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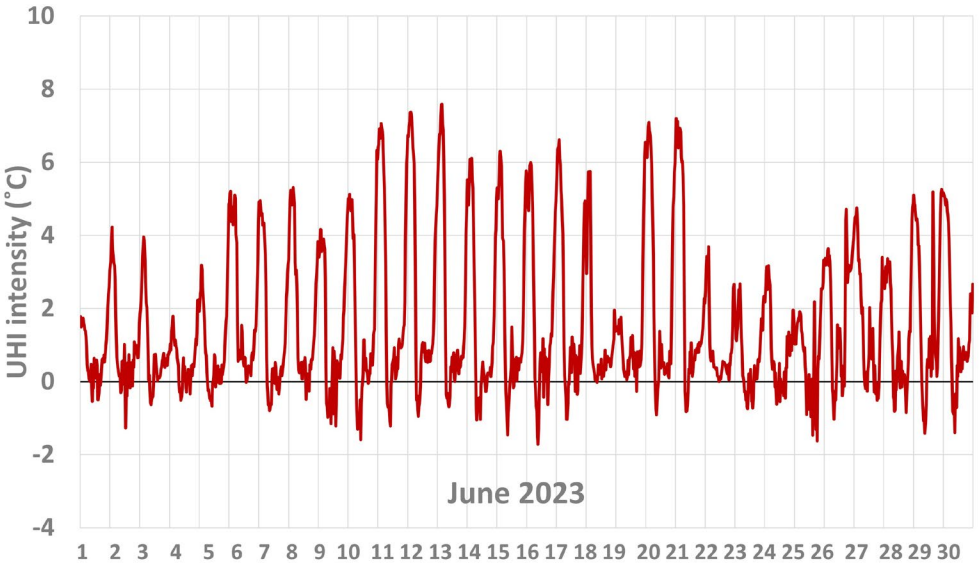
INTERACTION OF WEATHER, AIR QUALITY AND URBAN HEAT ISLAND IN THE CITY OF TURKU, SW FINLAND

A Case Study of 2021 and 2023



Juuso Suomi, Krista Väätäinen & Jukka Käyhkö

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Turku 2025
University of Turku
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CONTENTS

ABSTRACT

This paper examines connections between weather, air quality and urban heat island (UHI) in the mid-sized (206 000 inhabitants) coastal city of Turku, southwestern Finland during the years 2021 and 2023. The study is implemented as part of the RESPONSE research project (https://h2020response.eu/) funded by the European Commission's Horizon 2020 Framework Programme. The UHI intensity calculations and related spatial temperature difference analyses were based on the temperature data of Turku Urban Climate Research Group (TURCLIM) local climate observation network of the Geography Division at the University of Turku. TURCLIM network consists of 83 loggers, that record temperature and relative humidity (T/RH) in various kind of environments in the Turku region at half-an-hour interval. The temperature data of 18 of those loggers were utilised in this study. Air quality data was provided by the city of Turku, while the wind speed and cloudiness data were recorded by the Finnish Meteorological Institute (FMI). UHI intensity was quantified at half-an-hour interval based on the temperature differences between selected urban-suburban and urban-rural observation site pairs. Monthly and hourly summaries were also produced to capture seasonal and diurnal variability. Air quality was examined through five parameters (AQI, NO_2, NO, PM_{10}, $PM_{2.5}$), and its relationship with UHI intensity was tested with correlation analyses focusing on morning and afternoon rush hours. Additional analyses included the influence of wind speed, cloudiness, and the North Atlantic Oscillation (NAO) on UHI intensity, alongside with the case studies on heatwaves and frost periods to assess UHI behaviour during extreme weather events. Regarding the UHI intensity, the analysis revealed that UHI intensities were generally highest during summer months, but of the two single peak values of over 9 °C, one occurred in summer and one in winter. Urban cold islands (UCI) occurred occasionally, mainly during summer afternoons. The UHI intensity was generally higher, when calculated based on the rural reference site of 10 km distance from the city centre, compared to the respective suburban reference sites with respective distance of approximately 4 km. Air quality correlations with UHI were strongest during winter mornings, particularly regarding the nitrogen compounds, and generally weaker in summer. During wintertime these correlations were positive, denoting that the air quality was poorer during high UHI intensity situations, whereas in summer there were both positive and negative correlations. Wind speed and cloudiness correlated negatively with UHI, especially at night. Statistically significant positive correlations between the UHI and NAO index occurred in January and April, whereas statistically significant negative correlations appeared in February and October. However, no consistent correlation pattern between the NAO index and UHI intensity was found. Regarding spatial temperature differences during the cold and warm case study periods, urban areas were clearly warmer than the rural ones. Suburban Turku Student Village area settled thermally for most of the time between the urban and rural areas. In an annual comparison, 2021 showed stronger and more consistent statistically significant UHI–air quality relationships than 2023, emphasizing the complex interactions between urban climate, pollution, and local weather conditions. While both years exhibited broadly similar seasonal and spatial UHI patterns, some month-specific contrasts emerged. In 2021, higher UHI peaks were recorded in

several winter and autumn months, whereas in 2023 stronger peaks occurred in March, June, and November. The strongest UCI event of over 3 °C was also observed in 2023. Despite these differences, monthly UHI behaviour often reminded each other across the two years. Similarly, the overall number of statistically significant UHI–air quality correlations was comparable between the years, even if their timing and strength varied, the year 2021 showing generally stronger coefficients.

Keywords: Air quality, urban heat island intensity, cloudiness, wind speed, North Atlantic Oscillation

1
THEORETICAL BACKGROUND

Urban and other densely built areas are often characterized by specific microclimate that differs from surrounding rural areas. A common phenomenon is the urban heat island (UHI) effect in which the urban areas appear as warmer compared to the nearby rural areas (Oke, 1987). One reason for UHI is the larger amount of anthropogenic heat release in urban than in rural areas. Main contributors in anthropogenic heat release are traffic, industrial heat release and heating of buildings. Evapotranspiration is often lower in urban than in rural areas, which also contributes to the formation of UHI. One important factor behind the UHI is that building and pavement materials often have high heat storage capacity (Mohajerani et al., 2017), which enables the urban structures to absorb plenty of heat during daytime. The stored heat is released in the air during evening and night supporting the formation of UHI. This mechanism is in crucial role in summer. Multiple different factors have an impact on how UHIs appear in different cities. These include land use / land cover, topography, distance to larger water bodies and weather patterns (Suomi, 2014). Of the weather parameters, UHI intensity has often negative correlation with wind speed and cloudiness (Morris et al., 2001)

Air quality is posing a risk especially in urban environments. The World Health Organization (WHO) classifies air pollution as one of the highest environmental risks to people globally causing sickness and premature deaths (Sokhi, 2024). Air quality monitoring methods and activity vary regionally but it offers essential information about the city environment and welfare conditions. Measurements can be conducted either ground-based with on-site monitoring devices placed in city centres or by remote sensing where the measurements are conducted by satellites or UAVs. Global air quality guidelines (AQGs) are provided by WHO and are available for particulate matters that are equal to or less than 2.5 and 10 micrometres in diameter, tropospheric ozone, nitrogen dioxide, sulphur dioxide and carbon monoxide (Table 1). The European Union has set guidelines for the same air pollutant types but also provides guidelines for other pollutants like benzene, polycyclic aromatic hydrocarbons and heavy alloys such as nickel, cadmium and arsenic (Directive 2008/50/EC, 2008). Finland as an EU country follows the EU air quality legislation and guidelines. National guidelines set in 1996 exist and are meant to be used in planning and decision making performed by environmental authorities (Finlex 480/1996). Cities have an obligation to collect air quality data and warn citizens when the guideline values are exceeded.

The UHI can enhance the conditions for air pollution and diminish air quality in urban areas (Mohajerani et al., 2017; Vujovic et al., 2021). It can increase the amount of smog in cities and lead to a higher level of greenhouse gas emissions due to increased energy usage through cooling systems. Intense solar radiation during summers can additionally enhance photochemical reactions which produce tropospheric ozone, a poisonous compound for humans. In urban areas both UHI and air pollution are affected by anthropogenic activity (Cichow-

Table 1. Global air quality guidelines (World Health Organization, 2021), European Union air quality standards (Directive 2008/50/EC, 2008) and National air quality guidelines in Finland (Finlex 480/1996).

		Guidelines (µg/m³)		
Pollutant	Averaging period	Global (WHO)	European Union	National (Finland)
PM2.5	1 year	5	25	
	24 hours	15		
PM10	1 year	15	40	
	24 hours	45	50	70
O3	Peak season	60		
	8 hours	100	120	
NO2	1 year	10	40	
	24 hours	25		70
	1 hour	200	200	150
SO2	24 hours	40	125	80
	1 hour		350	250
	10 minutes	500		
CO	24 hours	4 000		
	8 hours		10 000	8 000
	1 hour	30 000		20 000
Lead	1 year	0.5	0.5	
Benzene	1 year		5	
Arsenic	1 year		0.006	
Cadmium	1 year	0.005	0.005	
Nickel	1 year		0.02	
PAHs*	1 year		0.001	
Total suspended particle	1 year			50
	24 hours			120
Total reduced sulphur	24 hours			10

*Polycyclic Aromatic Hydrocarbons

icz & Bochenek, 2024). When the pollutants are trapped close to ground-level with a mass of warmer air over, the distribution of the pollution accelerates. However, air pollutants and aerosols can prevent solar radiation from reaching the ground due to their reflective surfaces, and this can for its part mitigate the UHI (Han et al., 2020). This mechanism is most relevant in summer, while in winter the aerosols can have an intensifying effect on UHI. Wind conditions have an effect on both UHI and air pollution. Wind mixes air and dilutes air pollution concentrations and smog in urban areas (Wang et al., 2021). This is relatively effective especially in coastal cities with regular land-sea breeze circulation. By mixing air, wind also weakens the UHI intensity (Morris et al., 2001).

The North Atlantic Oscillation (NAO) refers to the atmospheric oscillation between the Arctic and the subtropical Atlantic. It is usual-

ly determined based on sea-level air pressure difference between the two rather permanent pressure centres in the North Atlantic; the Icelandic Low and Azores High. The NAO index gets positive values, when the air pressure difference between the Icelandic Low and Azores High is higher than on average, whereas during the negative NAO index conditions, the respective air pressure difference is lower than on average. In northern Europe, the impact of NAO is most obvious in winter, when positive NAO index situations are associated with wetter and milder than normal weather, whereas during negative NAO index situations, the winters are drier and colder than on average (Hurrell et al, 2001; NOAA, 2009; Rantanen et al., 2023)

This study examines the impact of weather on the UHI intensity by studying the connections between the NAO index, cloudiness, wind speed and UHI intensity. In addition, the connections between the UHI and air quality are examined.

2
STUDY AREA

Turku is a city in south-west Finland located at the coast of the brackish Baltic Sea (Figure 1). An extensive archipelago extends from the coast with thousands of islands. The centre of the city (60°27′ N, 22°16′ E) is built around the River Aura which runs from the eskers in Oripää and discharges into the Baltic Sea at the edge of the city centre. The proximity of the Baltic Sea and River Aura have an impact on the existing climate in Turku.

Turku belongs to the humid continental Dfb class in the Köppen's climate classification, denoting that it doesn't have a dry season and the summers are warm. Precipitation stays relatively steady with no significant differences throughout the year. The average temperature in Turku was 5.8 ˚C during the climatic reference period 1991–2020 measured in Turku airport (Jokinen et al., 2021). The region has an annual mean rainfall of 684 mm with the rainiest month being July (74 mm) and the driest April (32 mm). July is also the warmest month with an average temperature of 17.5 ˚C while the coldest month is February with an average temperature of –4.5 ˚C. The windiest month in Turku is December with an average wind speed of 3.7 m/s and the least windy conditions occur in the July–September period with an average wind speed of 3.1 m/s. The annual average wind speed in Turku is 3.4 m/s, and the most common wind direction is southeast.

A pronounced UHI effect, averaging approximately 2 °C, has been identified in the city of Turku (Suomi & Käyhkö, 2012). The Turku city centre is the core of the UHI, whereas the temperatures are on average lowest in rural inland areas. The UHI varies seasonally appearing as most evident during the summer months, particularly at night, due to the slow release of solar radiation originated heat energy absorbed by urban surfaces during the day. During summers, solar radiation is a key factor behind the formation of UHI. Three primary environmental factors influencing the characteristics of UHI in Turku have been recognized, and the land use has been identified principally as the most significant contributor. In addition to land use, the effects of water bodies and topography are remarkable, and of those the impact of topography is generally weakest, but is, however, pronounced during certain weather conditions. The presence of the Baltic Sea has a moderating seasonal effect on the local climate, reducing annual temperature variability. In spring, the sea exerts a cooling influence along the coastline, and during certain weather conditions supports to the formation of an urban cold island UCI. The shadowing effect of buildings and relatively slow warming of urban structures also promote UCI. This mechanism, causing daytime UHI, is most evident in summer. Conversely to spring, in autumn, the sea has a warming effect on the coastal zone.

In Finland, air quality is monitored by municipalities and Finnish Meteorological Institute (FMI). The city of Turku has currently two air quality observation sites, of which one is located in the Ruissalo island and the other in the Turku city centre. Air quality is monitored in cooperation with industrial and energy production facilities and neighbouring municipalities, like Kaarina, Raisio and Naantali, which

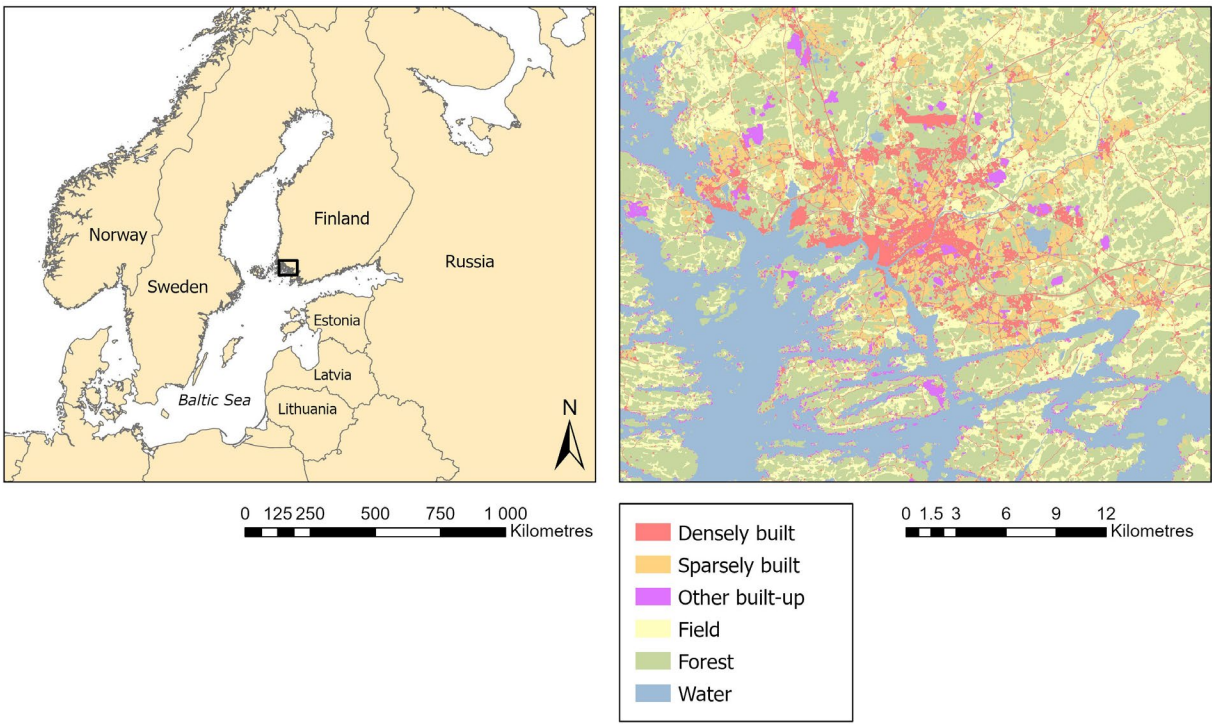

Figure 1. The study area with the geographical location of Turku region (left) and the land cover in Turku (right). The land cover map is produced based on the CORINE Land Cover 2018 dataset.

also have observation sites for specific pollutants. FMI publishes real-time air quality data collected by the cities' observation sites. On average, the air quality around the city of Turku is good, and poor air quality situations are not common. Mostly the air quality varies between good and satisfactory. Poor conditions often exist during spring months, when the air quality is weakened by road dust originated e.g., from sand used in slipperiness prevention (Kupiainen et al., 2003). Other peaks in poor air quality can be explained, for example, by high traffic during rush hours, causing pollution from exhaust pipes.

