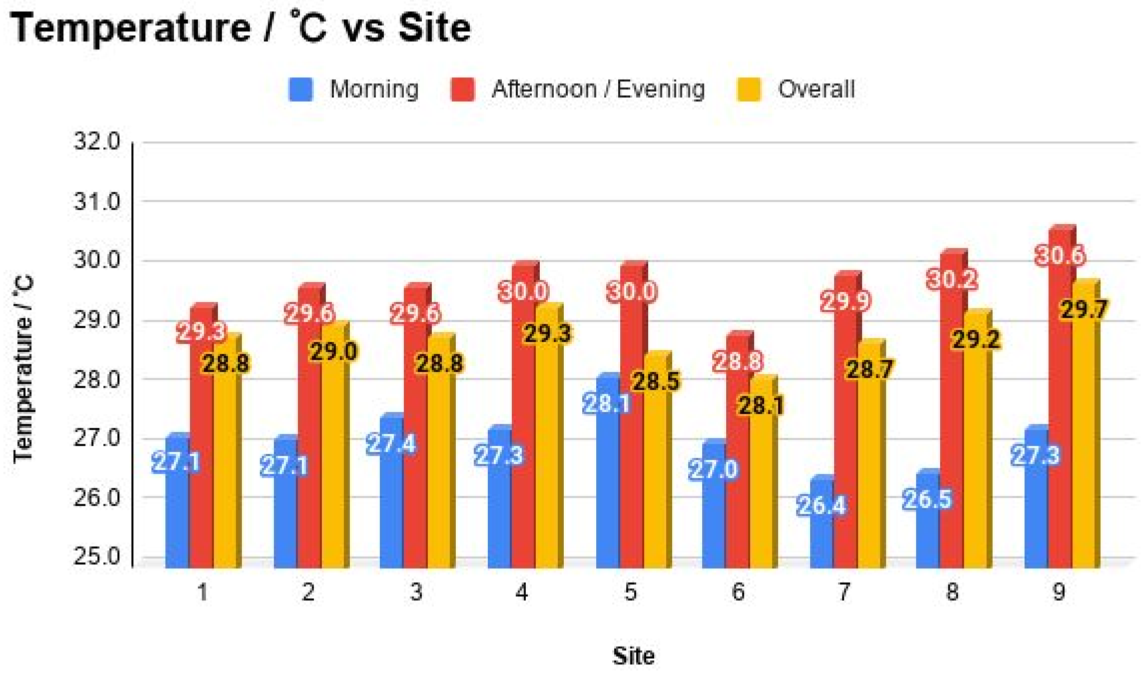

Figure 1. Recorded average temperature of each site

Taking the averages of all the data records obtained, it is observed that the wind speed is 1.8m/s, the air temperature is 29.0℃, the relative humidity is 82.1%, while the heat index (an index that combines air temperature and relative humidity to posit a human-perceived equivalent temperature) is 35.8℃.

Comparing this against the temperatures at Jurong shown in the aforesaid temperature maps of Singapore - 28.5℃ in July 2020 (MSS, 2020), the findings are somewhat similar and coherent. However, it is important to note that while most of the data for this study was collected during Phase Two of “Safe Transition”, some of it was collected during the COVID-19 “circuit breaker” period, where industrial, commercial and transportation operations were either ceased or dramatically curtailed. Hence, these findings may be slightly unrepresentative of the otherwise normal situations and the aforementioned temperatures may be abnormally but only slightly lower.

Also, due to a lack of more sophisticated and accurate measuring instruments, at every instance of data collection, the wind speed was recorded over a very short and brief period of time. Considering the volatile, unpredictable and often fluctuating nature of the wind speed, these findings should be taken with a pinch of salt and thus will not be further analysed in this paper. However, that is not to say that wind speed should be neglected in UHI studies, in fact, it should be earnestly considered. Increasing wind speed removes heat from the human body, creating a sensation of a cooler environment and increasing human thermal comfort level (Watkins et al., 2007).

4.2. Factors contributing to the UHI effect in Jurong

4.2.1. Temperature

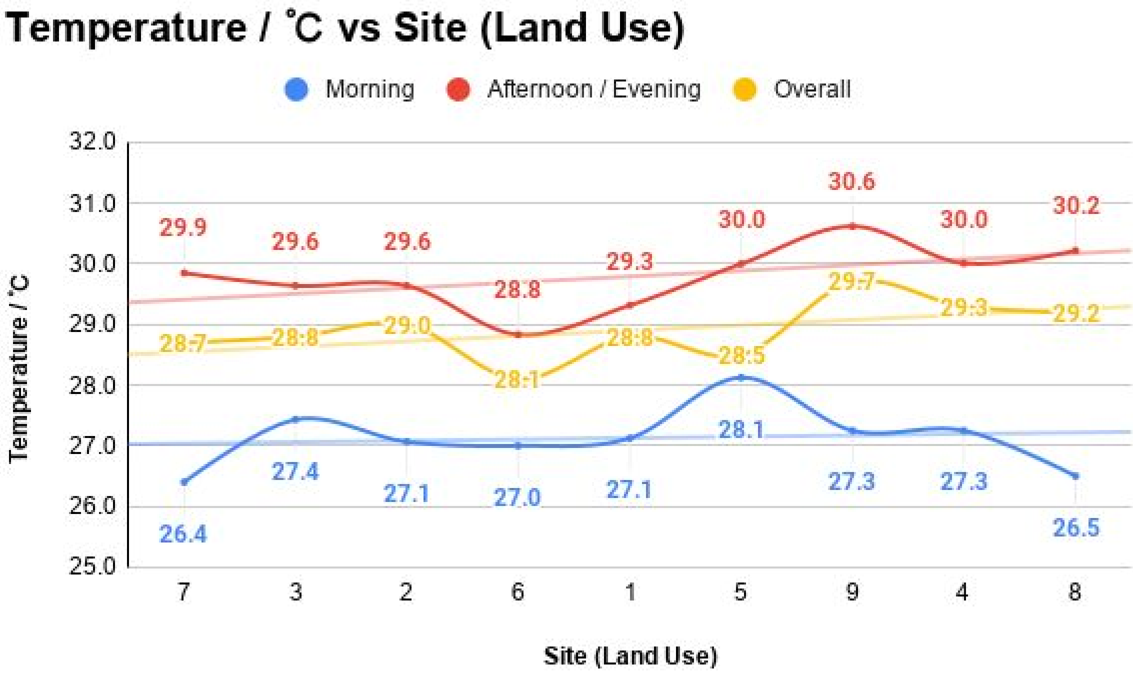

Figure 2. Temperature of each site, arranged by increasing number of buildings and extent of human activities in the positive x-direction

Studying Figure 2, it is evident that as the number of buildings and extent of human activity present increases, the average temperature also increases - an expected trend that is in line with the effects of the UHI phenomenon. The trendlines (which are less opaque than the graph lines) serve to highlight this overall trend.

