THE IMPACT OF LAND COVER AND SEA BREEZE ON BLACKPOOL'S COASTAL URBAN HEAT ISLAND

ABSTRACT

This research quantifies Blackpool's urban heat island (UHI) by examining land cover, sea-breezes and human comfort. Meteorological data, including dry-bulb temperature and relative humidity measurements, were collected along a 41-kilometre route incorporating a coastal transect during summer 2014. The measurements were obtained utilising a data logger attached to the roof of a vehicle, which captured a total of 18 transverses. Blackpool reported a strong UHI with a maximum intensity of 4.3°C. However, the Irish Sea moderated coastal areas, cooling parts by up to 3°C during the afternoon and warming nearby areas during the evening. The heat indices: Wet-Bulb Globe Temperature, Canadian Humidex and the South African Discomfort Index, revealed that discomfort from high temperatures and humidity reaches moderate-extreme levels at the 95th percentile (or on 5% of days). Urban parks were only effective at mitigating against high temperatures in the evening. This goes against prior research advocating the 'greening of cities' to effectively mitigate against the UHI.

Key Words: Urban heat island, transect, heat indices, land cover, sea breeze, human comfort, mitigation.

1 INTRODUCTION

1.1 Research context

The term Urban Heat Island (UHI) is used to describe the higher temperatures found in urban areas when compared to their rural surroundings (Landsberg, 1981; Voogt & Oke, 2003). The phenomenon is a direct consequence of urbanisation, which has significantly modified the landscape as a result of the simultaneous removal of natural land cover and the introduction of urban materials (Xu & Chen, 2004). These alterations have resulted in changes to the energy budget and poor air quality leading to higher temperatures (Xu & Chen, 2004). The intensity of the UHI phenomenon increases in proportion to the population of the urban area (Oke, 1973). Consequently, this is an increasingly significant issue due to the growing number of people expected to live in cities in the future (Cohen, 2006).

1.2 Rationale

Before mitigation measures against the UHI can be put in place, it is vital to understand the local variations in climate, its effects on the natural world, and the physiological importance of atmospheric factors (Sundborg, 1950). This study develops work carried out by Steeneveld et al. (2011) on the discomfort of Dutch cities. However, it incorporates a coastal element, looking at Blackpool's urban area in order to assess the interaction of the marine and terrestrial environment. This is accomplished by measuring the advancement of the sea breeze, which is essential as many of the world's most populous cities are located on the coast (Dawson et al., 2009; Small & Nichollis, 2003). Furthermore, this study looks at the impact of urban parks and water bodies on the area's dry-bulb temperature and relative humidity levels. Thus providing a platform to determine whether afforestation is an effective mitigation measure, or whether changes to urban design or layout would be more beneficial, as high humidity and temperatures can result in greater human discomfort (Conti et al., 2005; Gaffen & Ross, 1998; Watkins et al., 2007). The influence water has on coastal cities is not yet fully understood (Steeneveld et al., 2011), and the role water bodies play in increasing urban discomfort not reported.

1.3 Study area

This investigation studies the UHI phenomenon within the context of the Blackpool Wyre and Fylde Urban area (53.81° N, 3.05° W). The town is bordered to the north and west by the Irish Sea, to its south by the Ribble estuary, and to the east the English countryside. Blackpool's urban area is the 30th largest in England with a population of 239,409 in 2011, although in summer this value rises to 360,000 due to tourism (City Population, 2011). The urban centre is densely populated with 4066 people per km^2, considerably higher than the national average of 375 per km^2.

The land cover types are classified according to land cover data from 2007 (LCM2007) (Figure 1). Land types include grassland (42%), urban/suburban (32%), horticultural (17%) and inland water (2%). The elevation is relatively consistent throughout the region at 6 to 30 metres above sea level, and the climate is typical of towns in the mid-latitudes, with moderated temperatures and precipitation amounting to 882 mm per year (Met Office, 2014).