3
WEATHER DURING THE STUDY YEARS

To relate the weather conditions of the study years 2021 and 2023 to the long-term conditions, air temperature, precipitation, and wind speed of those years were compared on a monthly basis to the 1991–2020 climatological reference period (Table 2). The reference period temperature observations were recorded at the FMI Turku Airport weather station, as well as majority of precipitation and wind speed observations. In the cases they were not available, the precipitation and wind speed data of FMI Turku Artukainen station was used (Jokinen et al., 2021). In comparison, the temperature and wind speed data of the Turku Airport of the years 2021 and 2023 were used. As precipitation was not measured at Turku Airport during these years, rainfall data of Turku Artukainen station were used. Both study years exhibited higher annual mean temperatures relative to the reference period. The year 2021 was warmer by 0.2 °C, while 2023 showed a slightly greater deviation of 0.3 °C. In 2021, March, June, July, and October were warmer than during the reference period, April equalled the reference period, and all remaining months were colder than during the reference period. By contrast, in 2023, January, February, April, June, August, and September were warmer than on average, while the remaining months were colder. The largest positive anomaly in 2021 occurred in June (+4.0 °C), while the largest negative anomaly in December (–4.4 °C). For 2023, the most pronounced positive anomaly was observed in September (+3.4 °C), and largest negative anomaly in December (–3.2 °C). Precipitation sums of the years 2021 and 2023 were below that of the reference period. The year 2021 recorded a deficit exceeding 90 mm, whereas 2023 was nearly 40 mm drier than the reference period. In 2021, the greatest anomalies were observed in August (+69 mm) and July (–40 mm). In 2023, August showed a greater surplus (+76 mm), while December exhibited a substantial deficit (–47 mm). July was the wettest month during the reference period, whereas August was the wettest month in both 2021 and 2023. April was the driest month in the reference period and in 2023, while February was the driest month in 2021. Mean wind speeds in both study years were 0.1 m/s lower than during the reference period. In 2021, January, February, June, November, and December were less windy than during the reference period, whereas March, April, August, and October were windier. The largest negative anomaly occurred in February (–0.8 m/s), while March and August each exhibited positive anomalies of +0.4 m/s. In 2023, February, April, June, November, and December were less windy than during the reference period, while January, July, August, September, and October were windier. The strongest deviations were observed in November (–0.8 m/s) and in September and October (+0.4 m/s each).

Table 2. Monthly and annual deviations in mean temperature (°C), total precipitation (mm), and mean wind speed (m/s) in 2021 and 2023 compared with the 1991–2020 climatological reference period.

	Average temp. (°C)					Rainfall (mm)					Average wind speed (m/s)				
Month	Reference period	2021	Difference*	2023	Difference*	Reference period	2021	Difference*	2023	Difference*	Reference period	2021	Difference*	2023	Difference*
January	-3.8	-4.1	-0.3	-1.1	2.7	58	63	5	63	5	3.6	3.0	-0.6	3.8	0.2
February	-4.5	-6.5	-2.0	-1.7	2.8	42	12	-30	32	-10	3.5	2.7	-0.8	3.4	-0.1
March	-1.3	0.1	1.4	-2.1	-0.8	39	21	-18	73	34	3.4	3.8	0.4	3.4	0.0
April	4.1	4.1	0.0	4.9	0.8	32	23	-9	10	-22	3.4	3.6	0.2	3.1	-0.3
May	10.0	9.8	-0.2	9.9	-0.1	35	70	35	21	-14	3.4	3.4	0.0	3.4	0.0
June	14.4	18.4	4.0	16.0	1.6	55	19	-36	11	-44	3.4	3.0	-0.4	2.7	-0.7
July	17.5	20.2	2.7	16.5	-1.0	74	34	-40	37	-37	3.1	3.1	0.0	3.3	0.2
August	16.2	15.3	-0.9	16.7	0.5	73	142	69	149	76	3.1	3.5	0.4	3.3	0.2
September	11.3	9.6	-1.7	14.7	3.4	59	51	-8	47	-12	3.1	3.1	0.0	3.5	0.4
October	5.7	8.1	2.4	4.2	-1.5	73	75	2	100	27	3.3	4.3	1.0	3.7	0.4
November	1.5	1.4	-0.1	-0.7	-2.2	71	43	-28	77	6	3.6	3.2	-0.4	2.8	-0.8
December	-1.5	-5.9	-4.4	-4.7	-3.2	73	39	-34	26	-47	3.7	3.0	-0.7	3.1	-0.6
Year	5.8	6.0	0.2	6.1	0.3	684	592	-92	646	-38	3.4	3.3	-0.1	3.3	-0.1

*Difference is calculated by subtracting the reference period averages from the study year averages.

4
DATA AND METHODS

Correlations between the intensity of Turku's UHI and air quality were analysed for the years 2021 and 2023. UHI intensity was calculated using temperature observations of the TURCLIM weather observation network of the Geography division of the University of Turku. Air quality data were obtained from the monitoring station located at Turku Market Square and provided by the City of Turku.

UHI intensity was assessed between specific urban and suburban or rural observation sites, namely: Kauppatori–Kurala, Betel–Kurala, Kauppatori–Niuskala, and Betel–Niuskala (see Figure 2). Thirty-minute interval temperature data from these locations were used to generate monthly diagrams for each observation site pair.

Air quality was analysed with five parameters: the Air Quality Index (AQI), nitrogen dioxide (NO_2), nitrogen monoxide (NO), respirable particles (PM_{10}), and fine particles ($PM_{2.5}$). The AQI was determined on a scale from 1 to

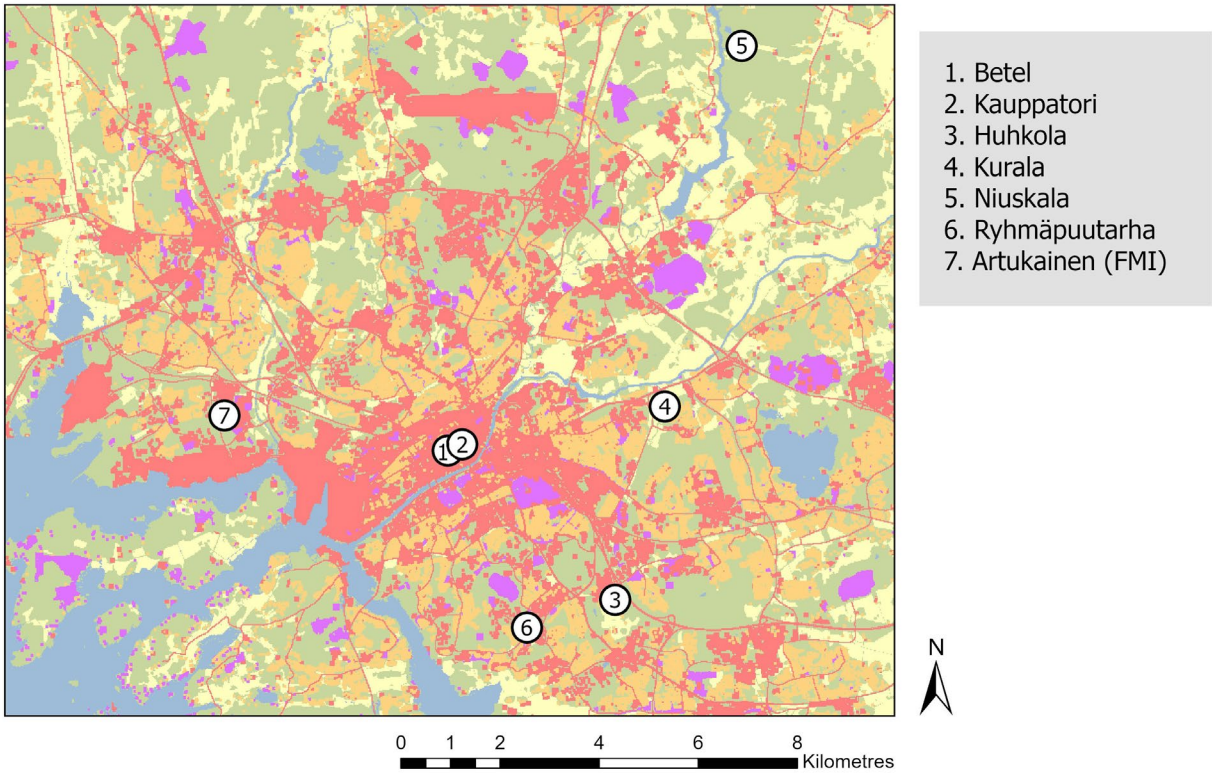

Figure 2. The TURCLIM observation site locations used in the monthly-based analyses of this study plus the location of Finnish Meteorological Institute's Turku Artukainen observation site. For information on the sites used in the heatwave and frost period analyses, see Figure 3. Background map: CORINE Land Cover 2018, reclassified.

5 (1 = good, 2 = satisfactory, 3 = fair, 4 = poor, 5 =very poor), while the concentrations of NO_2, NO, PM_{10}, and $PM_{2.5}$ were reported in micrograms per cubic meter ($\mu g/m^3$). Respirable particles are particles, whose diameter is less than 10 micrometres, whereas fine particles have diameter less than 2.5 micrometres.

Monthly summaries were also produced for air quality, based on hourly averages of each parameter using data from 2021 and 2023. Similarly, monthly summaries of UHI intensity between Kauppatori and Kurala were compiled for 2021, comprising hourly averages for each month.

The correlation between the UHI intensity and air quality was examined during the morning and afternoon traffic rush hours, i.e. from 07.00–09.00 and 15.00–17.00 local time (GMT+2), in January, February, March, November and December, using data from 2021 and 2023. During the other months, when the daylight saving time (GMT+3) is in use, we used same local time slots 07.00-09.00 and 15.00-17.00 (06.00–08.00 and 14.00–16.00 in GMT+2), as the rush hour patterns follow local time throughout the year. In these analyses, air quality data of the Turku Market Square observation site in the Turku city centre were used, and the UHI intensity values were determined based on all four observation site pairs separately. When reporting a moderate correlation in this report, it refers to coefficients between 0.4–0.6. Coefficients over 0.6 were reported as strong and under 0.4 as weak. Both Pearson and Spearman correlations were observed. Statistically significant correlations are bolded and marked with star symbols ('*').

Interconnections between the UHI intensity and air quality was also studied with correlation analysis based on 05.00 o'clock local time air quality parameters and 08.00 o'clock local time UHI intensity values of the same morning. Also, in these analyses this means that during the months of the daylight-saving time, i.e. from April to October, the times are 04.00 and 07.00 in GMT+2. The analyses were performed for all months with available data in 2021 and 2023. This UHI intensity was calculated based on the temperatures of Betel and Huhkola observation sites (see Figure 2).

Correlations between UHI intensity, average wind speed, and cloudiness were also analysed. For this purpose, average UHI values were calculated from the Betel–Kurala, Betel–Niuskala, Kauppatori–Kurala, and Kauppatori–Niuskala logger pairs, based on 2021 observations. Wind speed and cloudiness data were sourced from the Finnish Meteorological Institute (FMI), specifically from the Artukainen observation station. Average wind speed was reported in meters per second (m/s), and cloudiness was measured in oktas, on a scale from 0 to 8. Daytime and nighttime averages were computed for each day across the three variables, and correlations were examined from a monthly daytime and nighttime perspective. Daytime and nighttime were defined according to the times of sunrise and sunset on the 15th day of each month. Scatter plots were created to visualize the relationships between wind speed, cloudiness, and UHI intensity. These analyses were performed separately for daytime and nighttime, using data from the Betel and Kurala logger sites.

Furthermore, the correlation between the daily North Atlantic Oscillation (NAO) index and the average UHI intensity between 00.00–03.00 GMT+2 (throughout the year) in 2021 was analysed. For this analysis, data from the Betel, Kurala, Kauppatori, Niuskala, and Ryhmäpuutarha loggers were used, of which Betel and

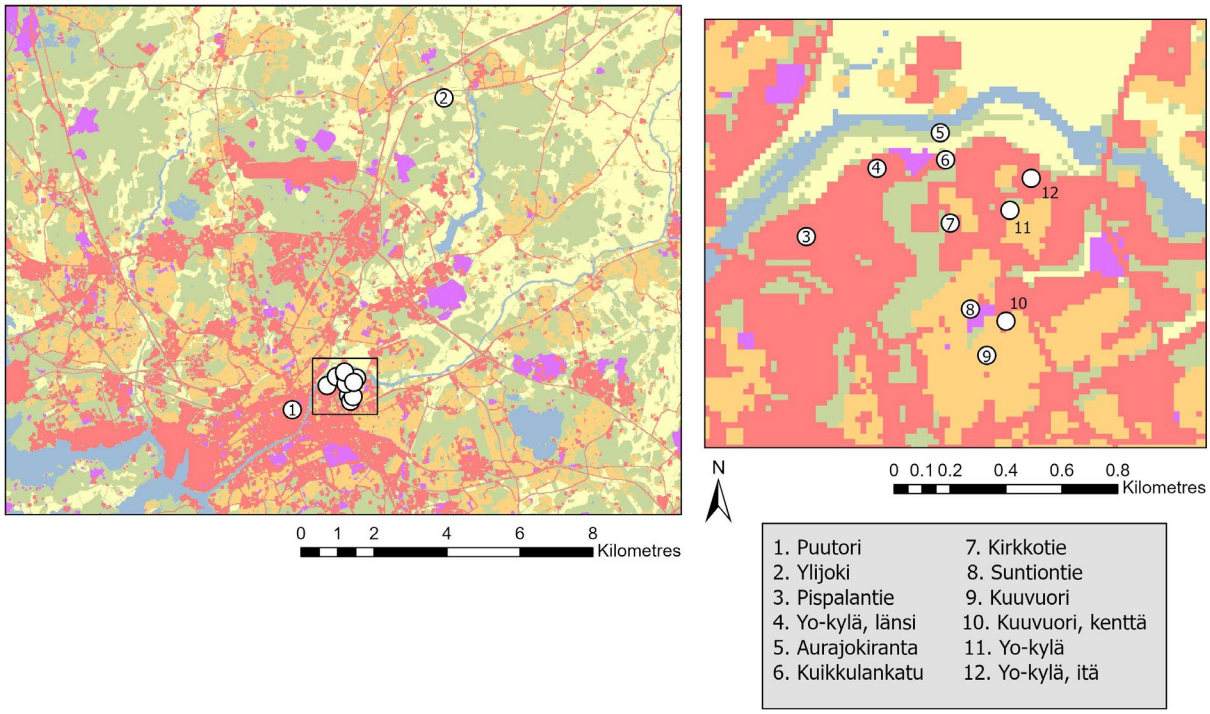

Figure 3. The TURCLIM logger site locations used in the heatwave and frost period analysis. CORINE Land Cover 2018 dataset as background.

Kauppatori are located in Turku's city centre. The same classification of correlation strength reporting was used for both Pearson and Spearman correlations as in the case of UHI intensity and air quality correlations (< 0.4 weak, 0.4–0.6 moderate, > 0.6 strong).