Yet, Site 6 appears to be an outlier to this trend, recording the lowest “Overall” temperature (28.1℃) amongst other sites. Considering its abundant grass cover, it may be easy to infer that the grass cover was the determining factor that significantly lowered its temperature. However, there were only 5 data records for Site 6 and 60% of them were taken during or just after it rained. Since air temperatures tend to be lower when there is rainfall, it cannot be concluded with certainty that Site 6 was exceptional in a way that distinctly set it apart from the other sites, in terms of air temperature.

When studying the “Morning” graph, Site 8 also appears anomalous, seeing the second lowest “Morning” temperature though there were the most buildings and human activities there. This, again, may be attributed to the severe lack of data records - only 2 recorded in the morning - due to the COVID-19 period, making the results unreliable.

On the other hand, Site 9 recorded the highest “Overall” temperature (29.7℃) amongst other sites, followed by Site 4 (29.3℃) and Site 8 (29.2℃). Unsurprisingly, the three sites with the highest recorded “Overall” temperatures are the ones with the most buildings and human activities, because of the UHI effect. The especially high “Overall” temperature at Site 9 can be explained by the high traffic flow there. Not only is it situated next to an occasionally congested road, but it is also located at the Jurong East MRT station and bus interchange. The high number of vehicles there may have produced a lot of anthropogenic heat, thus accounting for the high temperatures at Site 9. Moreover, Site 4 is also located beside a road, which could likewise explain its relatively high average temperature. Hence, it can be deduced that the heavier the traffic, the more intense the UHI effect, the higher the temperature.

It is also worth pointing out that the gradient of the “Morning” temperature trendline is significantly smaller (i.e. more gentle slope) than that of the “Afternoon / Evening” temperature trendline. This is an expected result, as human activities are less intense in the morning than in the afternoon / evening (e.g. few commercial businesses in shopping malls open early in the morning), so less anthropogenic heat is produced, alleviating the UHI effect and resulting in a smaller “Morning” temperature difference between sites with the most buildings and human activities and those with the least of both.

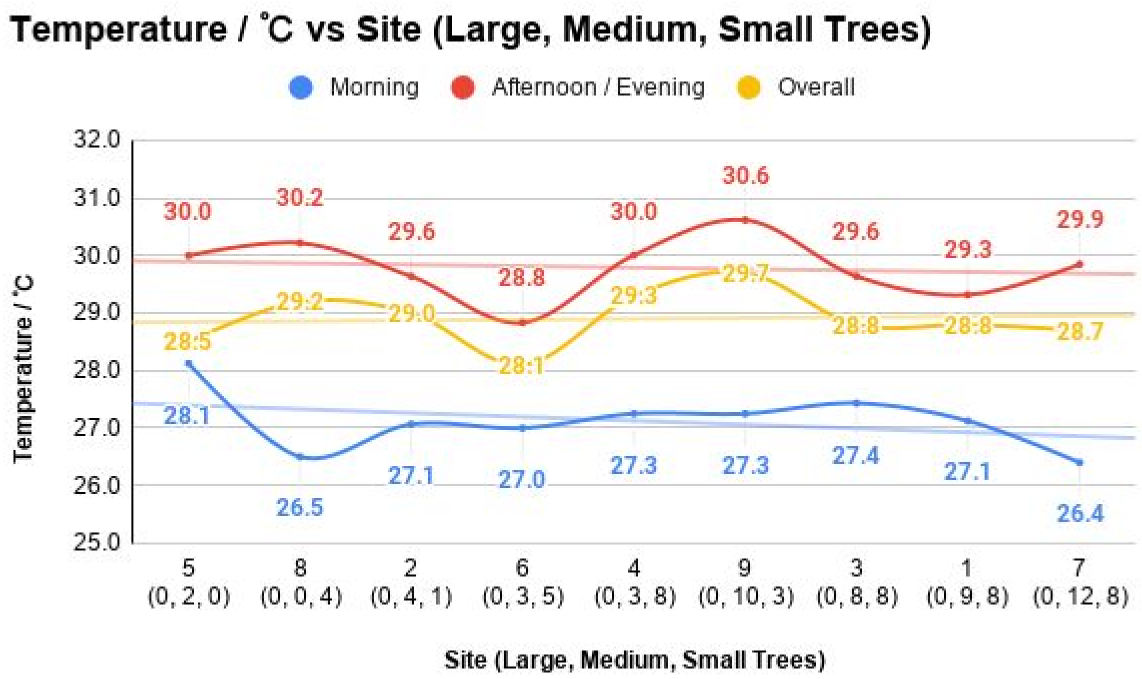

Figure 3. Temperature of each site, arranged by increasing tree cover in the positive x-direction (NB: small trees were accorded half the value of medium trees when calculating the overall tree cover)

Generally, as the tree cover increases, the temperature decreases. This is owing to the fact that trees lower temperatures through evapotranspiration, by providing shade and by increasing the albedo of the surfaces at the site such that more sunlight is reflected back into the atmosphere than is absorbed. Although the “Overall” trendline contradictorily demonstrates that the temperature increases with the tree cover, the “Overall” temperature increase is very slight and can be disregarded.

Intriguingly, despite the fact that both Site 4 and Site 9 have higher-than-average tree cover amongst all the sites, they experienced the highest “Overall” temperatures. From this, it can be implied that the tree cover is insufficient to counterbalance the anthropogenic heat produced by the vehicles at the sites, thereby suggesting that the greenery and vegetation frequently planted along many roadways in Singapore have little to no immediate cooling effect on the UHI effect, contrary to the belief that Singapore, as “a city in a garden” (Franklin & Chua, 2017), is less affected by the UHI effect. Nevertheless, the collective abundance of the greenery along these roadways may still serve as a significant and crucial mitigator to the UHI effect.