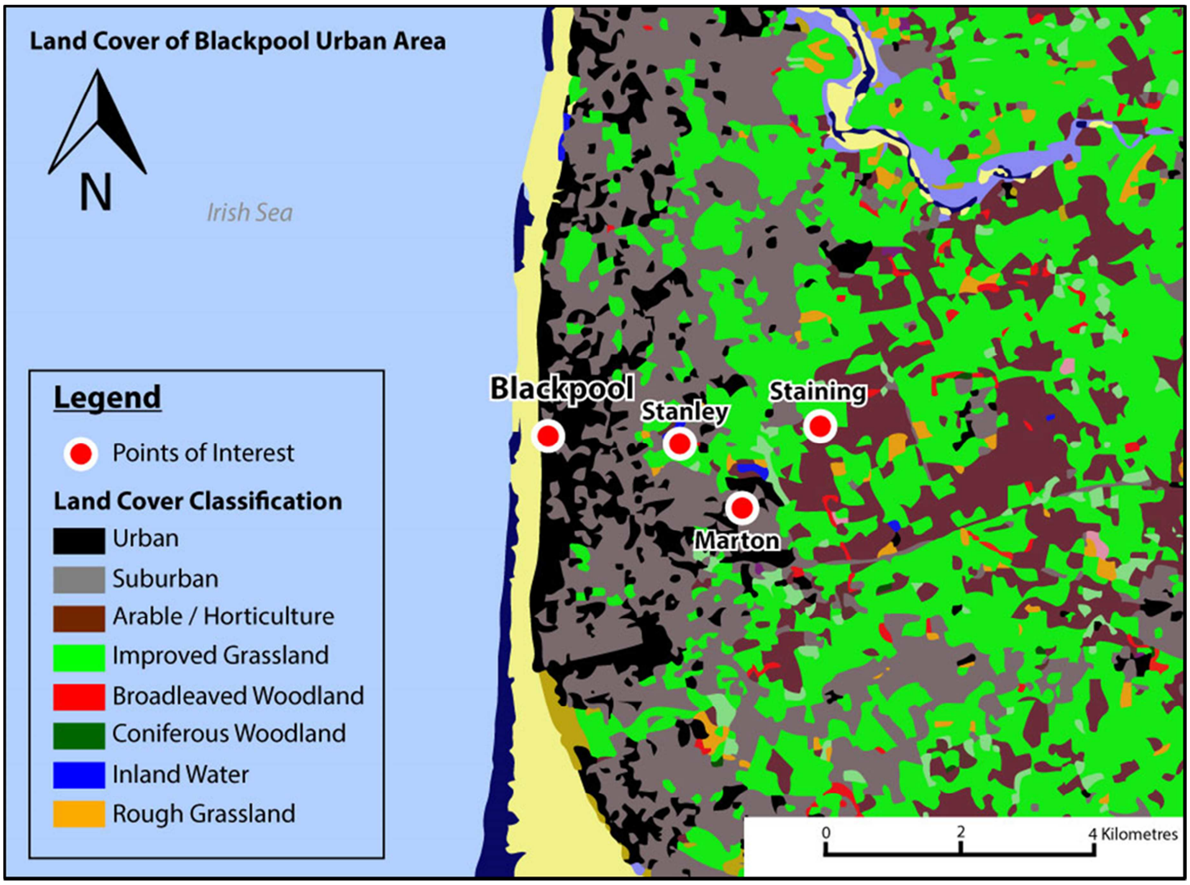

Figure 1: Land cover map of Blackpool and surrounding areas produced using Quantum GIS software (Land Cover Data 2007)

2 LITERATURE SYNOPSIS

2.1 Urban vegetation

Urban vegetation may provide a cooling ecosystem service by affecting the energy balance through the shading of solar radiation, blocking of the wind, and by transpiration from leaves (Georgi & Dimitriou, 2010). These benefits have been found by Mirzaei & Haghighat (2010) via observational and thermal remote sensing of the landscape. However, Jenerette et al. (2011) states that there are numerous "knowledge gaps [that] exist in the biophysical and social dynamics of using [vegetation] to reduce climate extremes" (p. 2637). Nevertheless, Spronken-Smith & Oke (1998) suggests that vegetated urban parks are likely to be cooler than surrounding built environments, with their study in British Columbia and California demonstrating the cooling influence of vegetation. These findings support the readily found patterns in many cross-sections of UHI's in temperate cities *(including London (Chandler, 1965); New York City and Syracuse, NY (Herrington et al., 1972; Montreal, PQ and Vancouver, BC (Oke et al., 1989))*. The benefits are not restricted to that of large parks, as even small green areas (between 29 and

500ha) are typically 1-2°C cooler than the surrounding urban area (Spronken-Smith & Oke, 1998).

2.2 Alternative mitigation strategies

Arguably, changes in building design and improved energy efficiency are more plausible long-term solutions to combat the issue of heat stress in cities. A recent study by the University of Oxford concluded that heat-related deaths could be reduced by up to 69% if buildings were adapted properly for high temperatures. This could be achieved through energy efficient buildings with better ventilation and a reduction of anthropogenic heat emissions. This would require a shift in focus toward sustainable urban design and changes to planning policy (Jenkins et al., 2014). Although at present, there are no regulations to guide building design on the risks of overheating (Jenkins et al., 2014).

2.3 Human discomfort

During the summer, high nighttime temperatures can lead to nocturnal heat-stress and an increase in mortality rates (Kunst et al., 1993; Laschewski & Jendritzky, 2002). This was demonstrated in the summers of 1976 and 1995 when daily death rates rose by 8.9% (Rooney et al., 1998). During the evening, rural areas cool allowing time for people's bodies to recover from the intense heat of the day, but in cities the high overnight temperatures exacerbate the effects of heat waves and can compromise the body's ability to 'thermoregulate' increasing the risk of mortality (Kovats & Hajat, 2008). Despite this, the impacts of high temperatures in temperate regions have not been substantially studied due to the mild climate regime, where impacts are assumed to be insignificant (Heusinkveld et al., 2010; Steeneveld et al., 2011).

When temperatures exceed 26.7°C with a relative humidity of 40%, an individual begins to feel hotter than the recorded air temperature (Steadman, 1979). Consequently, the heat index was adopted to measure the risk to human discomfort (Smoyer et al., 2000). This measure considers human psychology and the synergistic effects of high temperature and humidity, and their ability to stress the body's thermoregulatory systems (Steadman, 1984). Hence, the heat index provides a more accurate measure of discomfort than the value displayed by a standard thermometer (dry-bulb temperature). Steadman (1979) found that high relative humidity can make it feel hotter. Therefore, the role of vegetation and water for increasing evapotranspiration rates (increasing humidity), could have negative consequences, despite Niachou et al.'s (2001) promotion of 'green' roofed buildings for mitigating adverse heat effects in cities. Arguably, increased temperature does not often coincide with increased relative humidity levels (Steeneveld et al., 2011). However, a warmer atmosphere can hold more moisture and thus relative humidity can be misleading. For example, a relative humidity value of 50% at 20°C could be perceived as dry, whilst the same relative humidity at 30°C feels humid (Steadman, 1979).

2.4 Similarities between UK and Dutch Urban Heat Islands.

Steeneveld et al. (2011) observed the relationship between the UHI, land cover and human comfort in Dutch cities and found that heat stress was an issue at the 95th percentile. Since the Netherlands has a mild oceanic climate (like the UK) the impact of high temperatures is assumed to be minor, so there is a knowledge gap that currently exists surrounding heat stress. Blackpool has many similarities with Dutch cities (densely populated, mild climate regime of the *Cfb* type (Köppen, 1931), low elevation), and so this study replicated aspects of Steeneveld's work in order to bridge the knowledge gap. Although the Netherlands is given the same climate classification as the UK, it is noted that the position within mainland Europe makes Dutch cities more susceptible to high temperatures from the tropical continental (cT) air mass (Met Office, 2016). Nevertheless, contemporary studies of UHI's in the Netherlands best inform this investigation.

Note: **95th percentile (this level of heat stress is exceeded on 5% of days)*
**98th percentile (this level of heat stress is exceeded on 2% of days)*

2.5 Interactions between the Sea breeze and Heat Island Circulation

The interaction between the sea breeze and heat island circulation (HIC) has been reported in many UHI studies. When looking at past research (such as Ado, 1992; Freitas et al., 2007; Yoshikado, 1994), the following conclusions can be made. Firstly, the HIC is the local wind generated by the thermal contrasts associated with the UHI. Secondly, the HIC is influenced by synoptic-scale winds with a stronger HIC present under calm weather conditions. And thirdly, the sea-breeze front has a tendency to remain over urban areas due to the effect of the HIC, which can cause convergent flow patterns in coastal cities. Such that, the presence of an urban area can cause the acceleration of the sea-breeze front toward the centre whilst delaying its advancement further inland.