A more detailed investigation of UHI intensity was conducted for the Betel, Kurala, Kauppatori, and Niuskala sites during major heatwave and frost events in 2021. Additionally, temperature data from the Puutori and Ylijoki sites, as well as ten loggers located in the Turku Student Village, were analysed for the same extreme temperature periods (Figure 3). These sites were selected to compare temperature differences between an urban area (Puutori), a rural area (Ylijoki), and intra-urban variability within the Student Village. Heatwaves were defined as periods of consecutive days with daily maximum temperatures exceeding 25 °C, and frost periods as those with daily minimum temperatures falling below -15 °C. These kinds of conditions occurred only during summer and winter months.

5
RESULTS

5.1 Monthly overviews

5.1.1 January

The UHI intensities

In the 2021 observations of UHI intensities, notable peaks were recorded on the 17th and 31st of January (Figures 4–7). On January 17th, the UHI intensity reached up to 8 °C between the Betel and Kurala sites. The lowest peak values were observed between Kauppatori and Niuskala, where maximum UHI intensities reached approximately 6 °C. Negative UHI values were rare, with only a few instances reaching as low as -1 °C. Between the peak value moments, UHI intensity generally remained within the range of 0 to 2 °C. The peaks primarily occurred during the late evening hours, whereas negative

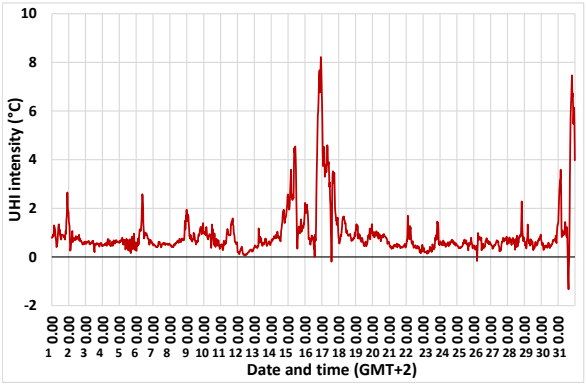

Figure 4. UHI intensity between Betel and Kurala during January 2021.

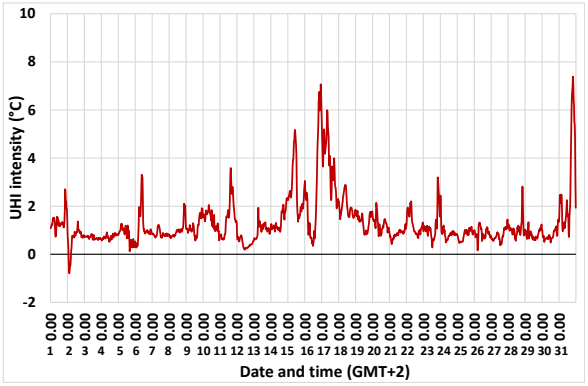

Figure 5. UHI intensity between Betel and Niuskala during January 2021.

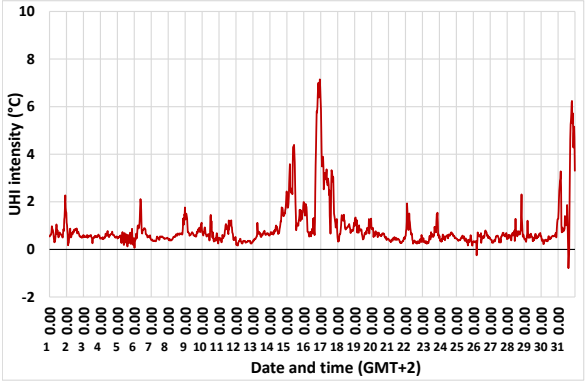

Figure 6. UHI intensity between Kauppatori and Kurala during January 2021.

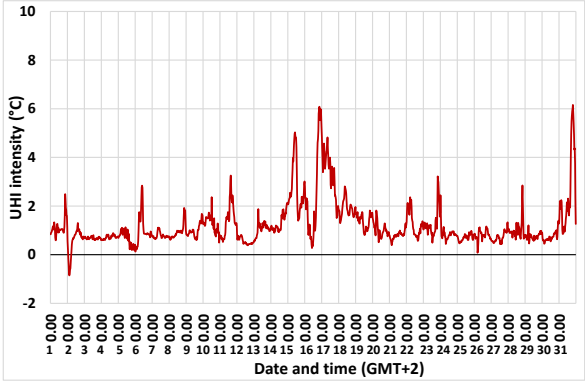

Figure 7. UHI intensity between Kauppatori and Niuskala during January 2021.

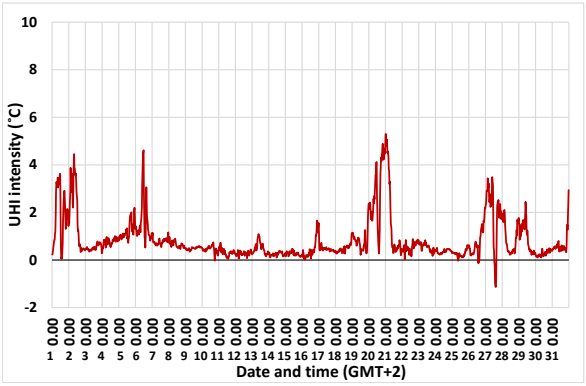

Figure 8. UHI intensity between Betel and Kurala during January 2023.

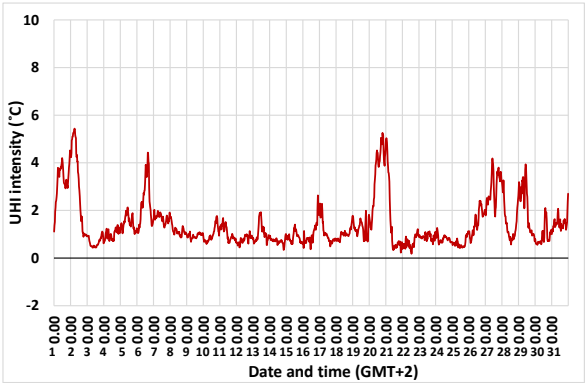

Figure 9. UHI intensity between Betel and Niuskala during January 2023.

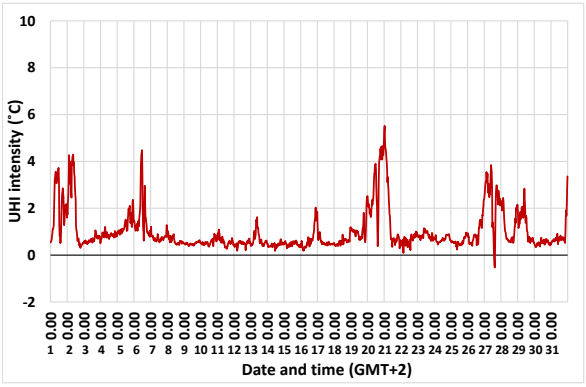

Figure 10. UHI intensity between Kauppatori and Kurala during January 2023.

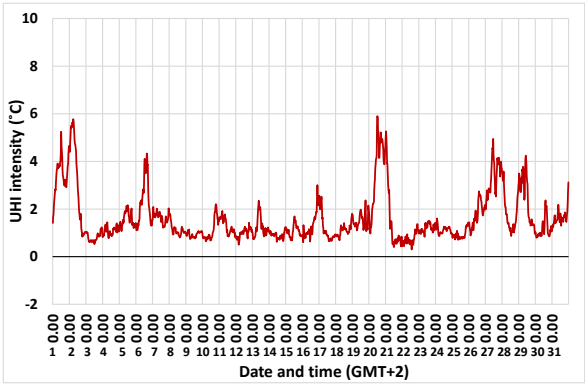

Figure 11. UHI intensity between Kauppatori and Niuskala during January 2023.

values were typically recorded during daytime or early morning hours.

In January 2023, the UHI between the Betel and Kurala logger sites exhibited greater variability (Figure 8). Prominent peaks were recorded during the early days of the month, as well as on the 6th, 21st, and during the final days of January. The highest peak occurred on the 21st, exceeding 5 °C. A negative UHI value of approximately -1 °C was recorded on the 27th. For the Betel–Niuskala logger pair, significant UHI peaks occurred in the first days of the month and around the 20th (Figure 9). This UHI series showed more pronounced variability compared to the Betel–Kurala series, and no negative UHI values were detected. The UHI intensity between Kauppatori and Kurala showed peak occurrences on the same days as observed in the other logger pairs (Figure 10). A negative UHI value, also observed between Betel and Kurala, occurred on the 27th. For the Kauppatori–Niuskala logger pair, the UHI pattern resembled that of Betel–Niuskala, though the peak values were slightly higher (Figure 11). In general, maximum UHI intensities occurred during nighttime, both before and after midnight, while negative values tended to appear during midday or afternoon.

Compared to January 2021, a greater number of UHI peaks were observed in January 2023. However, the conditions in 2021 were more stable overall, and the maximum UHI intensities were approximately 2 °C higher than those recorded in 2023.

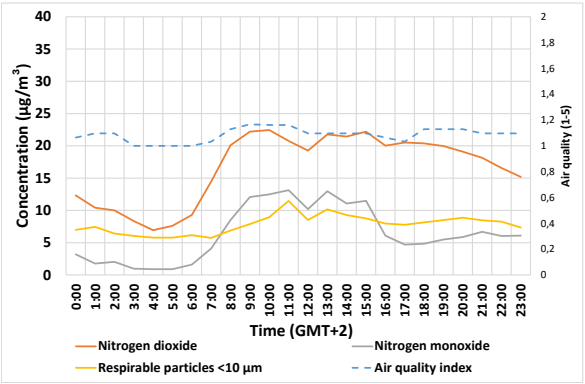

Figure 12. Hourly averages of air quality observations in January 2021.

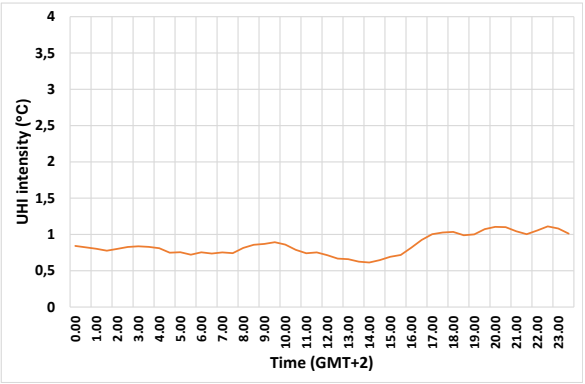

Figure 13. Hourly average UHI intensity between Kauppatori and Kurala in January 2021.

Monthly summaries

Among the air quality variables, nitrogen dioxide reached the highest concentrations in January 2021, exceeding 20 µg/m³ (Figure 12). In comparison, respirable particles and nitrogen monoxide recorded lower values. The air quality index remained relatively stable, ranging between 1.0 and 1.1. A distinct diurnal pattern was observed in all variables, with concentrations beginning to rise around 07.00, peaking during the day, and returning to baseline levels by approximately 17.00. During nighttime hours, most variables remained stable, except for nitrogen dioxide, which exhibited a continuous decline until around 03.00–04.00. The air quality index showed minimal variation throughout the day, with the highest values occurring in the morning and late evening, and the lowest values during the early morning hours.

In January 2023, peak concentrations of air quality variables occurred during morning rush hours (08.00–12.00) and again in the evening (16.00–19.00). The air quality index ranged from approximately 1.03 to 1.13. Nitrogen dioxide concentrations varied between 4.77 and 18.33 µg/m³, nitrogen monoxide between 1.34 and 7.19 µg/m³, respirable particles between 5.02 and 7.16 µg/m³, and fine particles between 3.75 and 4.98 µg/m³.

For UHI intensity, peak values were observed during the evening, beginning around 17.00, with the UHI reaching slightly above 1 °C (Figure 13). At other times of the day, UHI intensity remained relatively steady, averaging between 0.7 and 0.8 °C.

The correlations between the UHI and air quality

Between the Betel and Kurala sites in January 2021, all air quality variables except fine particles exhibited a positive Pearson correlation with UHI intensity during the 07.00–08.00 time period (Table 3). Among these, the air quality index showed the strongest correlation, while nitrogen monoxide exhibited the weakest. In the Spearman correlation analysis for the same period, only the air quality index demonstrated a moderate positive correlation with UHI intensity. Correlations for fine particles could not be determined due to insufficient data. During the 08.00–09.00 period, only nitrogen dioxide exhibited a statistically significant correlation, showing a moderately strong positive Pearson correlation with UHI intensity. For the 15.00–16.00 period, both the air quality index and nitrogen diox-

Table 3. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in January 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.735****	<0.001	0.292	0.117	**0.679****	<0.001	0.012	0.947
	Nitrogen dioxide	**0.485****	0.006	**0.421***	0.021	**0.607****	<0.001	**0.389***	0.031
	Nitrogen monoxide	**0.362***	0.046	0.039	0.836	0.061	0.743	-0.020	0.915
	Respirable particles	**0.497****	0.004	0.332	0.073	-0.058	0.757	-0.077	0.679
	Fine particles								
Spearman	Air quality index	**0.527****	0.002	0.336	0.070	**0.382***	0.034	0.204	0.271
	Nitrogen dioxide	0.332	0.068	0.319	0.086	**0.475****	0.007	**0.387***	0.031
	Nitrogen monoxide	0.232	0.210	0.033	0.861	0.120	0.521	0.074	0.692
	Respirable particles	0.237	0.199	0.235	0.212	-0.107	0.567	-0.087	0.640
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

ide were positively correlated with UHI intensity in both Pearson and Spearman analyses, with Pearson correlations being comparatively stronger. In the 16.00–17.00 period, nitrogen dioxide was the only variable with a statistically significant correlation, although this was a weaker positive association.

In January 2023, the UHI intensity between Betel and Kurala correlated moderately to strongly and positively with the air quality index, nitrogen dioxide, and nitrogen monoxide during the 07.00–08.00 period (Table 4), based on Pearson correlation. In the Spearman analysis for the same period, respirable particles also showed a positive

Table 4. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in January 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.592****	<0.001	**0.657****	<0.001			**0.650****	<0.001
	Nitrogen dioxide	**0.617****	<0.001	**0.526****	0.002	**0.384***	0.033	**0.705****	<0.001
	Nitrogen monoxide	**0.645****	<0.001	**0.493****	0.005	0.208	0.261	**0.658****	<0.001
	Respirable particles	0.282	0.124	**0.368***	0.041	**0.361***	0.046	**0.681****	<0.001
	Fine particles	-0.020	0.915	-0.022	0.906	0.076	0.686	0.270	0.141
Spearman	Air quality index	**0.409***	0.022	**0.506****	0.004			0.306	0.094
	Nitrogen dioxide	0.311	0.088	0.337	0.064	0.322	0.077	**0.402***	0.025
	Nitrogen monoxide	0.182	0.327	0.242	0.190	0.215	0.245	0.127	0.496
	Respirable particles	**0.364***	0.044	**0.357****	0.049	0.164	0.379	**0.422***	0.018
	Fine particles	0.069	0.711	0.124	0.508	0.093	0.620	0.305	0.095

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 5. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in January 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.759****	<0.001	0.351	0.057	**0.491****	0.005	0.070	0.708
	Nitrogen dioxide	**0.545****	0.002	**0.473****	0.008	**0.573****	<0.001	**0.410***	0.022
	Nitrogen monoxide	**0.414***	0.020	0.055	0.771	-0.045	0.811	-0.096	0.606
	Respirable particles	**0.512****	0.003	**0.408***	0.025	-0.227	0.219	-0.181	0.329
	Fine particles								
Spearman	Air quality index	**0.495****	0.005	**0.450***	0.013	0.352	0.052	0.184	0.322
	Nitrogen dioxide	**0.442***	0.013	**0.423***	0.020	**0.472****	0.007	**0.447***	0.012
	Nitrogen monoxide	**0.372***	0.039	0.154	0.417	0.052	0.783	-0.053	0.778
	Respirable particles	**0.450***	0.011	**0.426***	0.019	-0.223	0.229	-0.076	0.686
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

correlation, along with the air quality index. During the 08.00–09.00 period, Pearson correlations remained moderately strong and positive for the air quality index, nitrogen dioxide, and nitrogen monoxide, while a slight positive correlation was also observed with respirable particles. In the corresponding Spearman correlation, only the air quality index and respirable particles showed statistically significant positive associations. In the 15.00–16.00 period, weak positive Pearson correlations were identified for nitrogen dioxide and respirable particles; however, no statistically significant correlations were observed in the Spearman analysis. During the 16.00–17.00 period, strong positive Pearson correlations were found between UHI intensity and all air quality variables except fine particles. In the Spearman analysis for this period, nitrogen dioxide and respirable particles showed moderately strong positive correlations. Fine particles did not exhibit any statistically significant correlation with UHI intensity during any of the examined time periods.