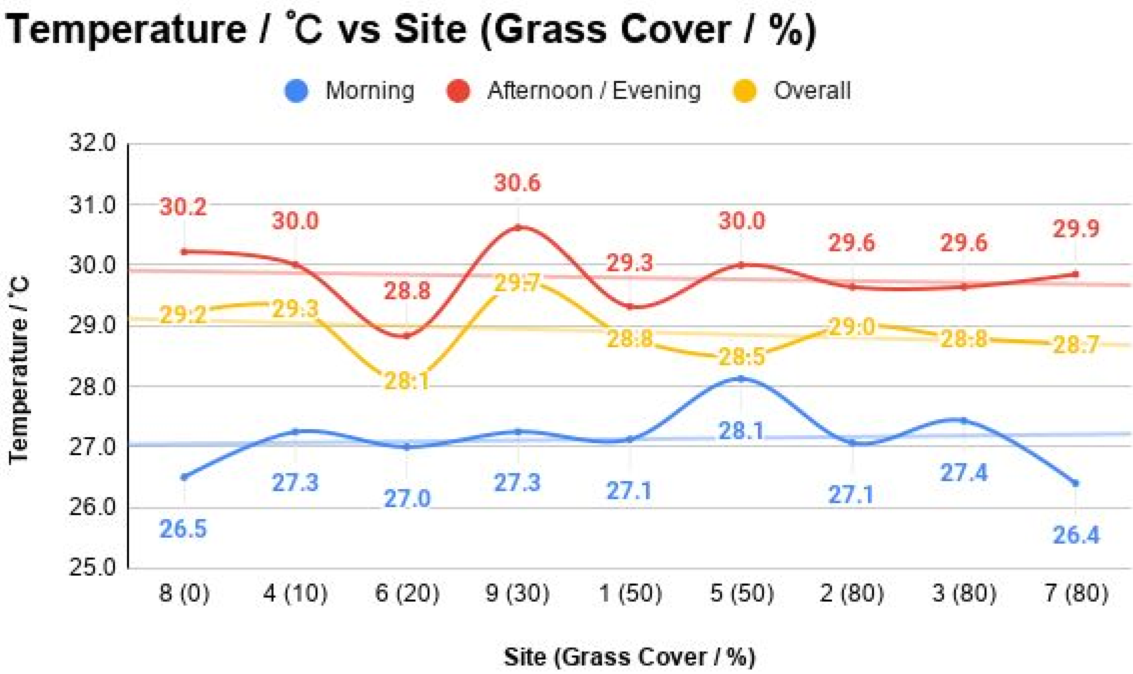

Figure 4. Temperature of each site, arranged by increasing grass cover in the positive x-direction

Similarly, Figure 4 shows that temperature generally decreases as the grass cover increases, because grass also undergoes evapotranspiration and lowers the albedo. However, the “Morning” trendline is instead increasing, though the increase is, again, negligible. This can also be explained by the anomalous “Morning” temperature observed at Site 8, due to the lack of data records (as previously mentioned).

Yet, this said decreasing trend runs contrary to the findings of Murphy et al. (2011) as well as Akbari, Pomerantz and Taha (2001), who concluded that increasing grass cover does not alleviate the daytime UHI effect and that increasing tree cover would instead be more useful. The correlation between increasing grass cover and increasing tree cover of the sites explains this contradiction, as the lower temperatures at the sites with higher grass cover can be attributed to the higher tree cover instead.

4.2.2 Relative humidity

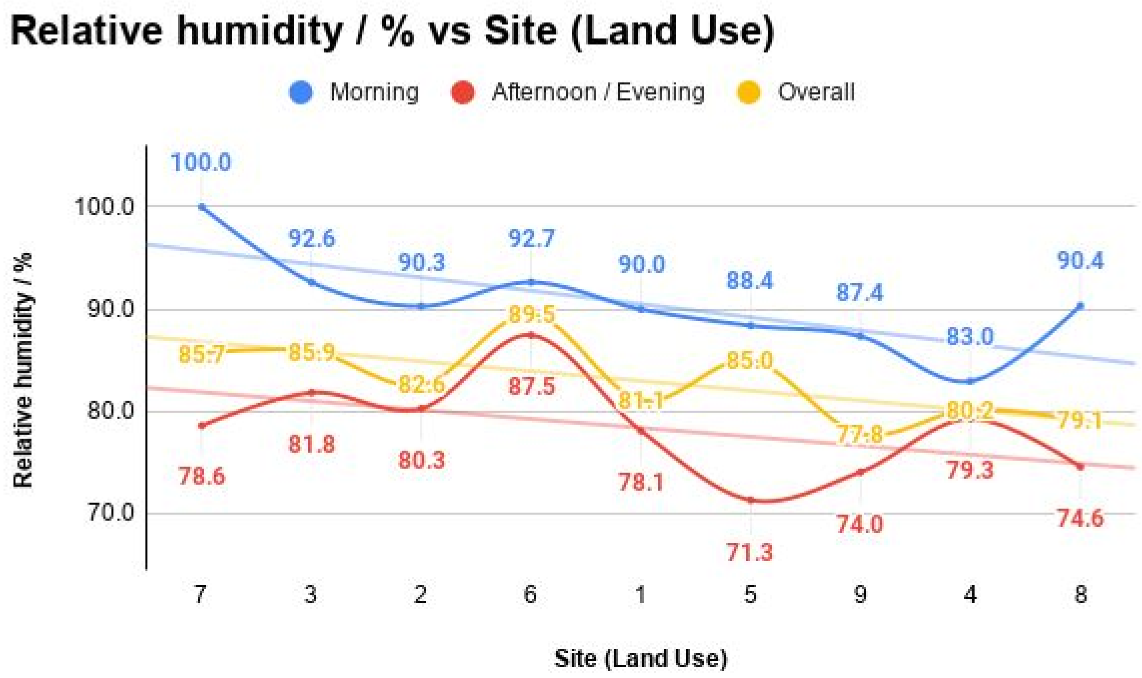

Figure 5. Relative humidity of each site, arranged by increasing number of buildings and extent of human activities in the positive x-direction

Looking at the average relative humidity recorded at the respective sites, a trend emerges - the relative humidity decreases as the number of urban buildings and extent of human activities increases. This comes off as unsurprising, as the more buildings there are in the site, the fewer the vegetation, the less frequent evapotranspiration takes place and thus the lower the relative humidity.

Again, Site 6 is an anomalous outlier to the aforementioned trend, also observing the highest "Overall" relative humidity (89.5%) amongst the sites. This can be accounted for by the fact that most of the data was collected when it was raining at Site 6, so relative humidity would have been uncommonly high.

It is also worth noting that the majority of the less urbanised areas are located in or very near to Jurong Lake Gardens, so the large lake there would have definitely increased the relative humidity levels at those sites. Hence, the presence of water bodies in Jurong increases relative humidity, which in turn, decreases human thermal comfort level, paralleling the findings of Gunawardena et al. (2017), which demonstrated that blue spaces may exacerbate heat stress under oppressive conditions.