3 Study Aims and Objectives

This study aims to develop the research of Steeneveld et al. (2011) by quantifying Blackpool's surface UHI, where the effects of land cover, water bodies, and sea breezes are examined. Additionally, human comfort is calculated by comparing three heat indicators (WBGT, Humidex and Discomfort Index) in order to determine the effects of land cover on heat stress. There are three key research objectives.

i. First, to analyse the relationship between land cover and humidity/dry-bulb temperature,
ii. Next, to assess the role of the Irish Sea by examining the landward change in dry-bulb temperature, and
iii. Finally, to utilise the dry-bulb temperature and relative humidity measurements to formulate and compare three heat index values.

4 Methods

4.1 Investigation route

The route originated and terminated at the coast by South Pier (see Figure 2), with a midpoint set near Staining (6.5 kilometres inland). The route had both an outward (landward) and inward (return) component (after Melhuish & Pedder, 1998), running a total distance of 41 kilometres, through various land types (to achieve objective 1). The data gathered during the landward and return journeys were then averaged to allow for temperature changes in response to the shifting position of the sun in the sky (Zoulia et al., 2009).

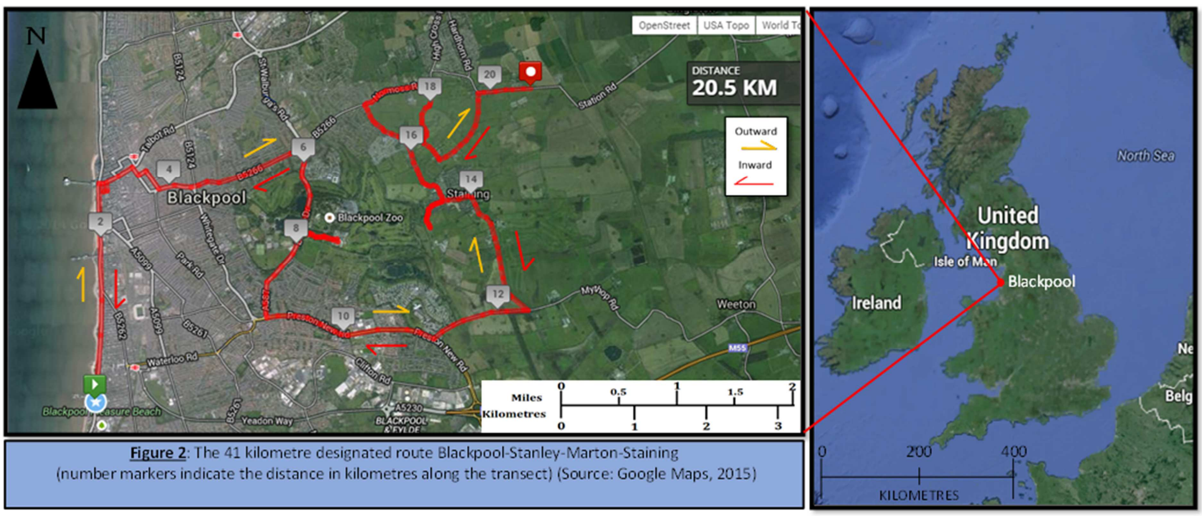

Figure 2: The 41 kilometre designated route Blackpool-Stanley-Marton-Staining (number markers indicate the distance in kilometres along the transect) (Source: Google Maps, 2015)

4.2 Data acquisition

The data collection period corresponded with anticyclonic conditions between July and September 2014. The data for morning profiles was achieved after sunrise (8.30-10.30am), between 2 and 4 pm for afternoon profiles, and around sunset for evening profiles (7.00 - 8.30pm) at a time of maximum heat island intensity (Oke, 1987). These times were chosen to reflect Oke's (1982) research demonstrating the variability in the UHI cycle for cities with temperature climates. The morning, afternoon and evening transects were repeated on six separate occasions in order to establish more reliable trends within the data (adapted from Gallo et al., 1993). However, the choice of sampling days needed to correspond with the available free time of both the observer and driver and relied upon particular weather conditions. Consequently, weather forecasts provided by the Met Office were routinely monitored, in addition to the regular analysis of the synoptic charts available from their website.

4.3 Instrumentation

Heusinkveld et al (2010) and Sundborg (1950) formed the basis for the following methodologies. Using a car for transportation, measurements were obtained using the Voltscraft digital data logger, with three sensors used for recording temperature, relative humidity and atmospheric pressure at 60-second intervals. These sensors positioned 1.5 metres above ground level secured using a suction cup tripod holder. The Voltscraft data logger is easy to use and has a relatively rapid response (lag constant 10 seconds) and is accurate to within one degree Celsius. Despite the data logger being sheltered using a Stevenson Screen, the values logged whilst the vehicle was stationary (for >2 minutes) was discarded to avoid heat-spikes (errors) caused by the residual heat from car engines. Ten minutes prior to recording, the data logger was exposed to the outside conditions and the Voltscraft software settings calibrated using a laptop.

4.3.1 Wind observations

In order to assess the advancement of the sea breeze, wind velocity measurements were collected from five sampling points at equal increments from the coastline. The sampling points were: South Pier, Blackpool Town Centre, Stanley Park, Marton-Mere, and Staining. An anemometer recorded the local wind speed, taking a 20 second average in km/h and observing wind direction.

4.4 Data processing and analytical methods

This research compares and evaluates the suitability of three heat indices, the WBGT, South African Discomfort Index and the Canadian Humidex. These indicators were chosen as they factor in relative humidity and the dry-bulb temperature. Moreover, the Canadian Humidex has been extensively used in previous studies (Basara et al., 2010; Kosatsky et al., 2005; Smoyer-Tomic & Rainham, 2001). Research carried out by Steeneveld et al. (2011) and Fischer et al. (2012) is replicated, with the WBGT estimated via the substituted approximation formula $AWBGT = 0.567T + 0.393e + 3.94$, where T is the dry-bulb temperature in °C, and e is the vapour pressure in hPa (hectopascal). The Discomfort Index (D.I) is calculated using the formula $D.I = (2 \times T) + (RH/100 \times T) + 24$, where RH is the relative humidity. Finally, the Canadian Humidex is obtained by the formula $Humidex = T + (0.5555 * (e - 10))$.