In 2021, the UHI intensity between the Betel and Niuskala sites exhibited relatively strong positive Pearson correlations with all air quality variables, except for fine particles, during the 07.00–08.00 time period (Table 5). The corresponding Spearman correlations were generally weaker. Among the variables, nitrogen monoxide showed the weakest correlation, while the air quality index had the strongest. During the subsequent hour (08.00–09.00), only nitrogen dioxide and respirable particles demonstrated moderate positive Pearson correlations. In the Spearman analysis for this time period, the air quality index also showed a statistically significant positive correlation. At 15.00–16.00, only the air quality index and nitrogen dioxide exhibited statistically significant moderate positive correlations in the Pearson analysis. The air quality index did not show a significant correlation in the Spearman analysis for this time period. During 16.00–17.00, nitrogen dioxide was the only variable to display a statistically significant moderate positive correlation in both Pearson and Spearman analyses. All statistically significant correlations observed were positive.

Table 6. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in January 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.549****	0.001	**0.663****	<0.001			**0.588****	<0.001
	Nitrogen dioxide	**0.558****	0.001	**0.500****	0.004	**0.383***	0.033	**0.644****	<0.001
	Nitrogen monoxide	**0.605****	<0.001	**0.496****	0.05	0.243	0.188	**0.594****	<0.001
	Respirable particles	0.206	0.268	0.318	0.081	0.191	0.302	**0.601****	<0.001
	Fine particles	-0.165	0.376	-0.119	0.524	-0.163	0.380	0.162	0.385
Spearman	Air quality index	0.355	0.050	**0.495****	0.005			0.306	0.094
	Nitrogen dioxide	0.235	0.203	0.228	0.218	0.261	0.156	0.282	0.124
	Nitrogen monoxide	0.179	0.334	0.204	0.270	0.157	0.399	0.218	0.240
	Respirable particles	0.293	0.110	0.308	0.092	-0.003	0.989	0.229	0.215
	Fine particles	-0.096	0.606	0.026	0.889	-0.265	0.150	-0.042	0.824

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

In 2023, between the Betel and Niuskala sites, moderate and strong positive correlations were observed between UHI intensity and the air quality index, nitrogen dioxide, and nitrogen monoxide during the 07.00–08.00 period (Table 6). These correlations remained relatively stable during the following hour (08.00–09.00). During the 15.00–16.00 period, only a slight positive correlation was found with nitrogen dioxide. In the 16.00–17.00 period, all air quality variables except fine particles exhibited relatively strong or moderate positive Pearson correlations with UHI intensity. In terms of Spearman correlation, the only statistically significant association was observed during the 08.00–09.00 period, where the air quality index demonstrated a moderate positive correlation.

Between Kauppatori and Kurala during the 07.00–08.00 period in 2021, all air quality variables except fine particles exhibited statistically significant correlations with UHI intensity (Table 7). Among these, nitrogen monoxide showed the weakest Pearson correlation, while respirable particles had the weakest Spearman correlation. In both correlation types, the air quality index exhibited the strongest positive relationship with UHI intensity. During the following hour (08.00–09.00), only the air quality index and nitrogen dioxide demonstrated statistically significant correlations in both Pearson and Spearman analyses. These correlations ranged from weak to moderate in strength, with nitrogen dioxide showing a stronger association in the Pearson correlation, and the air quality index in the Spearman correlation. The same two variables also correlated with UHI intensity during the 15.00–16.00 period, with stronger correlations observed in the Pearson analysis. In the subsequent hour (16.00–17.00), only nitrogen dioxide had a statistically significant correlation, which was positive and of moderate strength.

In 2023, the UHI intensity between Kauppatori and Kurala exhibited relatively strong positive Pearson correlations with the air quality index, nitrogen monoxide, and nitrogen dioxide during the 07.00–08.00 period (Table 8). During the 08.00–09.00 period, these correla-

Table 7. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in January 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.765****	<0.001	**0.393***	0.032	**0.695****	<0.001	0.055	0.769
	Nitrogen dioxide	**0.547****	0.001	**0.493****	0.006	**0.608****	<0.001	**0.427***	0.017
	Nitrogen monoxide	**0.408***	0.023	0.109	0.567	0.110	0.556	0.041	0.827
	Respirable particles	**0.480****	0.006	0.347	0.060	-0.065	0.728	-0.052	0.782
	Fine particles								
Spearman	Air quality index	**0.559****	0.001	**0.450***	0.013	**0.367***	0.042	0.225	0.225
	Nitrogen dioxide	**0.484****	0.006	**0.378***	0.040	**0.497****	0.004	**0.498****	0.004
	Nitrogen monoxide	**0.420***	0.019	0.099	0.602	0.266	0.149	0.176	0.343
	Respirable particles	**0.371***	0.040	0.322	0.083	-0.117	0.530	-0.148	0.425
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

tions remained similar, although the correlation with nitrogen monoxide weakened slightly. In the 15.00–16.00 period, a slight positive Pearson correlation was observed only with nitrogen dioxide. In the 16.00–17.00 period, all variables except fine particles demonstrated relatively strong positive correlations with UHI intensity. Regarding Spearman correlations in 2023, only nitrogen dioxide showed statistically significant correlations across all time periods, except during 08.00–09.00, when the air quality index also correlated positively. All statistically significant correlations were positive and of moderate or weak strength.

Table 8. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in January 2023.

		07.00-08.00		08.00-09.00		15.00-16.00		16.00-17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.550****	0.001	**0.695****	<0.001			**0.683****	<0.001
	Nitrogen dioxide	**0.637****	<0.001	**0.575****	<0.001	**0.434***	0.015	**0.756****	<0.001
	Nitrogen monoxide	**0.589****	<0.001	**0.436***	0.014	0.259	0.160	**0.692****	<0.001
	Respirable particles	0.216	0.242	0.336	0.065	0.311	0.089	**0.654****	<0.001
	Fine particles	-0.075	0.687	-0.065	0.729	-0.059	0.751	0.210	0.258
Spearman	Air quality index	0.334	0.067	**0.527****	0.002			0.306	0.094
	Nitrogen dioxide	**0.472****	0.007	**0.394***	0.028	**0.453***	0.011	**0.506****	0.004
	Nitrogen monoxide	0.261	0.156	0.202	0.275	0.285	0.121	0.115	0.537
	Respirable particles	0.156	0.402	0.277	0.132	0.063	0.738	0.223	0.227
	Fine particles	-0.141	0.449	-0.003	0.989	-0.196	0.289	0.009	0.962

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 9. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in January 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.776****	<0.001	**0.444***	0.014	**0.497****	0.004	0.116	0.535
	Nitrogen dioxide	**0.592****	<0.001	**0.544***	0.002	**0.579****	<0.001	**0.455***	0.010
	Nitrogen monoxide	**0.452***	0.011	0.114	0.549	-0.012	0.950	-0.036	0.847
	Respirable particles	**0.497****	0.004	**0.436***	0.016	-0.250	0.176	-0.159	0.393
	Fine particles								
Spearman	Air quality index	**0.516****	0.003	**0.512****	0.004	0.352	0.052	0.184	0.323
	Nitrogen dioxide	**0.467****	0.008	**0.458***	0.011	**0.477****	0.007	**0.504****	0.004
	Nitrogen monoxide	**0.428***	0.016	0.212	0.260	0.098	0.601	-0.043	0.817
	Respirable particles	**0.497****	0.004	**0.496****	0.005	-0.243	0.188	-0.103	0.580
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

In 2021, the UHI intensity between Kauppatori and Niuskala demonstrated moderate correlations with air quality variables during the 08.00–09.00 period, with the air quality index showing a strong positive Pearson correlation (Table 9). Nitrogen monoxide had the weakest correlation and did not exhibit a statistically significant association in the subsequent hour (09.00–10.00). In general, the correlation coefficients during 08.00–09.00 were weaker compared to the preceding hour (07.00–08.00). During the 15.00–16.00 period, only the air quality index and nitrogen dioxide showed statistically significant correlations, both of moderate strength in the Pearson analysis. However, the air quality index did not exhibit a statistically significant correlation in the Spearman analysis. In the 16.00–17.00 period, only nitrogen dioxide displayed a statistically significant moderate correlation with UHI intensity.

In 2023, the UHI intensity between Kauppatori and Niuskala was positively and relatively strongly correlated with the air quality index, nitrogen dioxide, and nitrogen monoxide during the 07.00–08.00 period (Table 10). These same three variables also exhibited positive correlations during the following hour (08.00–09.00). During the 15.00–16.00 period, only a weak positive correlation with nitrogen monoxide was observed. In the 16.00–17.00 period, the air quality index, nitrogen dioxide, nitrogen monoxide, and respirable particles all demonstrated relatively strong positive Pearson correlations with UHI intensity. In the Spearman correlation analysis for 2023, the air quality index showed a moderate positive correlation during the 08.00–09.00 period. Fine particles exhibited a weak negative correlation during the 15.00–16.00 period, and nitrogen dioxide displayed a weak positive correlation during the 16.00–17.00 period.

The correlation between the 05.00 UHI and the 08.00 air quality

In 2021, the UHI intensity between Betel and Huhkola at 05.00 demonstrated moderate pos-

Table 10. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in January 2023.

	Kauppatori & Niuskala	07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
		UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.506****	0.004	**0.698****	<0.001			**0.615****	<0.001
	Nitrogen dioxide	**0.574****	<0.001	**0.546****	0.001	**0.386***	0.032	**0.684****	<0.001
	Nitrogen monoxide	**0.548****	0.001	**0.441***	0.013	0.254	0.167	**0.622****	<0.001
	Respirable particles	0.140	0.452	0.287	0.118	0.150	0.420	**0.586****	<0.001
	Fine particles	-0.220	0.234	-0.160	0.391	-0.227	0.219	0.119	0.523
Spearman	Air quality index	0.280	0.128	**0.527****	0.002			0.306	0.094
	Nitrogen dioxide	0.311	0.089	0.248	0.179	0.239	0.195	**0.383***	0.034
	Nitrogen monoxide	0.220	0.235	0.183	0.326	0.112	0.550	0.212	0.253
	Respirable particles	0.212	0.251	0.241	0.191	-0.037	0.843	0.134	0.474
	Fine particles	-0.159	0.392	-0.061	0.745	**-0.359***	0.047	-0.176	0.343

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

itive Pearson correlations with the 08.00 air quality index, nitrogen dioxide, and respirable particles (Table 11). In contrast, the Spearman correlation analysis indicated a statistically significant correlation only with the air quality index, which was also positive.

In 2023, the UHI at 05.00 between Betel and Huhkola exhibited moderate positive Pearson correlations with all air quality variables except fine particles which did not have a statistically significant correlation and nitrogen monoxide which had a strong coefficient (Table 12). According to the Spearman analysis, only the air quality index and respirable particles showed statistically significant correlations, though both were relatively weak.

Table 11. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in January 2021. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index	**0.543****	0.002
	Nitrogen dioxide	**0.458****	0.010
	Nitrogen monoxide	0.350	0.053
	Respirable particles	**0.509****	0.003
	Fine particles		
Spearman	Air quality index	**0.409***	0.022
	Nitrogen dioxide	0.288	0.116
	Nitrogen monoxide	0.165	0.375
	Respirable particles	0.200	0.280
	Fine particles		

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 12. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in January 2023. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index	**0.453***	0.011
	Nitrogen dioxide	**0.538****	0.002
	Nitrogen monoxide	**0.653****	<0.001
	Respirable particles	**0.452***	0.011
	Fine particles	0.217	0.241
Spearman	Air quality index	**0.377***	0.037
	Nitrogen dioxide	0.238	0.197
	Nitrogen monoxide	0.180	0.332
	Respirable particles	**0.390***	0.030
	Fine particles	0.066	0.724

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Across both years, all statistically significant correlations were positive. While a greater number of statistically significant correlations were observed in 2023, the overall correlation magnitudes remained similar to those recorded in 2021.

The correlation between the UHI, average wind speed and cloudiness

In January the daytime defined by sunrise and sunset was roughly from 09.30 to 16.00. Other hours were included in the nighttime analysis. During the daytime, generally a moderate negative correlation was observed between UHI intensity and both average wind speed and cloudiness (Table 13). Similar negative correlations were also present during nighttime hours, with slightly stronger correlation coefficients than those observed during the day. The correlation with cloudiness was marginally stronger than that with wind speed in both time periods, although the difference was minimal.

Scatter plots were generated to visualize the relationship between UHI intensity (measured between Betel and Kurala) and the meteorological variables (Figures 14–17). The scatter plots for wind speed showed similar patterns during both daytime and nighttime. Most data points clustered in a region where UHI values ranged between 0.5 and 1.0 °C and wind speeds ranged from 1 to 4 m/s. A number of outliers were observed, including instances of high UHI with low wind speed and vice versa, suggesting an inverse relationship between wind speed and UHI intensity. Similarly, the scatter plots illustrating the relationship between cloudiness and UHI also revealed consistent patterns between daytime and nighttime (Figures 15 & 17). The majority of data points suggested that higher cloudiness was associated with lower UHI intensity. A few anomalies with scattered data placements were present, but the overall trend supports the moderating effect of cloudiness on UHI development.

The correlation between NAO index and UHI

In January, the North Atlantic Oscillation (NAO) index exhibited a moderate positive Pearson correlation with UHI intensity for the following logger pairs: Betel–Kurala, Betel–Niuskala, Kauppatori–Kurala, and Kauppatori–Niuskala (Table 14). In contrast, the Spearman correla-

Table 13. Pearson and Spearman correlation coefficients between the wind speed and UHI and between the cloudiness and UHI during daytime and nighttime in January 2021. Four different UHI intensities are calculated based on the Betel, Kurala, Kauppatori and Niuskala observation sites.

			Betel & Kurala UHI	Betel & Niuskala UHI	Kauppatori & Kurala UHI	Kauppatori & Niuskala UHI
Day	Pearson	Average wind speed	-0.575**	-0.551**	-0.540**	-0.523**
		Average cloudiness	-0.369*	-0.483**	-0.490**	-0.555**
	Spearman	Average wind speed	-0.639**	-0.547**	-0.659**	-0.546**
		Average cloudiness	-0.445*	-0.396*	-0.622**	-0.524**
Night	Pearson	Average wind speed	-0.602**	-0.593**	-0.582**	-0.564**
		Average cloudiness	-0.658**	-0.618**	-0.707**	-0.656**
	Spearman	Average wind speed	-0.735**	-0.504**	-0.655**	-0.447*
		Average cloudiness	-0.550**	-0.595**	-0.561**	-0.570**

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

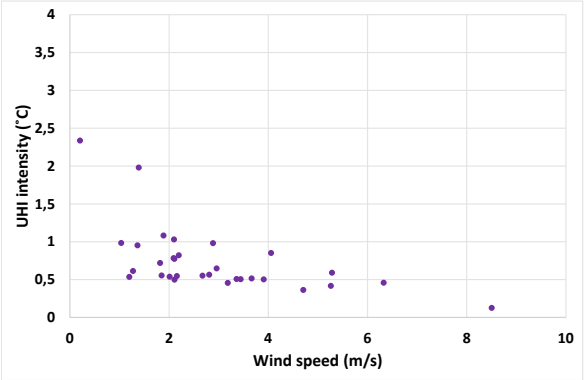

Figure 14. Scatter plot for wind speed and UHI between Betel and Kurala during daytime in January 2021.