In addition, the relative humidity in the morning is much higher than that in the afternoon / evening, because the cooler morning air has a smaller capacity for water vapour than the warmer afternoon / evening air, so even with the same amount of water vapour, the cooler morning air would have higher relative humidity.

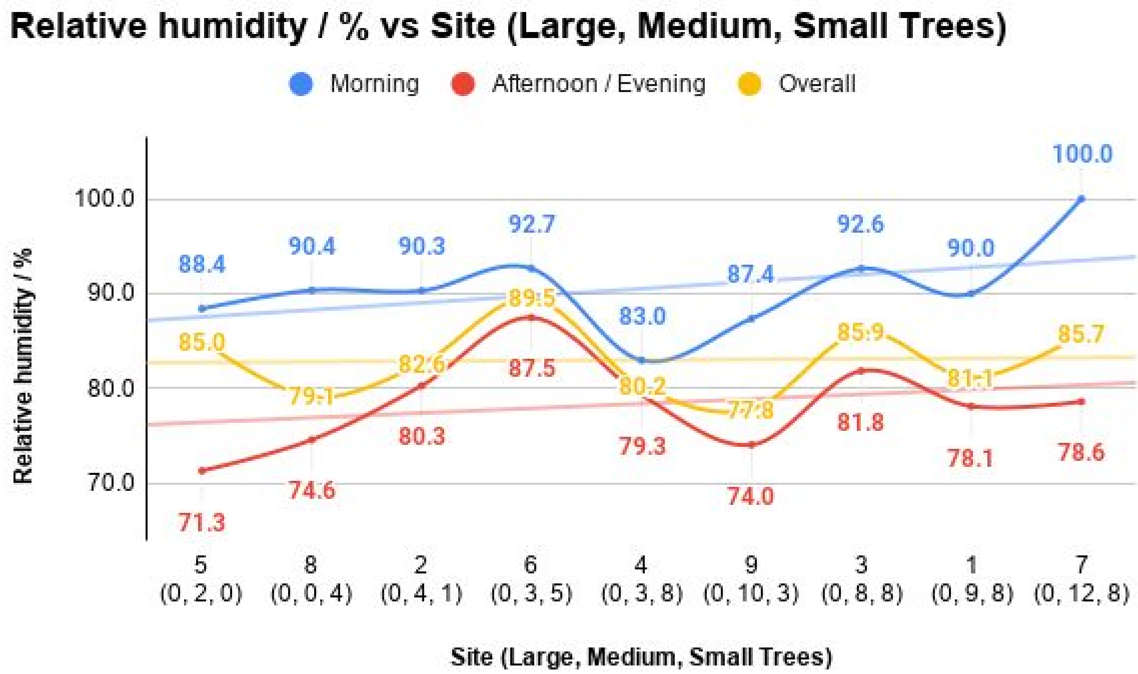

Figure 6. Relative humidity of each site, arranged by increasing tree cover in the positive x-direction (NB: small trees were accorded half the value of medium trees when calculating the overall tree cover)

The trend of relative humidity increasing with tree cover is particularly confirmed by Figure 6.

4.2.3. Heat index

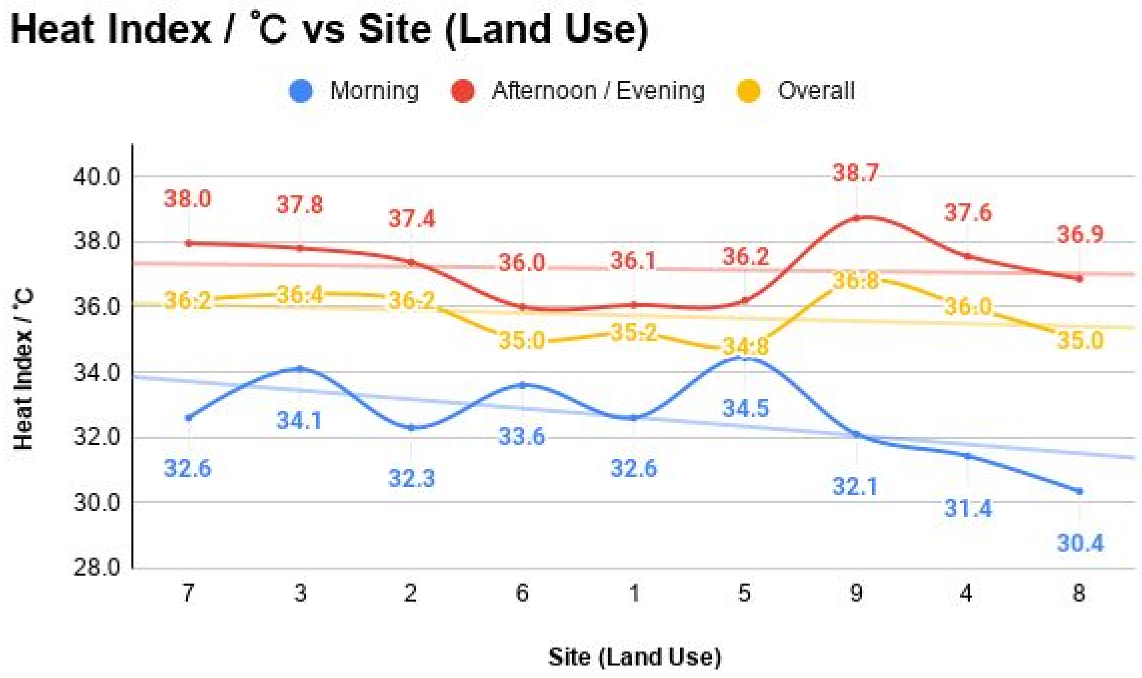

Figure 7. Heat index of each site, arranged by increasing number of buildings and extent of human activities in the positive x-direction

It is crucial that this study not only examines the effectiveness of Jurong Lake Gardens at reducing air temperatures, but also considers the human-perceived temperatures, which affects human thermal comfort level. This can be done through studying the heat index.

Very surprisingly, the average heat index, contrary to the average temperature, decreases as the number of buildings and extent of human activities increases, contradicting the established consensus that urbanised areas are less thermally comfortable to the human body when compared to less urbanised areas. This is in part due to the lower relative humidity in areas with more buildings and, consequently, less vegetation, as mentioned previously.

Furthermore, the decreasing heat index trend is more obviously exemplified by the “Morning” heat index trendline, whereby a staggering heat index discrepancy of 2.5°C between the site with the least number of urban buildings and extent of human activities and that with the most of both, is observed.