Tables 1 to 3 show the health risk categories and corresponding values for each of the three heat indicators. These risk tables are referred to in the following section in order to quantify heat stress.

Table 1: Discomfort Index Risk Chart (South African Weather Service, 2015)

Discomfort Value	**Health Risk (Heat Exposure)**
<90	**Low discomfort**
90 – 100	**Very uncomfortable**
100 – 110	**Extremely uncomfortable**
110 +	**Hazardous**

Table 2: Canadian Humidex Risk Chart (adapted from Environment Canada, 2014)

Humidex Value	**Health Risk (Heat Exposure)**
<29°C	**Comfortable**
30 – 39°C	**Moderate discomfort**
40 – 45°C	**High discomfort**
>45°C	**Extreme discomfort**

Table 3: Wet-Bulb Globe Temperature Risk Chart (adapted from Binkley et al., 2002)

WBGT	**Health Risk (Heat Exposure)**
<18°C	**Low**
18 – 23°C	**Moderate**
23 – 28°C	**High**
>28°C	**Extreme**

5 RESULTS

5.1 Heat indices

5.1.1 Discomfort Index

A minimum value of 65.0 was achieved on the evening of day 5 and a maximum value of 101.3 during the afternoon of day 2. The mean value lies below the minimum threshold value of 90 at 80.3 displaying low discomfort (Table 1). However, the 95th and 98th percentile values are considerably higher at 96.4 and 99.3 respectively, indicating high levels of heat stress. When looking at each time of day individually heat stress is most common in the afternoon and least common during the morning, with mean values ranging from 78.1 to 84.7.

5.1.2 Canadian Humidex

Regarding the Canadian Humidex, the range of values varies between 16.0°C and 37.0°C. The mean value of 24.0°C was below the discomfort threshold value of 30°C (Table 2). Nevertheless, similar to the D.I the 95th and 98th percentile showed extreme spikes for discomfort with at 34.5°C and 36°C, notably above the threshold value.

5.1.3 Wet Bulb Globe Temperature

The AWBGT calculations display similar patterns to the previous two real feel indicators with a relatively low mean value of 21.5°C (moderate discomfort). However, the 95th and 98th percentile values of 28.2°C and 29.4°C reach extreme levels (Table 3).

5.2 Extreme values

An absolute maximum dry-bulb value of 31.3°C was obtained on the 23rd July 2014 during a prolonged heat wave. The Canadian Humidex peaked at 36.1°C, the D.I rose to 99.4, and the WBGT to 29.1°C in the urban area (Table 4). Whereas the heat index values for the vegetated parks peaked at 36.6°C, 99.8 and 29.4°C correspondingly. The evening statistics show a slow cool down in the urban areas compared to urban parks, with all indices remaining high during the evening at 33.9°C, 95.4 and 27.9°C respectively (Table 5). This suggests that there is a relationship between land cover and the heat index.

Table 4: Direct comparison of peak afternoon heat indices for both urban and vegetated urban parks.

Afternoon Heat Index	Urban Areas	Urban Parks
Maximum D.I	99.4	99.8
Maximum Canadian Humidex	36.1°C	36.6°C

Maximum WBGT	29.1°C	29.4°C

Table 5: Direct comparison of peak evening heat indices for urban and vegetated urban parks.

Evening Heat Index	Urban Areas	Urban Parks
Maximum D.I	95.4	92.8
Maximum Canadian Humidex	33.9°C	32.3°C
Maximum WBGT	27.9°C	27.0°C

5.5 Interpolation outcomes

After calculating the mean dry-bulb temperatures along the route, the IDW interpolation was applied to plot the spatial distribution of values. Figures 3 and 4 provide a comparison of afternoon and evening conditions, illustrating the warm (red) and cool areas (green). The exact position of the UHI varied according to the time of day. During the afternoon, there were two visible hotspots (see Figure 3), the first located at 3.5-5.0 kilometres and the second at 7.0 - 8.0 kilometres. Whereas, the evening UHI was concentrated over the urban centre (Figure 4). It can be observed that the evening's highest values are located within the urban zone (toward the north and west of the town), where the UHI is normally found, with the coolest conditions located further inland around Staining. The magnitude of the evening urban-rural temperature difference (ΔT °C) in Figure 4 (3.1˚C) is over twice as large as the magnitude of the afternoon intensity (1.2 ˚C) in Figure 3. During the afternoon, anomalously cool values are present along the coast (0-0.4 ˚C), with the UHI displaced inland. Consequently, urban parks (6.75 – 8.25 kilometres along the route) achieved comparably high temperatures to the urbanised zone, but during the evening experienced relatively cool temperatures (1.2˚C lower).

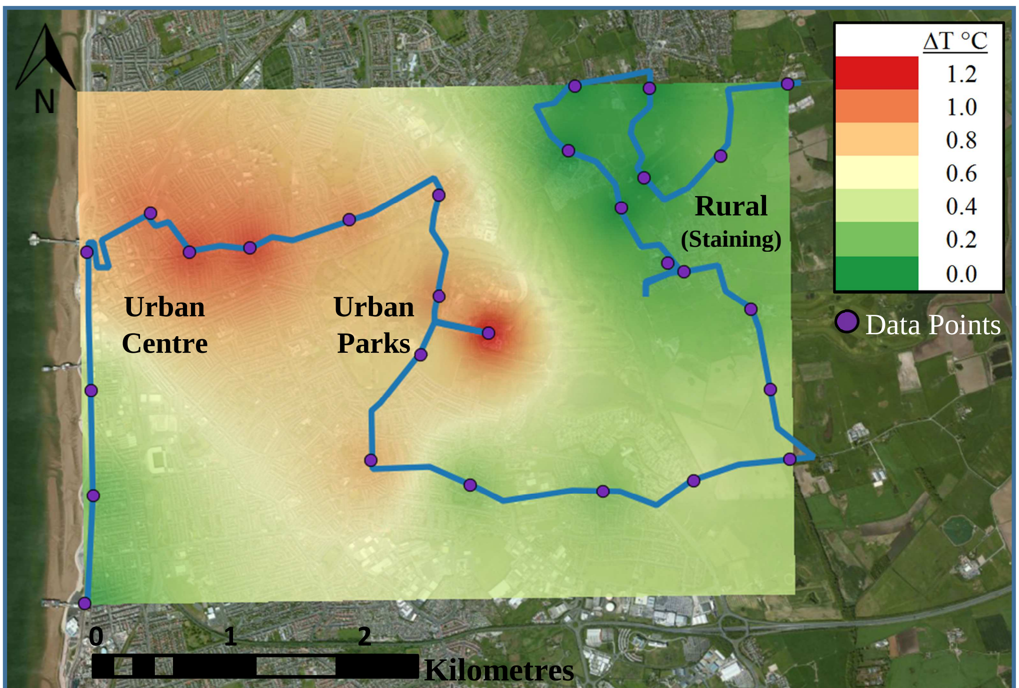

Figure 3: Spatial distribution of the mean afternoon UHI intensity for Blackpool and its surroundings with respect to the rural background temperature (lowest value), as calculated from the Inverse Distance Weighting (IDW) interpolation model in QGIS. The blue line shows the route taken.