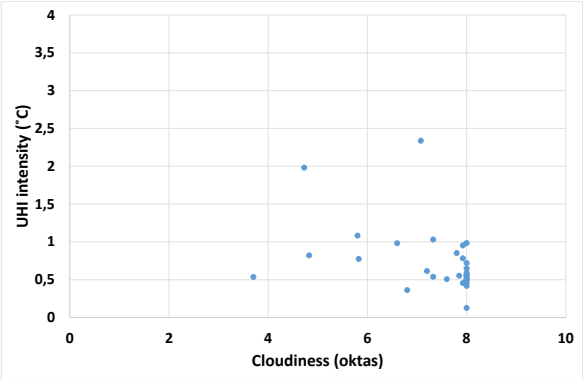

Figure 15. Scatter plot for cloudiness and UHI between Betel and Kurala during daytime in January 2021.

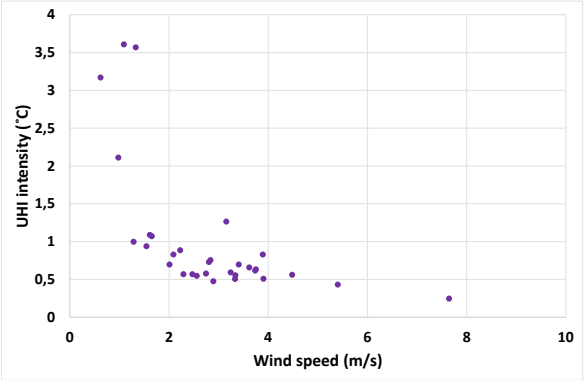

Figure 16. Scatter plot for wind speed and UHI between Betel and Kurala during nighttime in January 2021.

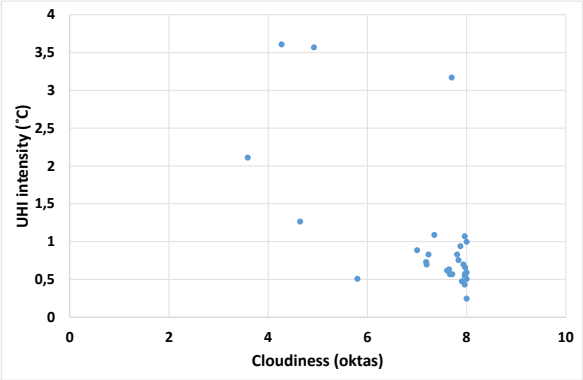

Figure 17. Scatter plot for cloudiness and UHI between Betel and Kurala during nighttime in January 2021.

Table 14. Pearson and Spearman correlations between NAO index and different UHI logger pairs in January 2021.

	UHI	NAO index	Significance level
Pearson	Betel & Kurala	**0.506****	0.004
	Betel & Niuskala	**0.477****	0.007
	Kauppatori & Kurala	**0.513****	0.003
	Kauppatori & Niuskala	**0.471****	0.007
	Betel & Ryhmäpuutarha	0.228	0.217
	Kauppatori & Ryhmäpuutarha	0.199	0.283
Spearman	Betel & Kurala	0.320	0.080
	Betel & Niuskala	0.351	0.053
	Kauppatori & Kurala	**0.393***	0.029
	Kauppatori & Niuskala	0.322	0.078
	Betel & Ryhmäpuutarha	0.146	0.432
	Kauppatori & Ryhmäpuutarha	0.086	0.644

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

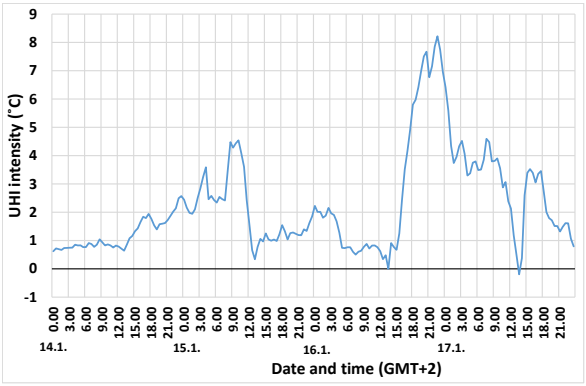

Figure 18. UHI intensity between Betel and Kurala during the frost period on the 14th-17th of January in 2021.

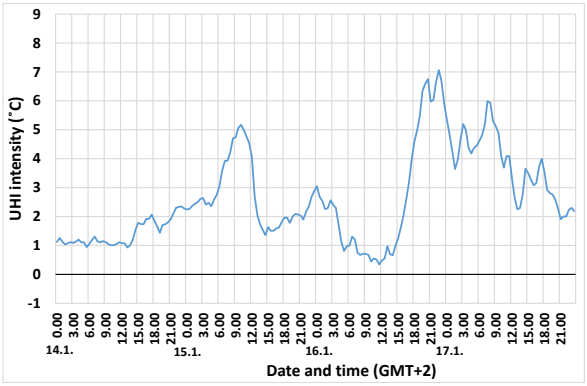

Figure 19. UHI intensity between Betel and Niuskala during the frost period on the 14th-17th of January in 2021.

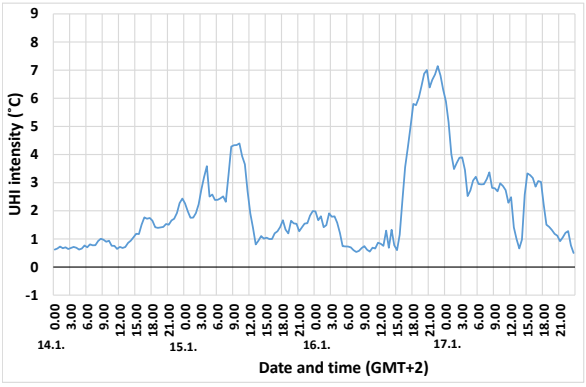

Figure 20. UHI intensity between Kauppatori and Kurala during the frost period on the 14th-17th of January in 2021.

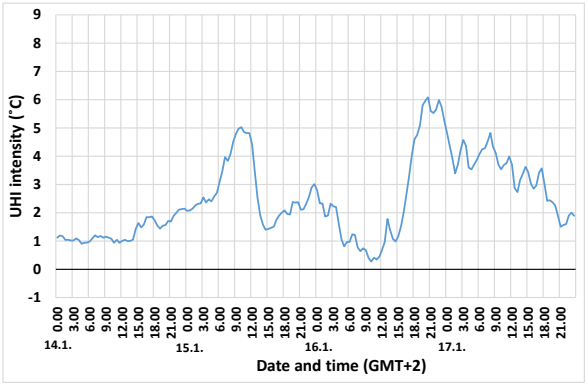

Figure 21. UHI intensity between Kauppatori and Niuskala during the frost period on the 14th-17th of January in 2021.

tion analysis revealed only a weak positive statistically significant correlation between the NAO index and the UHI intensity for the Kauppatori–Kurala pair. No statistically significant correlations were found for the remaining UHI logger pairs in the Spearman analysis.

Frost period review

In January 2021, a frost period occurred from the 14th to the 17th. During this four-day period, the UHI intensity exhibited two distinct peaks across all four logger pairs (Figures 18–21). The first peak occurred on the morning of the 15th, and the second during the night between the 16th and 17th. The UHI during the first peak reached values of approximately 4–5 °C, while the second peak reached 7–8 °C, depending on the logger pair. Minor negative UHI values were recorded only between the Betel and Kurala sites. Outside of these peak periods, the UHI intensity remained around 1–2 °C, gradually decreasing toward the end of the frost period.

During this same period, air temperatures ranged approximately between -7 °C and -22 °C (Figures 22 & 23). The temperature observations from the Turku Student Village were generally consistent, with only minor differences among the sites. However, notable deviations occurred

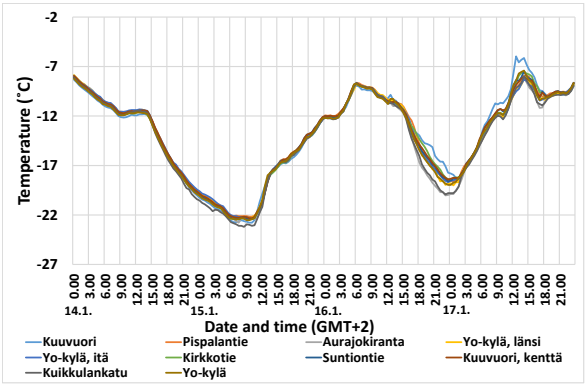

Figure 22. Turku Student Village temperatures during the frost period on the 14th-17th of January in 2021.

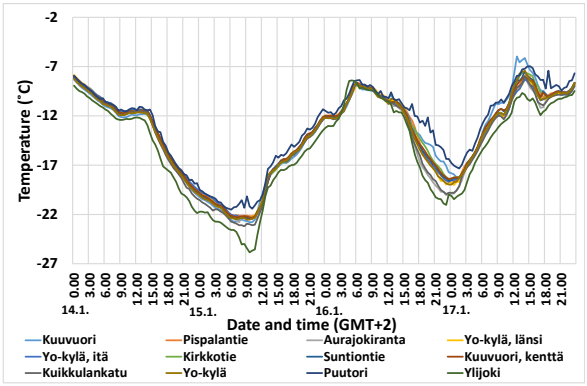

Figure 23. Turku Student Village, Puutori and Ylijoki temperatures during the frost period on the 14th-17th of January in 2021.

around midnight between the 16th and 17th and again at midday on the 17th, when the Kuuvuori site recorded significantly higher temperatures compared to the other locations. Kuuvuori registered the highest temperature during the midnight period on the 17th, whereas the lowest temperatures were observed at the Aurajokiranta and Kuikkulankatu sites. Among the comparison sites, Puutori and Ylijoki exhibited clear contrasts relative to the Student Village observations, particularly on the morning of the 15th and continuing through the 17th. Puutori, located in a central urban area, consistently recorded the highest temperatures during the frost period, while Ylijoki, situated in a rural setting, recorded the lowest temperatures.

5.1.2 February

The UHI intensities

In February 2021, significant variability in UHI intensities was observed during the first half of the month, with peak values primarily occurring during nighttime or early morning hours (Figures 24–27). In contrast, the latter half of the month exhibited more stable UHI intensities, generally remaining below 2 °C. Peak intensities reached up to 8 °C, with the weakest peaks, approximately 6 °C, occurring between Kauppatori and Niuskala. The most distinct peaks were recorded on the 2nd, 7th, 10th, 13th, and 18th of February. Negative UHI values were rare and appeared only in the Betel–Kurala and Betel–Niuskala logger pairs, with values barely reaching -1 °C and occurring only on a few isolated occasions.

In February 2023, the UHI intensities between Betel and Niuskala, as well as Kauppatori and Niuskala, exhibited relatively consistent variation, with average values ranging approximately from 0 to 4 °C (Figures 29 & 31). Notable peaks exceeding 6 °C occurred on the 5th, 12th, and 27th of February. No significant negative values were recorded for these logger pairs during the month. In contrast, the UHI intensities between Betel and Kurala, and Kauppatori and Kurala, displayed a pronounced peak exceeding 8 °C on the 27th of February (Figures 28 & 30). Negative UHI values were observed at the beginning and end of the month, with additional occurrences on the 11th and 14th. Apart from these cases, UHI values generally remained within the 0–4 °C range. As observed in January, maximum UHI values typically occurred during nighttime hours, while negative values appeared during the day.

In comparison to 2021, the UHI peaks in February 2023 were generally weaker and more

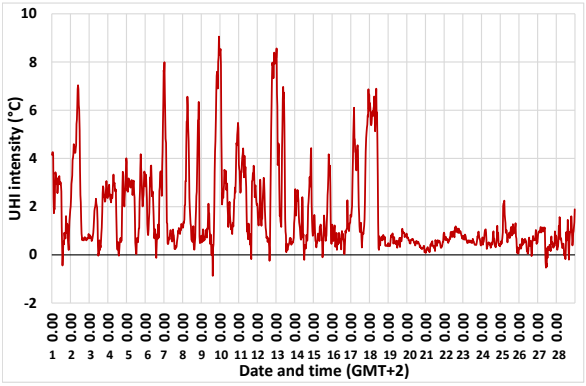

Figure 24. UHI intensity between Betel and Kurala during February 2021.

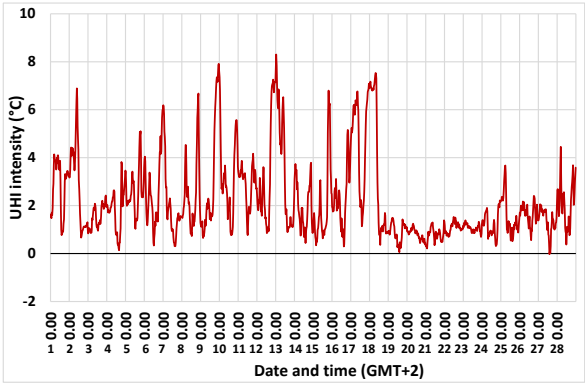

Figure 25. UHI intensity between Betel and Niuskala during February 2021.

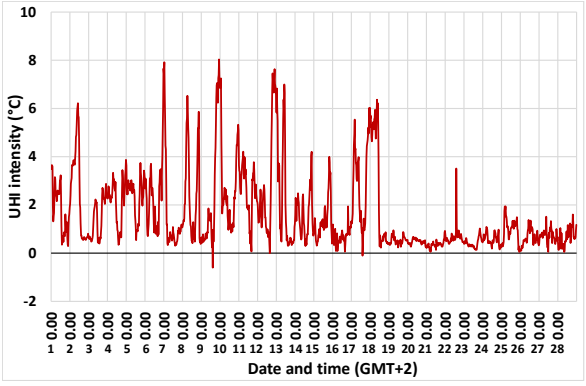

Figure 26. UHI intensity between Kauppatori and Kurala during February 2021.

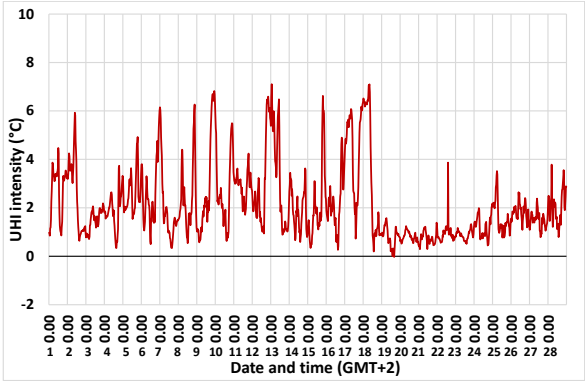

Figure 27. UHI intensity between Kauppatori and Niuskala during February 2021.

evenly distributed throughout the month. In 2021, peaks were more concentrated in the first half of the month and reached up to 8 °C.

Monthly summaries

In February 2021, peak air quality values were observed primarily during the morning hours between 07.00–12.00 and again in the evening between 19.00–21.00 for most measured variables (Figure 32). The air quality index ranged from 1.0 to 1.4, with nitrogen dioxide reaching the highest pollutant concentration of over 35 µg/m³. The most pronounced peaks in nitrogen dioxide, nitrogen monoxide, and the air quality index occurred between 08.00 and 11.00. Respirable particles remained relatively stable throughout the month. Of the measured pollutants, nitrogen dioxide recorded the highest concentrations, while nitrogen monoxide exhibited the lowest.

In February 2023, peak air quality values were similarly associated with rush hour periods, with elevated concentrations observed during 07.00–11.00 in the morning and 17.00–21.00 in the evening. The air quality index averaged between 1.07 and 1.29. Concentration ranges for the pollutants were as follows: nitrogen dioxide, 6.38–22.51 µg/m³; nitrogen monoxide, 0.47–10.53 µg/m³; respirable particles, 5.81–11.56 µg/m³; and fine particles, 4.08–6.66 µg/m³.