4.3. Significance of Jurong Lake Gardens in mitigating the UHI effect in Jurong

As expected, due to the correlation between the number of buildings and extent of human activities at the sites and their distance from Jurong Lake Gardens (the greater the distance from Jurong Lake Gardens, the more the buildings and human activities), the data and therefore the interpretations and analyses are, for the most part, similar and even almost identical. However, some additional conclusions can be drawn when comparing the distance of the site from Jurong Lake Gardens against the average temperature, relative humidity and heat index.

4.3.1. Temperature

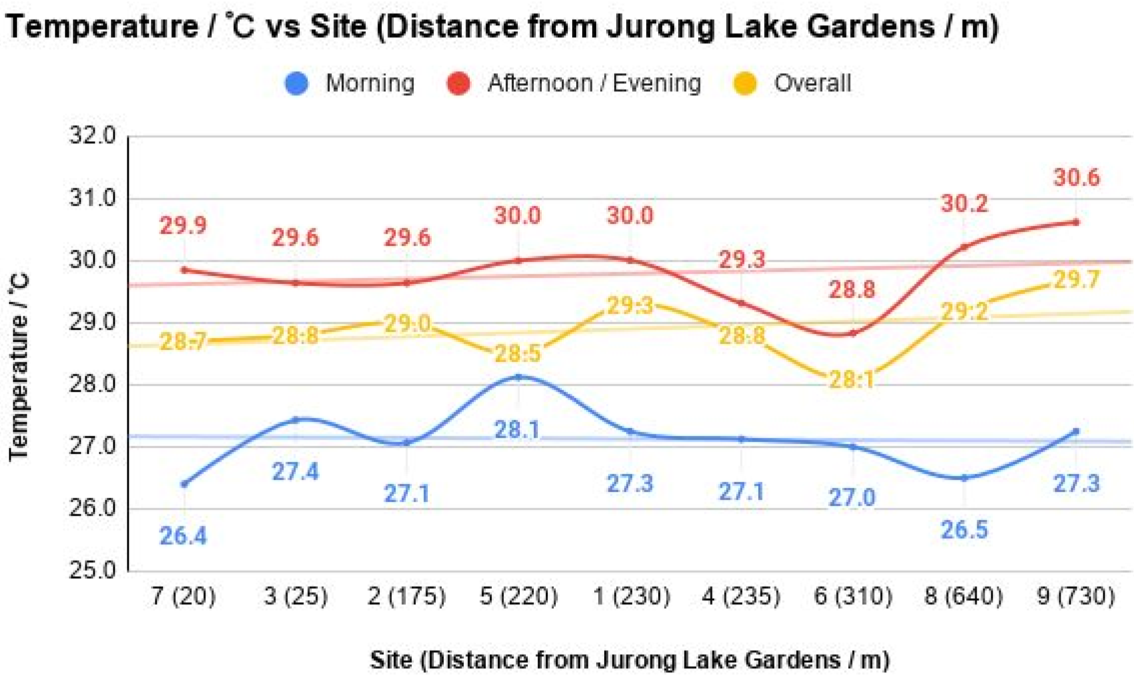

Figure 8. Temperature of each site, arranged by increasing distance from Jurong Lake Gardens in the positive x-direction

Importantly, as the distance between the sites and Jurong Lake Gardens increases, the temperature decreases. This trend is key as it proves that Jurong Lake Gardens is effective as a small-scale green space in mitigating the UHI effect. From the “Overall” trendline in Figure 8, it can be seen that Jurong Lake Gardens has a cooling effect of approximately 1℃ on its surrounding urban areas. However, some may deem this cooling effect as insignificant, since it is not enough to completely offset the maximum temperature difference of 4.01℃ in Singapore (Wong & Yu, 2005). Nonetheless, one must consider the fact that Jurong Lake Gardens is merely a small-scale green space spanning roughly 3km^2 (Google Earth, 2020), so its impact on the UHI phenomenon is bound to be smaller.

Having said that, one must be mindful of the possibility that this cooling effect may only prove effective within the park itself and not in the surrounding urban areas. In fact, from Figure 8, the cooler air in Jurong Lake Gardens does not seem to cool the surrounding urban areas 200m to 400m away from itself, as otherwise demonstrated by Watkins et al. (2007). This is evident when comparing Site 4, an urban area located 235m away from Jurong Lake Gardens, and Site 8, a similarly urbanised area located 640m away from Jurong Lake Gardens. Despite the fact that Site 4 is situated much closer to Jurong Lake Gardens, its temperature is quite similar to Site 8, implying that the cooling effect of the cooler air in Jurong Lake Gardens does not extend as far as to influence the temperature at Site 4.

To resolve this contradiction, a plausible explanation is the widely differing microclimate conditions of the data collection sites between this study and that of Watkins et al. (2007). The latter was conducted in London, a temperate region, whereas the former was carried out in Singapore, a region situated near to the Equator which has a coastal climate. Hence, it is expected that such disagreements in findings occur.

Though that is not to dismiss the other purposes of Jurong Lake Gardens as a green space. Jurong Lake Gardens does not only serve as a mitigator to the UHI effect in Jurong, but also as a recreational area and a Chinese and Japanese cultural icon.

So why do temperature maps of Singapore (MSS, 2020; Mughal M. O. & Zhong S., 2018) suggest otherwise that the difference between temperatures at Jurong Lake Gardens and those of its surrounding urban areas is either small or absent? This is likely due to the macro perspective that such temperature maps adopt when recording temperatures - that is, they group together small areas with actually dissimilar temperatures due to their proximity to one another, and categorise them under a single temperature (i.e. over-generalisation of data). In contrast, this study revolves around field research, granting a micro perspective when investigating this issue.

Apart from this, Site 6 is again anomalous to the said trend for the same reasons (as mentioned in Chapter 4.2).