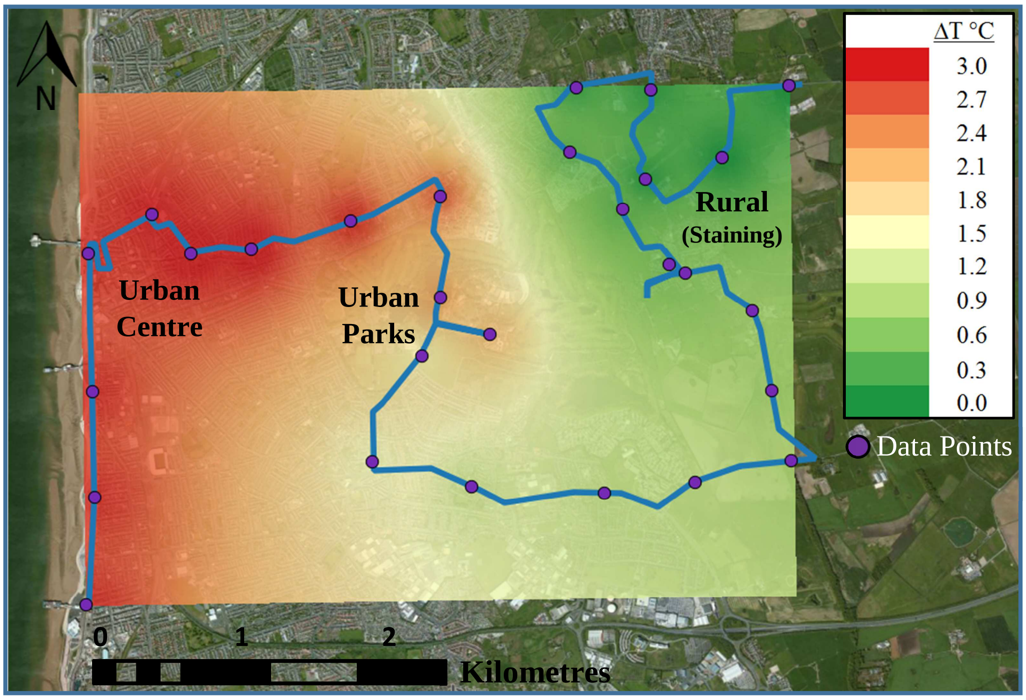

Figure 4: Spatial distribution of the mean evening UHI intensity for Blackpool and its surroundings with respect to the rural background temperature, as calculated from the IDW interpolation model in QGIS. The blue line shows the route taken.

The afternoon UHI during the heat wave is approximately 1.5 times the magnitude of the typical afternoon UHI at 1.9°C (see Figure 5). Similar to figure 3, the core of the warmth is displaced inland, situated close to urban parks (1.5-1.9°C), with cooler temperatures inland and along the coastal strip (0–0.9°C). Rural locations to the south-east of the region, and located by Staining experienced temperatures 1.0°C above the rural background temperature.

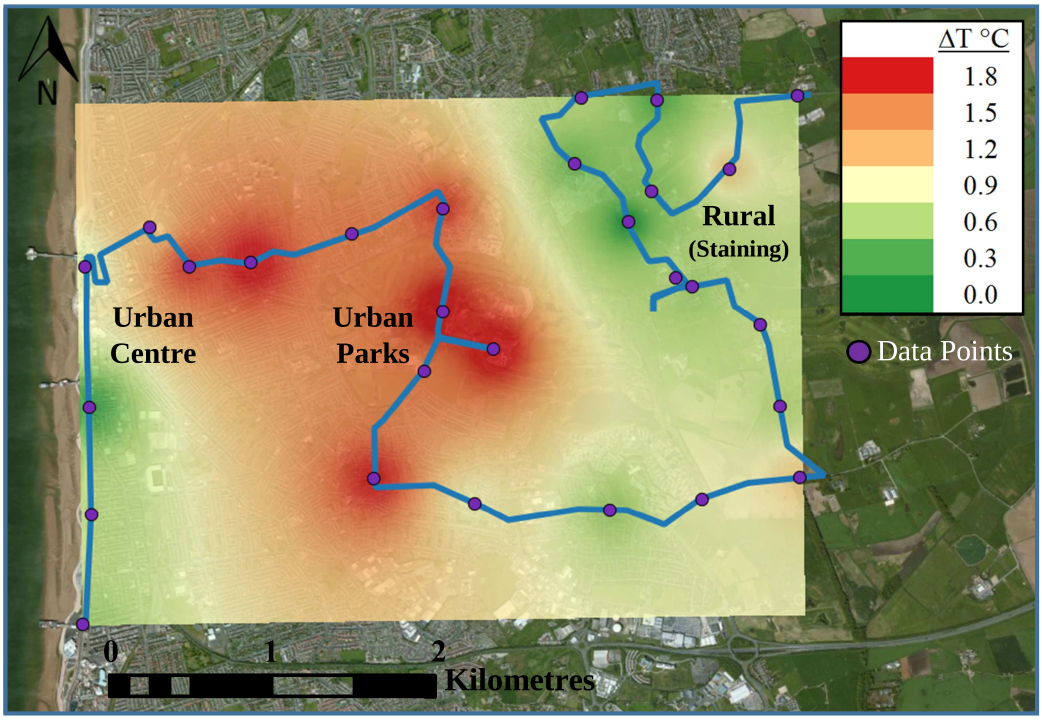

Figure 5: Spatial distribution of the mean UHI intensity for afternoon profiles during the July heat wave, for Blackpool and surrounding areas with respect to the rural background temperature, as calculated from the IDW interpolation model in QGIS. The blue line shows the route taken.