For UHI intensity in 2021, peak values were observed at midnight and between

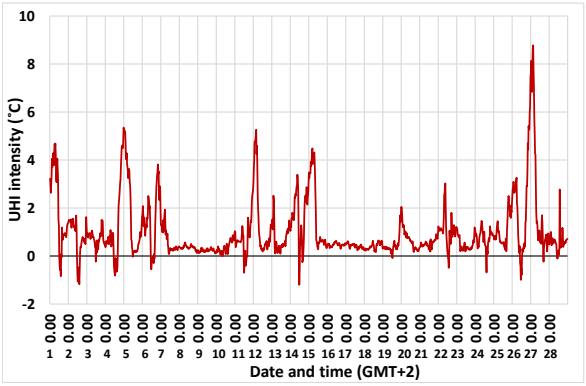

Figure 28. UHI intensity between Betel and Kurala during February 2023.

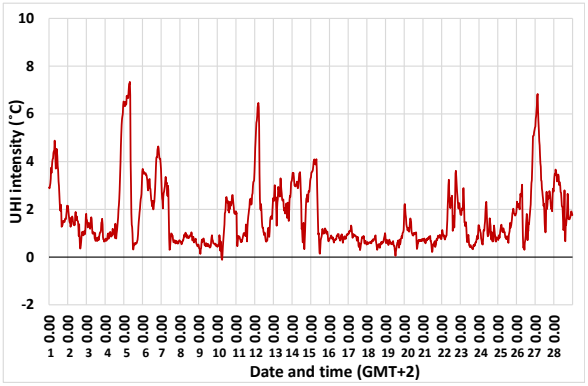

Figure 29. UHI intensity between Betel and Niuskala during February 2023.

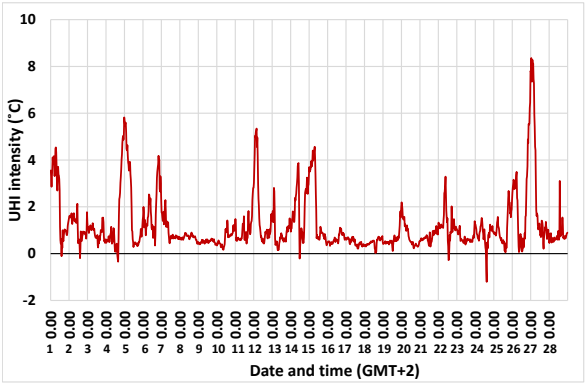

Figure 30. UHI intensity between Kauppatori and Kurala during February 2023.

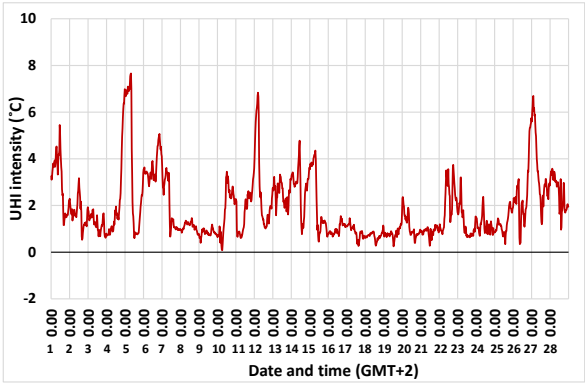

Figure 31. UHI intensity between Kauppatori and Niuskala during February 2023.

19.00 and 21.00 (Figure 33), with an additional smaller peak visible shortly after 09.00. During these peak periods, the average UHI intensity exceeded 2 °C, whereas during other hours it typically ranged from 0.7 to 2.0 °C.

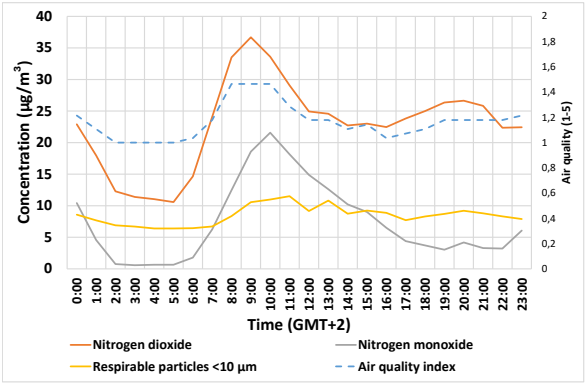

Figure 32. Hourly averages of air quality observations in February 2021.

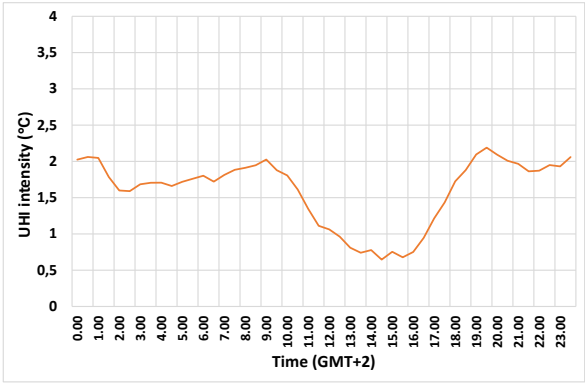

Figure 33. Hourly average UHI intensity between Kauppatori and Kurala in February 2021.

The correlations between the UHI and air quality

During the morning hours of 07.00–08.00 in 2021, all air quality variables except for respirable and fine particles exhibited statistically significant correlations with the UHI intensity between Betel and Kurala (Table 15). These correlations were of medium to relatively strong strength, with stronger coefficients observed during the earlier hour. Although the same variables remained correlated during the 08.00–09.00 period, the correlation coefficients weakened. In the afternoon period from 15.00 to 16.00, only the air quality index showed a weak correlation with UHI intensity according to the Pearson correlation. During the subsequent hour (16.00–17.00), statistically significant correlations were found only for nitrogen monoxide and nitrogen dioxide, with the latter showing a relatively strong positive correlation and the former a weaker one.

In 2023, the UHI intensity between Betel and Kurala correlated positively and relatively strongly with nitrogen dioxide and nitrogen monoxide during the 07.00–08.00 period (Table 16). Between 08.00 and 09.00, moderately strong positive correlations persisted with nitrogen dioxide and nitrogen monoxide, and a medium-strength correlation also emerged with the air quality index. During the 15.00–16.00 interval, no statistically significant correlations were observed with any of the air quality variables. However, in the following hour (16.00–17.00), a moderately strong positive correlation was observed with respirable particulate matter. The Spearman correlations closely followed the patterns observed in the Pearson correlations, though the coefficients were generally weaker. Notably, a statistically significant correlation with fine particles was observed during 16.00–17.00 in the Spearman analysis, while the previously noted correlation with the air quality index at 08.00–09.00 was absent.

In February 2021, no statistically significant correlations were found between respirable particles or fine particles and the UHI intensity between Betel and Niuskala (Table 17).

Table 15. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in February 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.654****	<0.001	**0.459***	0.014	**0.378***	0.048	0.342	0.075
	Nitrogen dioxide	**0.613****	<0.001	**0.453***	0.016	0.157	0.423	**0.614****	<0.001
	Nitrogen monoxide	**0.554****	0.002	**0.507****	0.006	0.301	0.120	**0.406***	0.032
	Respirable particles	0.280	0.149	0.229	0.241	0.235	0.228	0.341	0.076
	Fine particles								
Spearman	Air quality index	**0.605****	<0.001	**0.586****	0.001	0.322	0.095	0.309	0.110
	Nitrogen dioxide	**0.570****	0.002	**0.551****	0.002	0.155	0.430	**0.646****	<0.001
	Nitrogen monoxide	**0.516****	0.005	**0.506****	0.006	0.292	0.132	**0.458***	0.014
	Respirable particles	0.329	0.088	0.328	0.088	0.101	0.608	0.348	0.069
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 16. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in February 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.252	0.197	**0.431***	0.022	0.073	0.713	0.373	0.051
	Nitrogen dioxide	**0.673****	<0.001	**0.670****	<0.001	0.190	0.333	0.033	0.868
	Nitrogen monoxide	**0.721****	<0.001	**0.699****	<0.001	0.318	0.100	-0.084	0.672
	Respirable particles	0.302	0.118	0.220	0.260	-0.114	0.563	**0.561****	0.002
	Fine particles	0.061	0.757	0.097	0.624	0.115	0.560	0.345	0.072
Spearman	Air quality index	0.152	0.441	0.233	0.234	0.060	0.760	0.330	0.086
	Nitrogen dioxide	**0.572****	0.001	**0.625****	<0.001	0.158	0.423	0.022	0.910
	Nitrogen monoxide	**0.385***	0.043	**0.533****	0.003	0.267	0.170	-0.190	0.333
	Respirable particles	0.204	0.299	0.293	0.130	-0.001	0.997	**0.543****	0.003
	Fine particles	0.165	0.402	0.207	0.290	0.067	0.735	**0.405***	0.033

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

However, nitrogen monoxide, nitrogen dioxide, and the air quality index exhibited medium-strength positive correlations during the morning hours, with the air quality index showing the strongest association. During the afternoon period from 16.00 to 17.00, only nitrogen monoxide displayed a statistically significant correlation, which was relatively weak. All correlations were positive.

For February 2023, the UHI intensity between Betel and Niuskala showed a medium-strength positive Pearson correlation with nitrogen dioxide and a weak one with nitrogen monoxide during the 07.00–08.00 period

Table 17. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in February 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.504****	0.006	**0.494****	0.008	-0.089	0.651	0.233	0.232
	Nitrogen dioxide	**0.436***	0.020	**0.414***	0.028	0.278	0.153	**0.391***	0.040
	Nitrogen monoxide	**0.410***	0.030	**0.458***	0.014	0.212	0.278	0.104	0.598
	Respirable particles	0.304	0.115	0.213	0.276	-0.007	0.971	0.173	0.378
	Fine particles								
Spearman	Air quality index	**0.635****	<0.001	**0.671****	<0.001	-0.107	0.587	0.103	0.602
	Nitrogen dioxide	**0.461***	0.014	**0.534****	0.003	0.201	0.305	0.264	0.175
	Nitrogen monoxide	0.366	0.055	**0.477***	0.010	0.219	0.263	0.105	0.594
	Respirable particles	0.298	0.123	0.317	0.100	-0.003	0.987	0.084	0.672
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 18. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in February 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.033	0.867	0.145	0.461	-0.125	0.525	-0.042	0.830
	Nitrogen dioxide	**0.432***	0.022	**0.470***	0.012	-0.178	0.366	0.214	0.273
	Nitrogen monoxide	**0.384***	0.044	**0.455***	0.015	-0.178	0.366	-0.088	0.656
	Respirable particles	-0.007	0.973	-0.027	0.890	-0.066	0.738	0.084	0.671
	Fine particles	-0.172	0.381	-0.167	0.395	-0.164	0.403	-0.019	0.925
Spearman	Air quality index	0.038	0.848	0.083	0.674	-0.120	0.544	0.033	0.868
	Nitrogen dioxide	**0.558****	0.002	**0.535****	0.003	-0.195	0.319	0.125	0.525
	Nitrogen monoxide	0.305	0.114	0.371	0.052	-0.203	0.300	-0.096	0.627
	Respirable particles	0.008	0.969	0.147	0.456	-0.012	0.951	0.267	0.170
	Fine particles	0.022	0.913	-0.041	0.838	-0.104	0.599	0.088	0.656

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

(Table 18). A similar pattern was observed between 08.00 and 09.00, with both correlation coefficients slightly stronger than those recorded during the earlier hour. In the Spearman correlation analysis, only nitrogen dioxide demonstrated a statistically significant correlation during the morning hours. In the afternoon, between 15.00 and 17.00, no statistically significant correlations were observed between UHI intensity and any of the air quality variables.

Between Kauppatori and Kurala in 2021, statistically significant correlations were primarily concentrated in the morning hours

Table 19. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in February 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.684****	<0.001	**0.448***	0.017	0.244	0.211	0.369	0.053
	Nitrogen dioxide	**0.641****	<0.001	**0.456***	0.015	-0.008	0.969	**0.563****	0.002
	Nitrogen monoxide	**0.538****	0.003	**0.464***	0.013	0.126	0.523	0.341	0.076
	Respirable particles	0.260	0.182	0.221	0.259	0.038	0.847	0.235	0.230
	Fine particles								
Spearman	Air quality index	**0.648****	<0.001	**0.536****	0.003	0.226	0.247	0.309	0.110
	Nitrogen dioxide	**0.621****	<0.001	**0.532****	0.004	-0.034	0.863	**0.517****	0.005
	Nitrogen monoxide	**0.552****	0.002	**0.459***	0.014	0.096	0.625	0.325	0.091
	Respirable particles	0.316	0.101	0.262	0.179	0.017	0.932	0.282	0.146
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 20. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in February 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.205	0.294	**0.445***	0.018	-0.121	0.539	0.241	0.216
	Nitrogen dioxide	**0.679****	<0.001	**0.694****	<0.001	0.111	0.573	0.160	0.416
	Nitrogen monoxide	**0.695****	<0.001	**0.677****	<0.001	0.043	0.829	-0.127	0.519
	Respirable particles	0.269	0.166	0.237	0.225	-0.221	0.258	**0.405***	0.033
	Fine particles	0.077	0.695	0.134	0.497	0.032	0.873	0.314	0.104
Spearman	Air quality index	0.202	0.302	0.304	0.116	-0.136	0.491	0.239	0.220
	Nitrogen dioxide	**0.685****	<0.001	**0.707****	<0.001	0.069	0.727	0.174	0.377
	Nitrogen monoxide	**0.508****	0.006	**0.603****	<0.001	0.014	0.943	-0.096	0.628
	Respirable particles	0.313	0.105	**0.414***	0.028	0.067	0.737	**0.525****	0.004
	Fine particles	0.323	0.094	0.355	0.064	0.103	0.601	**0.478***	0.010

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

(Table 19). Most of these were of medium strength, with some reaching a relatively strong level. No statistically significant correlations were found for respirable or fine particles. In the afternoon, only nitrogen dioxide exhibited a statistically significant medium positive correlation.

In 2023, the UHI intensity between Kauppatori and Kurala showed a moderately strong positive correlation with nitrogen dioxide and nitrogen monoxide between 07.00 and 08.00 (Table 20). These correlations remained relatively consistent during the following hour (08.00–09.00), alongside a slight positive correlation with the air quality index. Between 15.00 and 16.00, no statistically significant correlations were observed. However, during the 16.00–17.00 period, a slight positive correlation emerged with respirable particulate matter and with fine particles for Spearman.

In 2021, between Kauppatori and Niuskala, all air quality variables except respirable and fine particles exhibited statistically significant correlations with UHI intensity, though with varying strengths (Table 21). Nitrogen monoxide displayed the weakest correlation, while the air quality index showed the strongest. Overall, the correlations ranged from quite weak to moderate in strength, with the air quality index reaching relatively strong Spearman coefficients. During the afternoon hours, none of the variables demonstrated statistically significant correlations.

In 2023, between 07.00 and 08.00, a moderate positive correlation was observed between UHI intensity and nitrogen dioxide concentrations (Table 22). In the following hour (08.00–09.00), a similarly moderate positive correlation emerged with nitrogen monoxide, while the correlation with nitrogen dioxide remained stable. The Spearman correlation coefficients were consistent with those of the Pearson correlation but slightly stronger. No statistically significant correlations were identified during the afternoon period (15.00–17.00).