4.3.2. Relative humidity

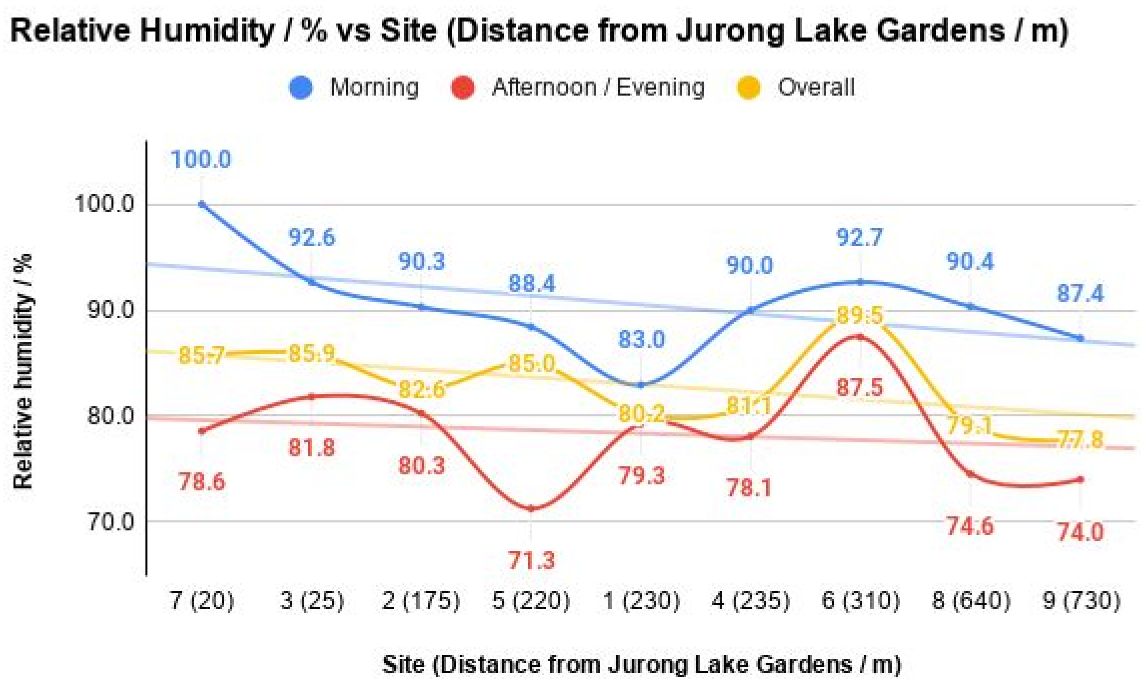

Figure 9. Relative humidity of each site, arranged by increasing distance from Jurong Lake Gardens in the positive x-direction

The same trend is observed as in Chapter 4.2.2: as the distance from Jurong Lake Gardens increases, the average relative humidity decreases, with Site 6 being an extreme outlier.

Additionally, it can be inferred from Figure 9 that the humid air in Jurong Lake Gardens (caused by the presence of vegetation and the large lake) does not spread to the sites located outside of Jurong Lake Gardens.

4.3.3. Heat index

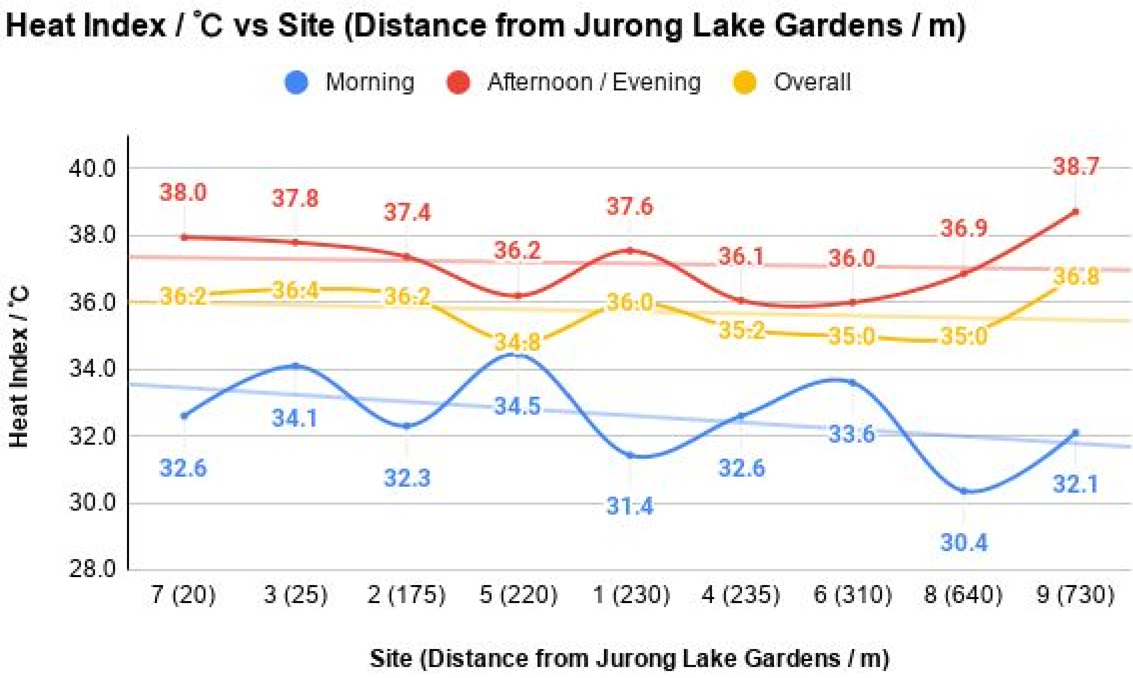

Figure 10. Heat index of each site, arranged by increasing distance from Jurong Lake Gardens in the positive x-direction

Although a similar pattern emerges (when compared to Figure 4), more can be inferred: Jurong Lake Gardens does lower air temperatures in the park itself and at most, slightly in the surrounding urban areas; but the higher relative humidity in the park negates this, instead increasing the heat index and worsening the human thermal comfort level. In other words, when considering human thermal comfort level, the problem lies more in the high relative humidity levels, rather than the insignificant cooling effects of Jurong Lake Gardens.

This evidently contradicts the very purpose of green spaces in the first place - to improve human thermal comfort level, presenting a perplexing problem that demands a prompt and effective solution.

4.4. Modifications to maximise the effectiveness of Jurong Lake Gardens in mitigating the UHI effect in Jurong

Clearly, the higher relative humidity levels need to be reduced so as to alleviate the poorer human thermal comfort levels in Jurong Lake Gardens, as opposed to the surrounding more urbanised areas. One feasible solution would be to reconfigure Jurong Lake Gardens in a way that allows for more air circulation and wind to pass through, similar to the proposals of Watkins et al. (2007) as well as Trihamdani et al. (2017). For example, artificial structures which obstruct the wind flow can either be modified to be more streamline or relocated to another area. Wind flow and speed should be especially maximised over the large lake in Jurong Lake Gardens, so that the wind is able to sweep away and disperse the airborne water particles (Sciencing, 2018), lowering the relative humidity and at the same time increasing evaporation, which lowers temperatures, together improving the human thermal comfort level.

While it may be tempting to plant more trees in Jurong Lake Gardens to increase evapotranspiration, shade and the albedo, one must be cautious to consider that relative humidity levels may increase and winds may be blocked by doing this.

Moreover, the highest temperatures were observed at sites nearby roadways. Therefore, measures should be taken to reduce traffic congestion and flow, so that less vehicles would produce anthropogenic heat, which exacerbates the UHI effect.