6 Discussion

6.1 Diurnal Heat Island intensity

The intensity and variation of Blackpool's UHI reflect research carried out by Oke (1987) with the most intense conditions occurring at sunset (3.4°C), and the least intense during the afternoon (1.8°C). When considering all times of day (morning, afternoon and evening conditions), the warmest values occurred 3 to 5 kilometres along the transect - where there is a balance between the moderating effects of the sea and warmth provided by urban fabrics. The coolest values reflect rural areas inland, where stored energy (solar radiation) is lost quickly after sunset (Arnfield, 2003; Rizwan et al., 2008; Taha 1997).

6.2 Objective 1: Influence of land cover

The importance of land type for modifying the strength of Blackpool's UHI is consistent with the reviewed literature (Dimoudi & Nikolopoulou, 2003; Georgi & Dimitriou, 2010; Mirzaei & Haghighat 2010; Niachou et al., 2001), with vegetation proving to be a fundamental aspect of reducing local temperatures. Evening profiles revealed a meaningful reduction in temperatures within urban parks of up to 1.1°C (see Figure 4). This was anticipated due to the lack of urban fabrics, which are able to retain solar radiation received during daylight (Arnfield, 2003; Heusinkveld et al., 2010; Rizwan et al., 2008). Furthermore, the cooler evening period surrounding urban parks and horticultural (rural) land types provided relief during the hottest periods of weather, supporting research by Dimoudi & Nikolopoulou (2003) and Niachou et al. (2001). This is vital as lower evening and overnight temperatures are required to minimise mortality rates (Kovats & Hajat, 2008). The urban/suburban land types experienced the greatest range in temperatures, suggesting that the urban area may be subject to greater extremes. This supports the use of vegetation to reduce extremes within the urbanised region because they seem to regulate the local climate, evidenced by the smaller range in temperature. For afternoon profiles, the small difference in dry-bulb temperature (0.1°C) between grassland (parks) and urban land types indicate that the cooling capabilities of vegetation are reduced during the warmest part of the day. Likewise, the value is less than the accuracy of the sensor (±1°C), so the difference should be discredited. Consequently, vegetation would not be able to moderate heat stress in the city. The ameliorating effect of the urban parks is diminished further by the heat wave interpolation model in figure 5, which shows the highest values situated within the vegetated locality. These findings support claims that in humid environments cooling benefits of vegetation are reduced (Theodosiou, 2003).

6.3 Objective 2: Coastal location

The dry-bulb temperature distribution for Blackpool and its surroundings indicate that the UHI is conditioned by two main factors: the Irish Sea, and the concentration of human activity in the urban centre. Water bodies influenced the intensity of the UHI whilst illustrating the complex interaction between the marine and terrestrial environment. The interpolation outcomes (Figures 3-5), and landward temperature profiles reflect the great thermal inertia of the ocean, illustrating its slower response to fluctuating air temperatures. This caused a rapid landward decline in dry-bulb temperature during the evening, with larger anomalies by the coast and cool conditions visible by Staining (Figure 4). This research validates the importance of interactions between the sea breeze and heat island circulation (HIC) (Freitas et al., 2007). Thermal contrasts between the coastal strip (up to 3°C) (Figure 3 and 5) and the urban centre resulted in a strong sea breeze during the afternoon. This caused the landward advancement of maritime air (Freitas et al., 2007) that displaced the UHI by 1.5 kilometres inland. Large temperature gradients were also a feature along the coastal strip supporting past research of coastal UHIs in New York, California and Aveiro, Portugal by Bornstein, (1968) and Pinho & Orgaz (2000), which indicates an interaction between the sea breeze and HIC. The Irish Sea and HIC appear to work together to enhance the urban-rural temperature contrast (strong landward decline) in the evening. As a result, the UHI corresponds with the built-up area by the coast for evening profiles (see Figure 4). Perhaps this is due to the development of the land breeze limiting the maritime influence of large water bodies. But in the afternoon, they work against one another, resulting in cooler values 0-3 kilometres along the route.

Wind speeds were lower in the urban centre than along the coastal strip, which suggests that the sea breeze has caused an urban stagnation region. The urban stagnation region has been documented to delay the advancement of sea breezes inland, encouraging the development of UHI's (Freitas et al., 2007; Yoshikado, 1994), contesting Hidore & Oliver's (1993) findings that the sea breeze acts to disperse urban heat. As the land cooled in the evening, the sea caused warmer conditions to be retained by the coast. This amplified the urban-rural difference, with a strong landward decline in temperatures that magnified the UHImax (Gedzelman et al., 2003; Roth et al., 1989). Therefore, the coastal position of the town may not reduce the UHImax as the UHI persists under the influence of the sea breeze. This supports the study in Tokyo by Yoshikado (1994). Throughout the afternoon, the onshore flow provides a local cooling service along the coastal strip, which could provide locals with comparably cool temperatures in the hottest weather conditions.

6.4 Objective 3: Quantifying heat stress

The Canadian Humidex, D.I and WBGT indicators agree that, while mean heat stress values are low-moderate, the 95th and 98th percentiles show much greater discomfort from high temperatures and humidity. This is a noteworthy result for two reasons:

1) It demonstrates the irregularity of extreme heat, and
2) It shows that heat stress can be an issue for cities in a cooler temperate climate zone (supporting Steeneveld et al., 2011).

When the combined effects of heat and humidity are taken into consideration, urban parks result in a less valuable cooling service, which is reflected in the real feel values (see Table 4). This was previously unconfirmed in academic literature (Dimoudi & Nikolopoulou, 2003; Niachou et al., 2001; Zoulia et al., 2009). The results of the interpolation models (Figures 3-5) and temperature anomaly profiles suggest that smaller UHI intensity and sea breeze contribute to the higher heat indices found in urban parks during the afternoon. Sea breezes are likely to have reduced levels of discomfort by the coast - by lowering dry bulb temperature (shown by the cooler anomalies by the coast (at 0 – 2 kilometres). This seems to have caused the landward migration of the heat island (Figure 3) as suggested previously, directly affecting the spatial distribution and intensity of the UHI. The development of the land breeze in the evening supports this explanation, as it resulted in cooler evening heat indices within the vegetated locality compared to the urban centre (Table 5). Therefore, there is a relationship between land cover and heat index values in the evening, but this is less evident during the afternoon because of Blackpool's coastal position.