Table 21. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in February 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.537****	0.003	**0.488****	0.008	-0.120	0.544	0.244	0.211
	Nitrogen dioxide	**0.463***	0.013	**0.414***	0.028	0.157	0.426	0.344	0.073
	Nitrogen monoxide	**0.392***	0.039	**0.408***	0.031	0.106	0.591	0.058	0.769
	Respirable particles	0.294	0.130	0.204	0.299	-0.093	0.637	0.097	0.623
	Fine particles								
Spear-man	Air quality index	**0.681****	<0.001	**0.629****	<0.001	-0.131	0.506	0.120	0.542
	Nitrogen dioxide	**0.531****	0.004	**0.502****	0.007	0.083	0.676	0.210	0.283
	Nitrogen monoxide	**0.420***	0.026	**0.431***	0.022	0.124	0.529	0.055	0.781
	Respirable particles	0.279	0.150	0.286	0.140	-0.054	0.785	0.030	0.879
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 22. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in February 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	-0.006	0.978	0.149	0.450	-0.180	0.361	-0.076	0.702
	Nitrogen dioxide	**0.423***	0.025	**0.476***	0.010	-0.182	0.353	0.259	0.183
	Nitrogen monoxide	0.351	0.067	**0.424***	0.025	-0.250	0.200	-0.107	0.589
	Respirable particles	-0.037	0.851	-0.019	0.925	-0.100	0.613	0.043	0.828
	Fine particles	-0.163	0.409	-0.140	0.479	-0.174	0.376	-0.012	0.954
Spear-man	Air quality index	0.051	0.798	0.122	0.535	-0.119	0.547	-0.038	0.846
	Nitrogen dioxide	**0.610****	<0.001	**0.600****	<0.001	-0.166	0.397	0.146	0.459
	Nitrogen monoxide	0.364	0.057	**0.442***	0.019	-0.233	0.233	-0.127	0.519
	Respirable particles	0.077	0.696	0.230	0.240	0.062	0.756	0.200	0.309
	Fine particles	0.097	0.625	0.076	0.699	-0.022	0.911	0.057	0.774

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

The correlation between the 05.00 UHI and the 08.00 air quality

In February 2021, the UHI intensity recorded at 05.00 exhibited statistically significant positive correlations with the 08.00 concentrations of the air quality index, nitrogen dioxide, and nitrogen monoxide in both the Pearson and Spearman correlations (Table 23). Among these, nitrogen monoxide showed the strongest correlation, while nitrogen dioxide had the weakest. Overall, the correlations were relatively strong and positive.

In 2023, the UHI showed a moderate positive Pearson correlation with nitrogen dioxide and nitrogen monoxide (Table 24), with nitrogen monoxide again demonstrating the stronger association. A statistically significant Spearman correlation was observed only for nitrogen dioxide, which was positive but relatively weak. Compared to 2021, the number of statistically significant correlations in 2023 was reduced, with only nitrogen dioxide and nitrogen monoxide displaying meaningful associations.

The correlation between the UHI, average wind speed and cloudiness

In February, daytime extended approximately from 08.00 to 17.30. During this period, UHI intensity exhibited a moderately strong negative correlation with cloudiness (Table 25). At night, the UHI intensity maintained a negative correlation with both average wind speed and cloudiness. The correlation with cloudiness remained relatively consistent across day and night, with a slight increase in strength during nighttime. In contrast, the correlation with average wind speed was weaker than that with cloudiness during both periods.

Scatter plots illustrating wind speed reveal that UHI intensity values were generally lower during the daytime compared to nighttime (Figures 34 & 36). While a few daytime wind speed values exceeded 4 m/s, the majority fell within the 1–3 m/s range. Maximum daytime UHI intensities reached approximately 3 °C, with most values concentrated between 0.5–

Table 23. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in February 2021. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index	**0.717****	<0.001
	Nitrogen dioxide	**0.659****	<0.001
	Nitrogen monoxide	**0.782****	<0.001
	Respirable particles	0.326	0.090
	Fine particles		
Spearman	Air quality index	**0.677****	<0.001
	Nitrogen dioxide	**0.633****	<0.001
	Nitrogen monoxide	**0.693****	<0.001
	Respirable particles	0.370	0.053
	Fine particles		

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 24. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in February 2023. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index	0.040	0.841
	Nitrogen dioxide	**0.388***	0.041
	Nitrogen monoxide	**0.501****	0.007
	Respirable particles	0.062	0.754
	Fine particles	-0.095	0.631
Spearman	Air quality index	0.051	0.798
	Nitrogen dioxide	**0.376***	0.049
	Nitrogen monoxide	0.208	0.287
	Respirable particles	-0.036	0.855
	Fine particles	0.002	0.992

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 25. Pearson and Spearman correlation coefficients between the wind speed and UHI and between the cloudiness and UHI during daytime and nighttime in February 2021. Four different UHI intensities are calculated based on the Betel, Kurala, Kauppatori and Niuskala observation sites.

			Betel & Kurala Average UHI	Betel & Niuskala Average UHI	Kauppatori & Kurala Average UHI	Kauppatori & Niuskala Average UHI
Day	Pearson	Average wind speed	**-0.375***	-0.364	-0.300	-0.275
		Average cloudiness	-0.042	-0.329	-0.265	**-0.528****
	Spearman	Average wind speed	**-0.394***	-0.322	-0.297	-0.193
		Average cloudiness	-0.240	**-0.536****	**-0.497****	**-0.702****
Night	Pearson	Average wind speed	**-0.549****	**-0.458***	**-0.550****	**-0.460***
		Average cloudiness	**-0.491****	**-0.575****	**-0.486****	**-0.587****
	Spearman	Average wind speed	**-0.522****	**-0.436***	**-0.521****	**-0.438***
		Average cloudiness	**-0.535****	**-0.550****	**-0.507****	**-0.543****

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

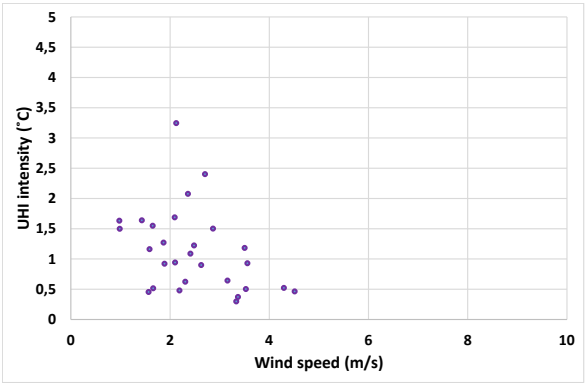

Figure 34. Scatter plot for wind speed and UHI between Betel and Kurala during daytime in February 2021.

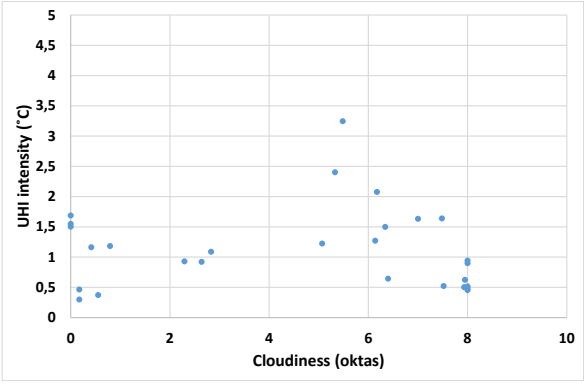

Figure 35. Scatter plot for cloudiness and UHI between Betel and Kurala during daytime in February 2021.

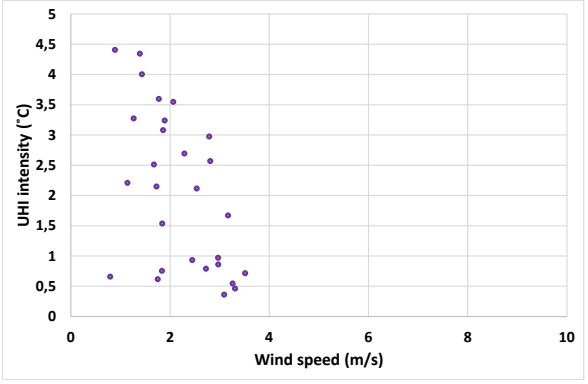

Figure 36. Scatter plot for wind speed and UHI between Betel and Kurala during nighttime in February 2021.

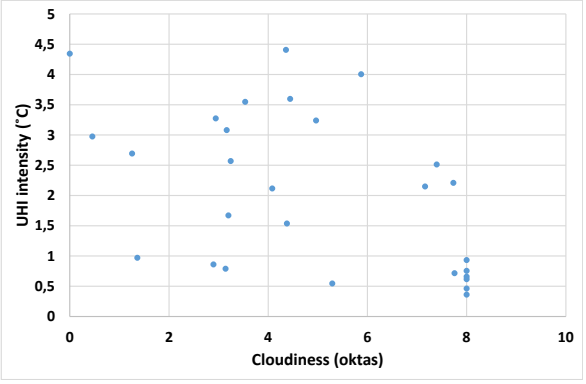

Figure 37. Scatter plot for cloudiness and UHI between Betel and Kurala during nighttime in February 2021.

2 °C. At night, UHI intensities were higher and more broadly distributed, ranging from 0.5 to nearly 4.5 °C. Nighttime wind speeds peaked around 3.5 m/s and were similarly clustered in the 1–3 m/s range. The scatter plots for cloudiness show a dispersed distribution of values for both daytime and nighttime (Figures 35 & 37). During the day, data points tend to cluster at both low (0–3) and high (5–8) cloudiness levels. Across these ranges, most UHI intensity values remained between 0.5 and 1.5 °C. At night, the data appeared more randomly scattered, reflecting increased variability. However, a notable concentration of points was observed at a cloudiness level of 8, where UHI intensity values were approximately 0.5–1 °C.

The correlation between NAO index and UHI

In February, statistically significant correlations with the NAO index were observed only for the Betel–Kurala and Kauppatori–Kurala logger pairs (Table 26). These correlations were present in both Pearson and Spearman analyses and were negative in direction, indicating that higher NAO index values were associated with lower UHI intensities. The strength of the correlations was moderate, with the Spearman coefficients slightly exceeding those of Pearson.

Frost period review

In February 2021, three frost periods were identified: 3rd–6th February, 10th–11th February, and 17th–18th February, comprising one four-day period and two shorter two-day periods. During the first frost period, UHI intensities exhibited a clear diurnal pattern, often reaching 3–4 °C at night and decreasing to around 0 °C during midday (Figures 38–41). The highest peak was observed during the final night of this period, with UHI intensities reaching up to 7.5 °C.

Temperature measurements within the Student Village remained relatively consistent throughout the frost period. However, Aurajokiranta and Kuikkulankatu frequently appeared as the coldest locations (Figure 42). On several occasions, Suntiontie recorded the highest temperatures among the Student Village logger sites. In comparing Puutori and Ylijoki, Puutori consistently showed significantly higher night-

Table 26. Pearson and Spearman correlations between NAO index and different UHI logger pairs in February 2021.

	UHI	NAO index	Significance level
Pearson	Betel & Kurala	**-0.479****	0.010
	Betel & Niuskala	-0.270	0.165
	Kauppatori & Kurala	**-0.508****	0.006
	Kauppatori & Niuskala	-0.276	0.156
	Betel & Ryhmäpuutarha	-0.303	0.116
	Kauppatori & Ryhmäpuutarha	-0.319	0.098
Spearman	Betel & Kurala	**-0.587****	0.001
	Betel & Niuskala	0.282	0.146
	Kauppatori & Kurala	**-0.589****	<0.001
	Kauppatori & Niuskala	-0.338	0.079
	Betel & Ryhmäpuutarha	-0.349	0.069
	Kauppatori & Ryhmäpuutarha	-0.368	0.054

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

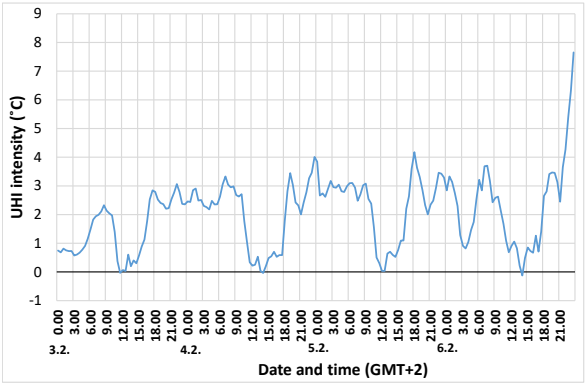

Figure 38. UHI intensity between Betel and Kurala during the frost period on the 3rd-6th of February in 2021.

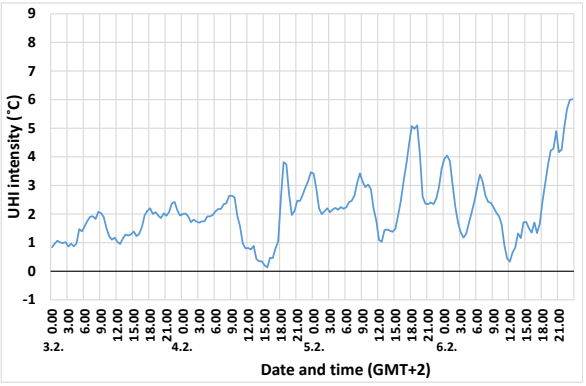

Figure 39. UHI intensity between Betel and Niuskala during the frost period on the 3rd-6th of February in 2021.

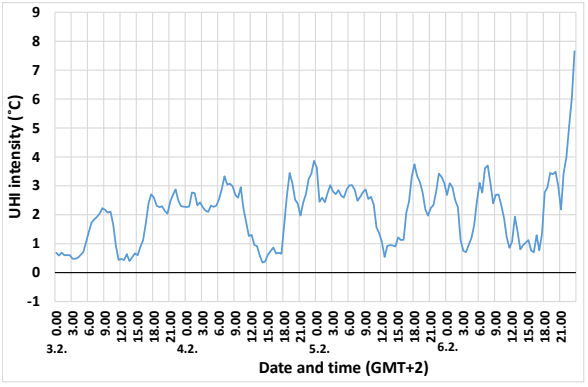

Figure 40. UHI intensity between Kauppatori and Kurala during the frost period on the 3rd-6th of February in 2021.

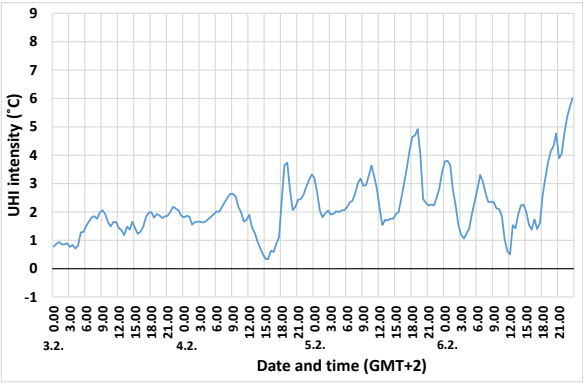

Figure 41. UHI intensity between Kauppatori and Niuskala during the frost period on the 3rd-6th of February in 2021.

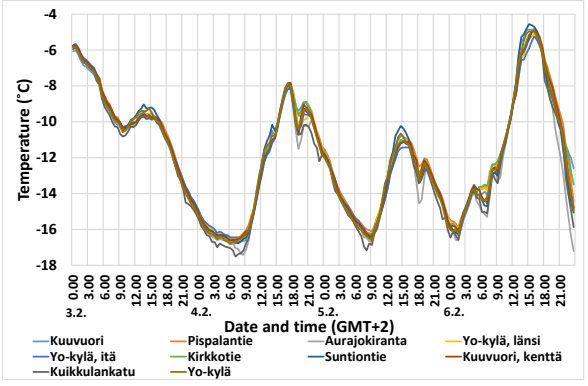

Figure 42. Turku Student Village temperatures during the frost period on the 3rd-6th of February in 2021.

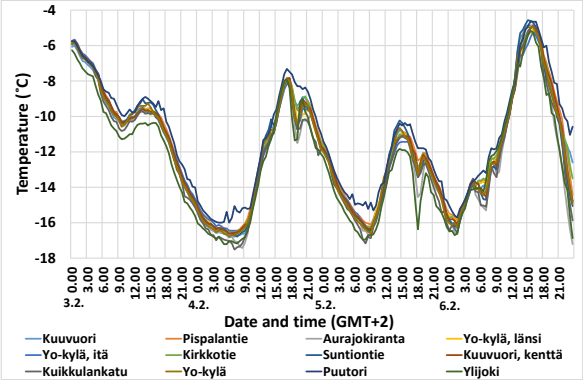

Figure 43. Turku Student Village, Puutori and Ylijoki temperatures during the frost period on the 3rd-6th of February in 2021.