By improving the effectiveness of Jurong Lake Gardens as a mitigation measure to the UHI effect, temperatures can be reduced, thereby lowering energy consumption and demand for means of improving human thermal comfort level (e.g. air conditioning), further reducing temperatures. This establishes a positive feedback loop, amplifying the cooling effects of small-scale green spaces.

Chapter 5: Conclusion

From the results obtained in this study, it is evident that the urban buildings and high traffic flow present in Jurong contributes directly to the increase in air temperatures - an expected finding. Urban buildings provide many surfaces for heat to be trapped and then released and their presence implies higher energy consumption, which along with the high number of vehicles in Jurong, produce significant amounts of waste heat. On the other hand, the large lake and extensive vegetation in Jurong Lake Gardens specifically act as catalysts for increased relative humidity levels, which, in turn, raise the heat index and worsen human thermal comfort levels. The discrepancy in the heat indices of areas located near to Jurong Lake Gardens and that of areas with high number of urban buildings and extent of human activity is especially great in the morning, explained by the higher relative humidity levels during that time.

Jurong Lake Gardens exhibits a cooling effect of approximately 1℃ on its surrounding urban areas, which is significant for a small-scale green space in Singapore’s context. However, this cooling effect does not appear to extend very far beyond the park itself.

To resolve the poor human thermal comfort levels observed in Jurong Lake Gardens, the green space should be reconfigured in a manner that allows for more air circulation and wind flow (especially over the large lake) so as to lower relative humidity levels as well as to encourage more evaporation, which together lower the heat index. One should also be cautious when planting more trees in Jurong Lake Gardens, as this may prove itself counterproductive, instead increasing the already very high relative humidity levels there. Outside of Jurong Lake Gardens, measures should be taken to markedly reduce the traffic flow and congestion, so as to minimise the waste heat from vehicles which contributes to the UHI effect in Jurong.

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Appendix A: Graphs of data records

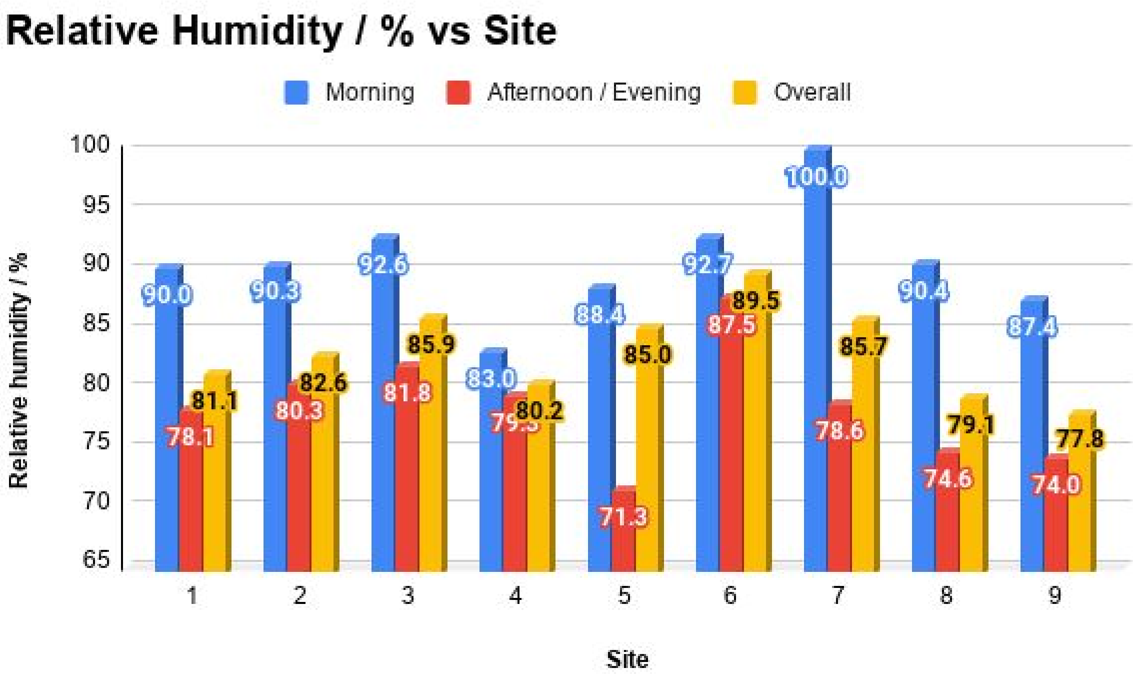

Figure 11. Recorded average relative humidity of each site

Figure 12. Recorded average heat index of each site

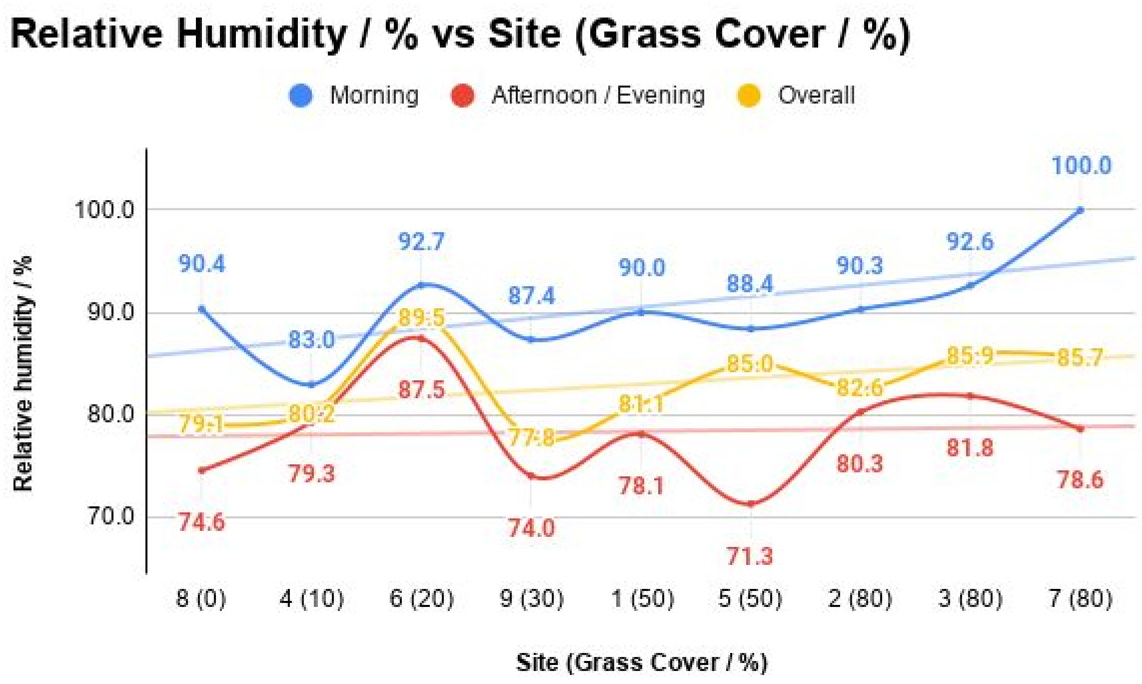

Figure 13. Relative humidity of each site, arranged by increasing grass cover in the positive x-direction