7 CONCLUSION

7.1 Research implications

This investigation has effectively quantified the magnitude of Blackpool's urban heat island and delivered a convincing measure of the role the ocean plays on moderating the temperature profile of the coastal strip. The heat indices reveal that discomfort from high temperatures and humidity reaches extreme levels at the 95th percentile, despite low average values. This goes against the viewpoint highlighted by Steeneveld et al. (2011), that the impacts of high temperatures are insignificant in temperate climate zones. The role of vegetation as a mitigation measure is shown to be limited as lowered temperatures are counteracted by higher humidity values resulting in similar heat indices. This shows a marked discrepancy with the works of Chandler, 1965; Herrington et al., 1972; Oke, 1989; Spronken-Smith & Oke 1998; and Oláh 2012, outlined earlier in section 2.6.1. However, these findings support the idea that increasing vegetation in humid climates may not offer many advantages (Theodosiou, 2003) and that alternative solutions should be considered (e.g. reducing in anthropogenic energy generation).

7.2 Limitations and improvements

There are limitations that must be considered when interpreting these results. The data collected on both the outward and return components of the route were averaged. This method assumes that there is a constant cooling rate, which is unlikely to be valid in reality (Melhuish & Pedder, 1998). The method could be improved by utilising a bicycle (Heusinkveld et al, 2010) rather than a car for transportation, which would facilitate data acquisition within Marton-Mere nature reserve, by utilising bike lanes. Using a bicycle would also result in a greater number of data points and perhaps a more reliable interpolation of the nature reserve.

8 REFERENCES

Ado, H. Y. (1992). Numerical study of the daytime urban effect and its interaction with the sea breeze. Journal of Applied Meteorology, 31(10), 1146-1164.

Arnfield, A. J. (2003). Two decades of urban climate research: a review of turbulence, exchanges of energy and water, and the urban heat island. *International journal of climatology*, *23*(1), 1-26.

Basara, J. B., Basara, H. G., Illston, B. G., & Crawford, K. C. (2010). The impact of the urban heat island during an intense heat wave in Oklahoma City. *Advances in Meteorology*, *2010*.

Binkley, H. M., Beckett, J., Casa, D. J., Kleiner, D. M., & Plummer, P. E. (2002). National Athletic Trainers' Association position statement: exertional heat illnesses. *Journal of Athletic Training*, *37*(3), 329.

Bornstein, R. D. (1968). Observations of the urban heat island effect in New York City. *Journal of Applied Meteorology*, *7*(4), 575-582.

Chandler, T. J. (1965). *The climate of London* (Vol. 292). London: Hutchinson.

City Population. (2011). *Population United Kingdom: Urban Areas*. Retrieved from http://www.citypopulation.de/UK-UA.html

Cohen, B. (2006). Urbanization in developing countries: Current trends, future projections, and key challenges for sustainability. *Technology in society*, *28*(1), 63-80.

Conti, S., Meli, P., Minelli, G., Solimini, R., Toccaceli, V., Vichi, M., ... & Perini, L. (2005). Epidemiologic study of mortality during the Summer 2003 heat wave in Italy. *Environmental research*, *98*(3), 390-399.

Dawson, R. J., Dickson, M. E., Nicholls, R. J., Hall, J. W., Walkden, M. J., Stansby, P. K., & Watkinson, A. R. (2009). Integrated analysis of risks of coastal flooding and cliff erosion under scenarios of long term change. *Climatic Change*, *95*(1-2), 249-288.

Dimoudi, A., & Nikolopoulou, M. (2003). Vegetation in the urban environment: microclimatic analysis and benefits. *Energy and buildings*, *35*(1), 69-76.

Environment Canada. (2014). Spring and Summer Weather Hazards. Retrieved 2nd December 2015 from https://ec.gc.ca/meteoweather/default.asp?lang=En&n=6C5D4990-1

Fischer, E. M., Oleson, K. W., & Lawrence, D. M. (2012). Contrasting urban and rural heat stress responses to climate change. *Geophysical research letters*, *39*(3).

Freitas, E. D., Rozoff, C. M., Cotton, W. R., & Dias, P. L. S. (2007). Interactions of an urban heat island and sea-breeze circulations during winter over the metropolitan area of São Paulo, Brazil. *Boundary-Layer Meteorology*, *122*(1), 43-65.

Gaffen, D. J., & Ross, R. J. (1998). Increased summertime heat stress in the US. *Nature*, *396*(6711), 529-530.

Gallo, K. P., McNab, A. L., Karl, T. R., Brown, J. F., Hood, J. J., & Tarpley, J. D. (1993). The use of a vegetation index for assessment of the urban heat island effect. *Remote Sensing*, *14*(11), 2223-2230.

Gedzelman, S. D., Austin, S., Cermak, R., Stefano, N., Partridge, S., Quesenberry, S., & Robinson, D. A. (2003). Mesoscale aspects of the urban heat island around New York City. *Theoretical and Applied Climatology*, *75*(1-2), 29-42.

Georgi, J. N., & Dimitriou, D. (2010). The contribution of urban green spaces to the improvement of environment in cities: Case study of Chania, Greece. *Building and Environment*, *45*(6), 1401-1414

Google Maps, (2015). *Location Maps* retrieved from https://www.google.co.uk/maps/@53.8542149,- 3.11838,2204657m/data=!3m1!1e3

Herrington, L. P., Bertolin, G. E., & Leonard, R. E. (1972, October). Microclimate of a suburban park. In *Proceedings of a Conference on the Urban Environment, American Meteorological Society, Boston* (pp. 43-44).

Heusinkveld, B. G., Van Hove, L. W. A., Jacobs, C. M. J., Steeneveld, G. J., Elbers, J. A., Moors, E. J., & Holtslag, A. A. M. (2010, April). Use of a mobile platform for assessing urban heat stress in Rotterdam. In *Proceedings of the 7th Conference on Biometeorology* (Vol. 12).

Jenerette, G. D., Harlan, S. L., Stefanov, W. L., & Martin, C. A. (2011). Ecosystem services and urban heat riskscape moderation: water, green spaces, and social inequality in Phoenix, USA. *Ecological Applications*, *21*(7), 2637-2651.

Jenkins, K., Hall, J., Glenis, V., Kilsby, C., McCarthy, M., Goodess, C., ... & Birkin, M. (2014). Probabilistic spatial risk assessment of heat impacts and adaptations for London. *Climatic change*, *124*(1-2), 105-117.

Köppen, W. (1931). *Grundriss der Klimatkunde. Zweite, verbesserte Auflage der Klimate der Erde*. Walter de Gruyter und Company.

Kovats, R. S., & Hajat, S. (2008). Heat stress and public health: a critical review. *Annu. Rev. Public Health*, *29*, 41-55.

Kosatsky, T., King, N., & Henry, B. (2005). How Toronto and Montreal (Canada) respond to heat. In *Extreme Weather Events and Public Health Responses* (pp. 167-171). Springer Berlin Heidelberg.

Kunst, A. E., Looman, C. W., & Mackenbach, J. P. (1993). Outdoor air temperature and mortality in the Netherlands: a time-series analysis. *American Journal of epidemiology*, *137*(3), 331-341.

Landsberg, H. E. (1981). The Urban Climate. New York: Academic Press.

Laschewski, G., & Jendritzky, G. (2002). Effects of the thermal environment on human health: an investigation of 30 years of daily mortality data from SW Germany. *Climate Research*, *21*(1), 91-103.

Melhuish, E., & Pedder, M. (1998). Observing an urban heat island by bicycle. *Weather*, *53*(4), 121-128.

Met Office. (2014). *Blackpool 1981-2010 Averages*. Retrieved from the Met Office website http://www.metoffice.gov.uk/climate/uk/averages/19812010/sites/blackpool.html

Met Office. (2016). *Air Mass Types*. Retrieved from the Met Office website http://www.metoffice.gov.uk/learning/learn-about-the-weather/how-weather-works/air-masses/types

Mirzaei, P. A., & Haghighat, F. (2010). Approaches to study urban heat island–abilities and limitations. *Building and Environment*, *45*(10), 2192-2201.

Niachou, A., Papakonstantinou, K., Santamouris, M., Tsangrassoulis, A., & Mihalakakou, G. (2001). Analysis of the green roof thermal properties and investigation of its energy performance. *Energy and buildings*, *33*(7), 719-729.

Oke, T. R. (1973). City size and the urban heat island. *Atmospheric Environment (1967)*, *7*(8), 769-779.

Oke, T. R. (1982). The energetic basis of the urban heat island. *Quarterly Journal of the Royal Meteorological Society*, *108*(455), 1-24.

Oke, T. R., & Cleugh, H. A. (1987). Urban heat storage derived as energy balance residuals. *Boundary-Layer Meteorology*, *39*(3), 233-245.

Oke, T. R., Crowther, J. M., McNaughton, K. G., Monteith, J. L., & Gardiner, B. (1989). The micrometeorology of the urban forest [and discussion]. *Philosophical Transactions of the Royal Society B: Biological Sciences*,*324*(1223), 335-349.

Oláh, A. B. (2012). The possibilities of decreasing the urban heat island. *Applied Ecology and Environmental Research*, *10*(2), 173-183.

Pinho, O. S., & Orgaz, M. M. (2000). The urban heat island in a small city in coastal Portugal. *International Journal of biometeorology*, *44*(4), 198-203.

Rizwan, A. M., Dennis, L. Y., & Liu, C. (2008). A review on the generation, determination and mitigation of Urban Heat Island. *Journal of Environmental Sciences*, *20*(1), 120-128.

Small, C., & Nicholls, R. J. (2003). A global analysis of human settlement in coastal zones. *Journal of Coastal Research*, 584-599.

Smoyer, K. E., Rainham, D. G., & Hewko, J. N. (2000). Heat-stress-related mortality in five cities in Southern Ontario: 1980–1996. *International Journal of Biometeorology*, *44*(4), 190-197.

Smoyer-Tomic, K. E., & Rainham, D. G. (2001). Beating the heat: development and evaluation of a Canadian hot weather health-response plan. *Environmental health perspectives*, *109*(12), 1241.

South African Weather Service. (2015). What is the Discomfort Index? Retrieved December 6, 2015, from http://www.weathersa.co.za/learning/educational-questions/58-what-is-the-discomfort-index?recache=1

Spronken-Smith, R. A., & Oke, T. R. (1998). The thermal regime of urban parks in two cities with different summer climates. *International journal of remote sensing*, *19*(11), 2085-2104.

Steadman, R. G. (1979). The assessment of sultriness. Part I: A temperature-humidity index based on human physiology and clothing science. *Journal of Applied Meteorology*, *18*(7), 861-873.

Steadman, R. G. (1984). A universal scale of apparent temperature. *Journal of Climate and Applied Meteorology*, *23*(12), 1674-1687.

Steeneveld, G. J., Koopmans, S., Heusinkveld, B. G., Van Hove, L. W. A., & Holtslag, A. A. M. (2011). Quantifying urban heat island effects and human comfort for cities of variable size and urban morphology in the Netherlands. *Journal of Geophysical Research: Atmospheres (1984–2012)*, *116*(D20).

Sundborg, Å. (1950). Local climatological studies of the temperature conditions in an urban area. *Tellus*, *2*(3), 222-232.

Taha, H. (1997). Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat. *Energy and buildings*, *25*(2), 99-103.

Theodosiou, T. G. (2003). Summer period analysis of the performance of a planted roof as a passive cooling technique. *Energy and Buildings*, *35*(9), 909-917.

Voogt, J. A., & Oke, T. R. (2003). Thermal remote sensing of urban climates. *Remote sensing of environment*, *86*(3), 370-384.

Watkins, R., Palmer, J., & Kolokotroni, M. (2007). Increased temperature and intensification of the urban heat island: implications for human comfort and urban design. *Built Environment (1978)*, 85-96.

Xu, H. Q., & Chen, B. Q. (2004). Remote sensing of the urban heat island and its changes in Xiamen City of SE China. *Journal of Environmental Sciences*, *16*(2), 276-281.

Yoshikado, H. (1994). Interaction of the sea breeze with urban heat islands of different sizes and locations. *Journal of the Meteorological Society of Japan*, *72*(1), 139-143.

Zoulia, I., Santamouris, M., & Dimoudi, A. (2009). Monitoring the effect of urban green areas on the heat island in Athens. *Environmental monitoring and assessment*, *156*(1-4), 275-292.