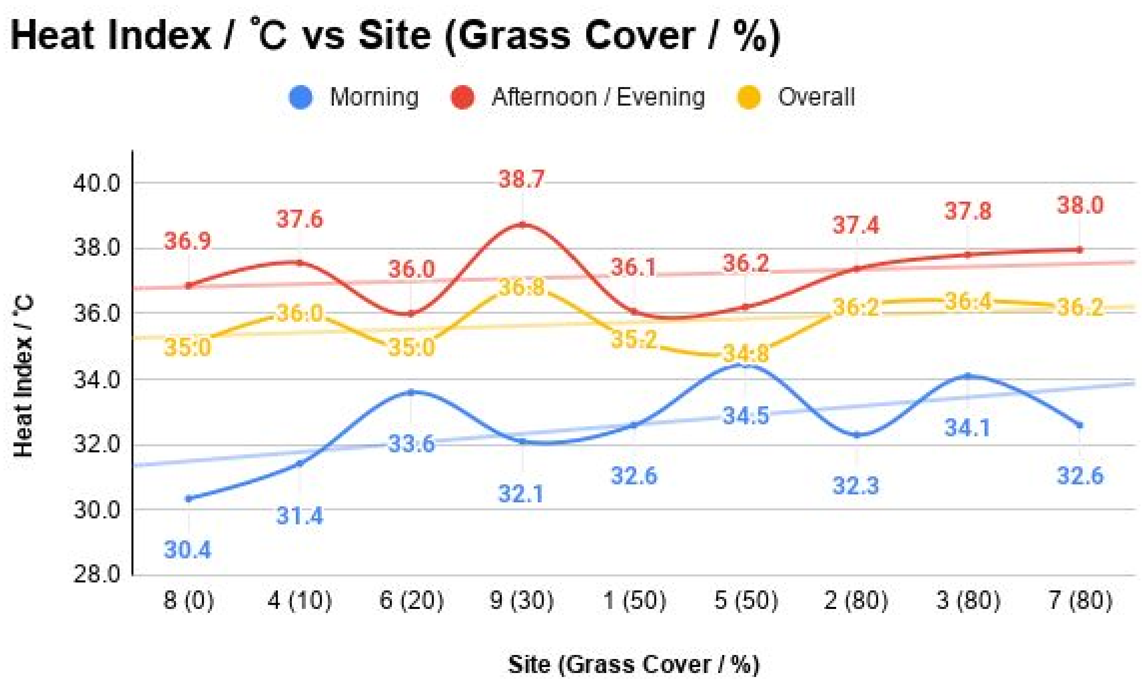

Figure 14. Heat index of each site, arranged by increasing grass cover in the positive x-direction

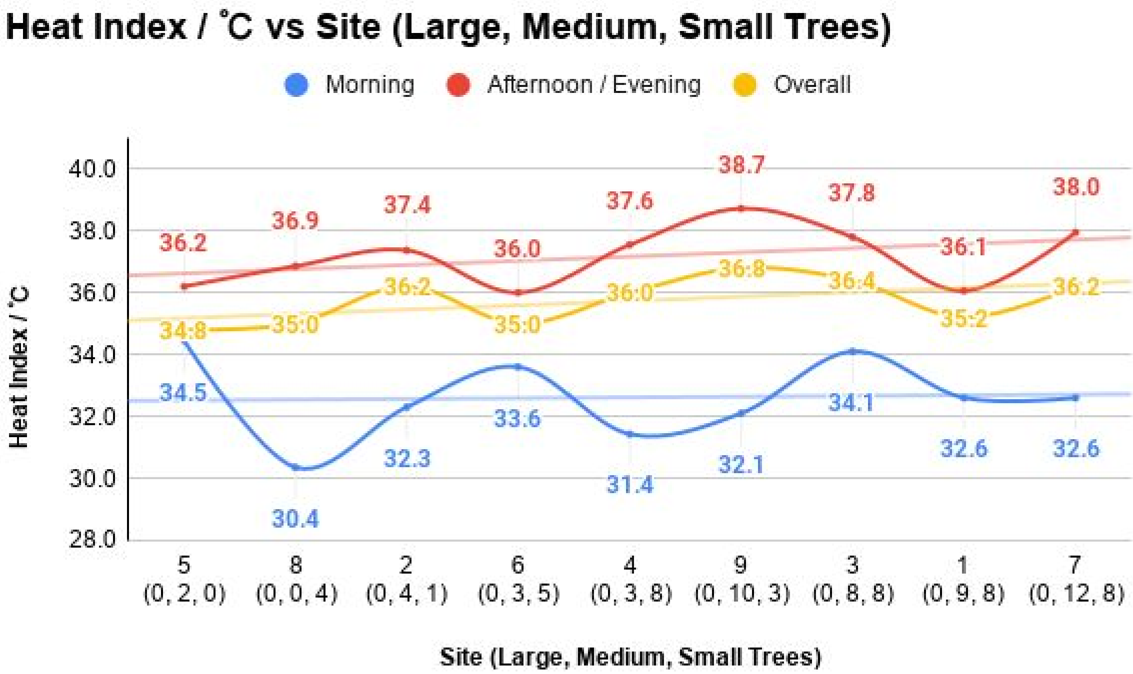

Figure 15. Heat index of each site, arranged by increasing tree cover in the positive x-direction (NB: small trees were accorded half the value of medium trees when calculating the overall tree cover)

Appendix B: Photographs of data collection sites

Figure 16. Site 1

Figure 17. Site 1

Figure 18. Site 2

Figure 19. SIte 2

Figure 20. Site 3

Figure 21. Site 3

Figure 22. Site 4

Figure 23. Site 4

Figure 24. Site 5

Figure 25. Site 5

Figure 26. Site 6

Figure 27. Site 6

Figure 28. SIte 7

Figure 29. Site 7

Figure 30. Site 8

Figure 31. Site 9

Figure 32. Site 9