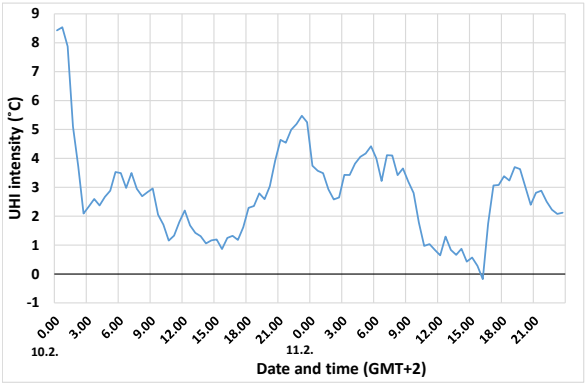

Figure 44. UHI intensity between Betel and Kurala during the frost period on the 10th-11th of February in 2021.

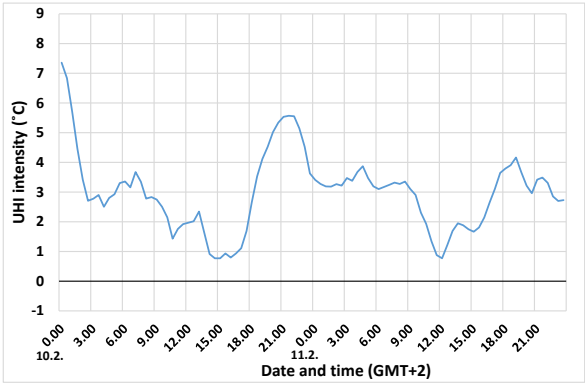

Figure 45. UHI intensity between Betel and Niuskala during the frost period on the 10th-11th of February in 2021.

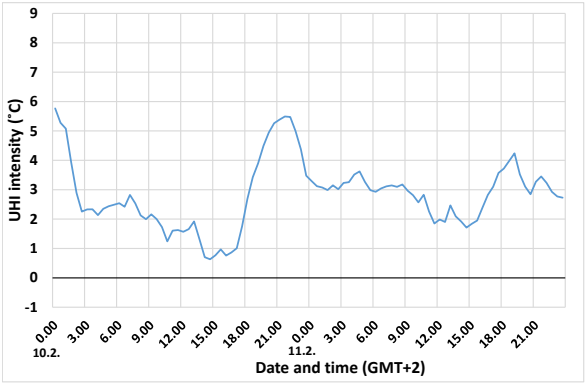

Figure 46. UHI intensity between Kauppatori and Kurala during the frost period on the 10th-11th of February in 2021.

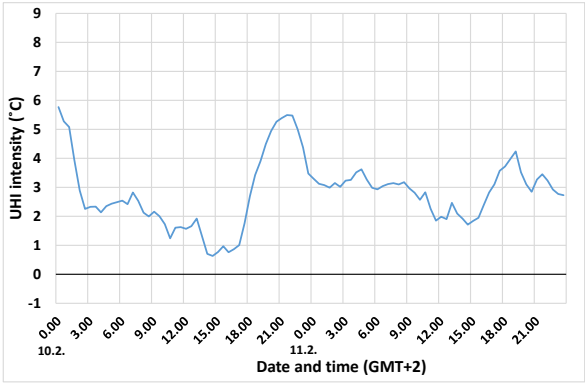

Figure 47. UHI intensity between Kauppatori and Niuskala during the frost period on the 10th-11th of February in 2021.

time temperatures, particularly when overall temperatures dropped (Figure 43). Conversely, Ylijoki occasionally recorded even lower temperatures than Aurajokiranta during the coldest intervals.

During the frost period on 10th–11th February, the highest UHI intensity peaks were observed around midnight and again during the evening of the 10th (Figures 44–47). Between Betel and Kurala, the first peak reached up to 8.5 °C, while other logger pairs recorded values around 6–7 °C. The UHI intensity followed a typical diurnal pattern, with lower values during daytime and higher values at night.

Temperature data from the Student Village show increased variability during this frost period, particularly around midnight and in the evening of the 10th (Figure 48). Aurajokiranta consistently recorded the lowest temperatures, while Kuuvuori and Pispalantie measured the highest. Notably, after 21.00 on the 10th, Aurajokiranta's temperatures diverged sharply from the others, showing a difference of nearly 4 °C compared to the rest of the logger sites. Among the Puutori and Ylijoki locations, Puutori remained the warmest throughout the frost period, while Ylijoki was the coldest registering even lower temperatures than Aurajokiranta at nearly every time point (Figure 49).

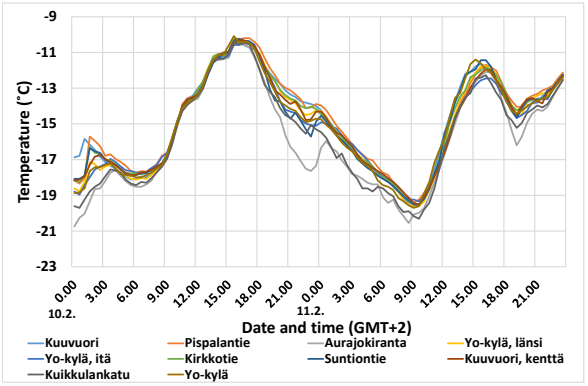

Figure 48. Turku Student Village temperatures during the frost period on the 10th-11th of February in 2021.

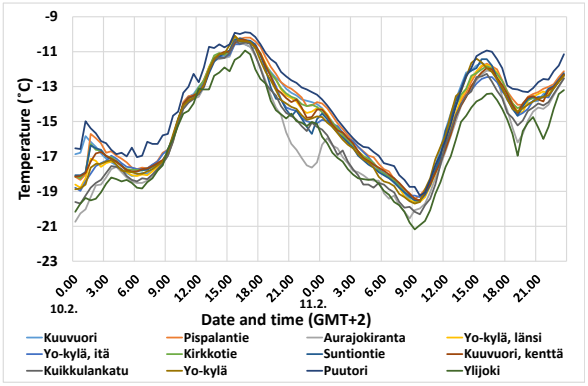

Figure 49. Turku Student Village, Puutori and Ylijoki temperatures during the frost period on the 10th-11th of February in 2021.

During the frost period between 17th–18th February, the UHI intensity remained relatively strong throughout (Figures 50–53). This was particularly evident during nighttime, when the UHI peaked at around 7 °C, depending on the logger pair. During daytime, the intensi-

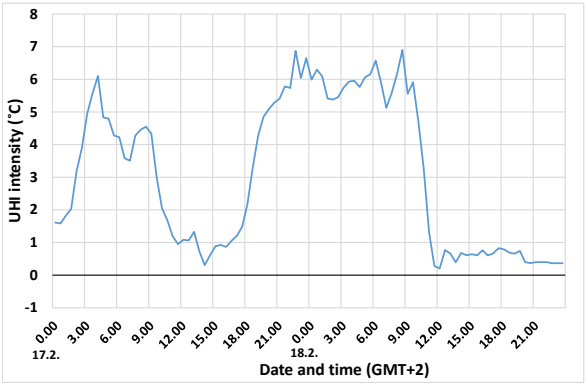

Figure 50. UHI intensity between Betel and Kurala during the frost period on the 17th-18th of February in 2021.

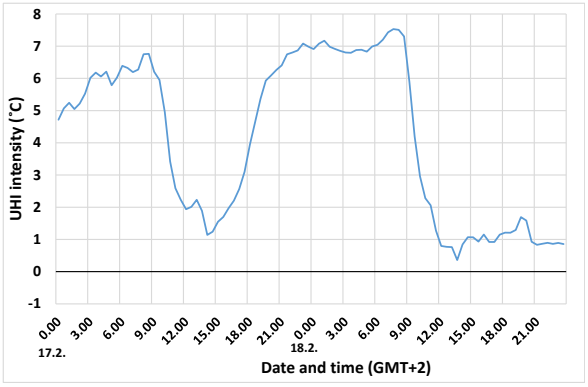

Figure 51. UHI intensity between Betel and Niuskala during the frost period on the 17th-18th of February in 2021.

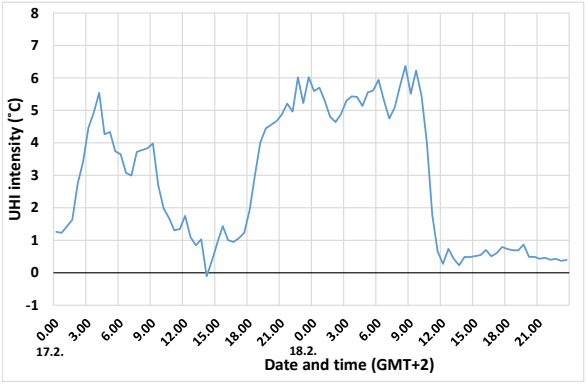

Figure 52. UHI intensity between Kauppatori and Kurala during the frost period on the 17th-18th of February in 2021.

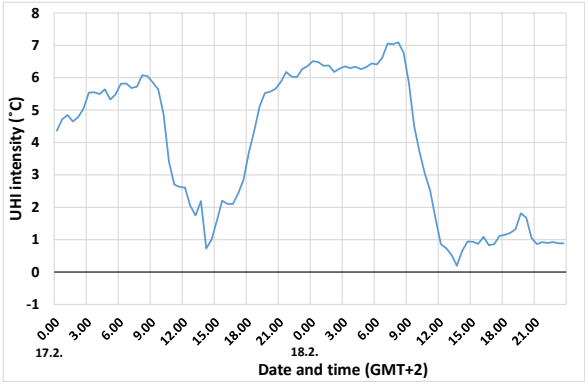

Figure 53. UHI intensity between Kauppatori and Niuskala during the frost period on the 17th-18th of February in 2021.

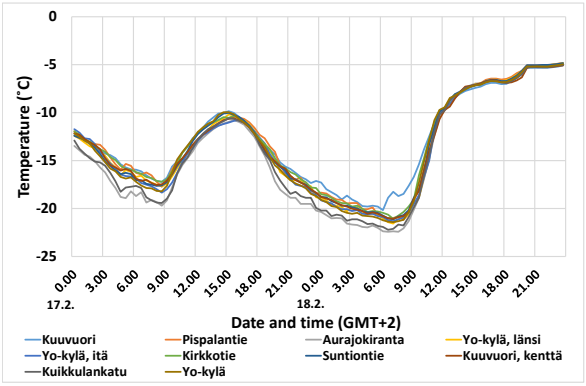

Figure 54. Turku Student Village temperatures during the frost period on the 17th-18th of February in 2021.

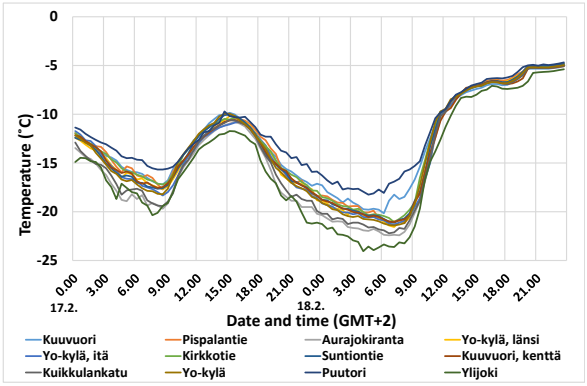

Figure 55. Turku Student Village, Puutori and Ylijoki temperatures during the frost period on the 17th-18th of February in 2021.

ty notably declined, approaching nearly 0 °C around midday and remaining low throughout the afternoon before increasing again in the evening.

Temperatures across the Student Village sites were relatively consistent during this frost period (Figure 54). However, some variability was observed at night, with Aurajokiranta and Kuikkulankatu recording the lowest temperatures. On the 18th, Kuuvuori recorded the highest nighttime temperatures, although it was not as clearly distinguishable on the 17th. Puutori was clearly the warmest site during colder times while Ylijoki was the coldest (Figure 55).

5.1.3 March

The UHI intensities

In March 2021, UHI intensities exhibited varying peak values throughout the month (Figures 56–59). The highest peaks reached up to 6 °C and frequently occurred around midnight. The most pronounced peak values across all logger pairs were recorded shortly after midnight on the 5th of March. Although some minor negative values were observed, between Betel and Niuskala and between Kauppatori and Niuskala, the UHI intensity approached nearly –3 °C on the afternoon of the 26th, while other logger pairs remained below –1 °C. Generally, UHI intensity fluctuated between 0 and 2 °C outside of the peak periods.

In March 2023, the UHI intensities among all four sites appeared to be quite similar to one another (Figures 60–63). Significant peaks were recorded both at the end of the month and during the period from the 8th to the 18th, during which intensities reached up to 8 °C. A relatively stable period was observed from the 18th to the 29th. A few negative values were registered on the 9th and again at the end of the month, particularly between Betel and Kurala and Kauppatori and Kurala. Additional negative values were also observed on the 21st between Betel and Niuskala and between Kauppatori and Niuskala, reaching down to –2 °C. Most UHI peaks occurred shortly after midnight or during the early morning hours, while the few instances of UCIs tended to occur during the afternoon.

In comparison to 2021, higher UHI intensity peaks were recorded in 2023, with a difference of approximately 2 °C. Both years exhibited minor, randomly occurring negative values, as well as a distinct singular peak during the

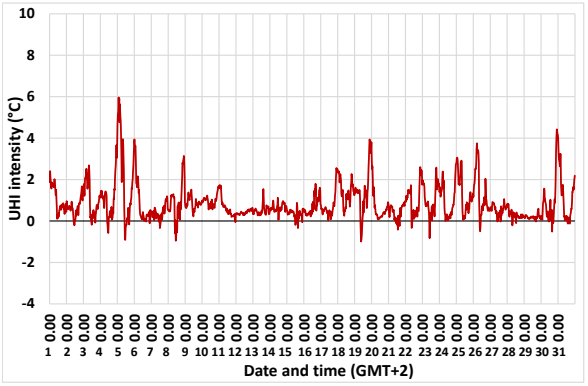

Figure 56. UHI intensity between Betel and Kurala during March 2021.

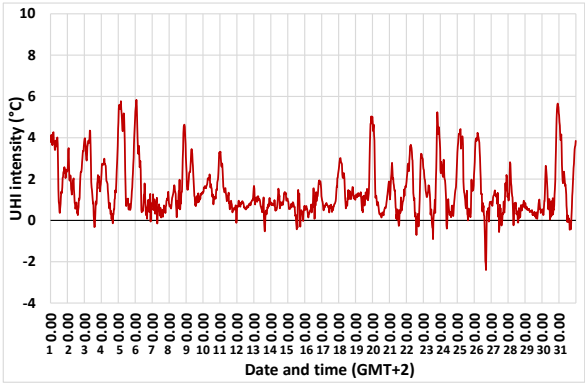

Figure 57. UHI intensity between Betel and Niuskala during March 2021.

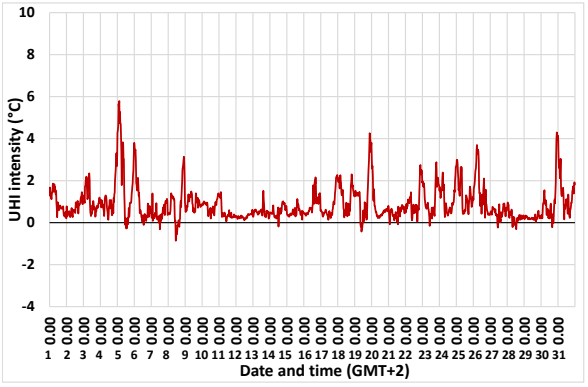

Figure 58. UHI intensity between Kauppatori and Kurala during March 2021.

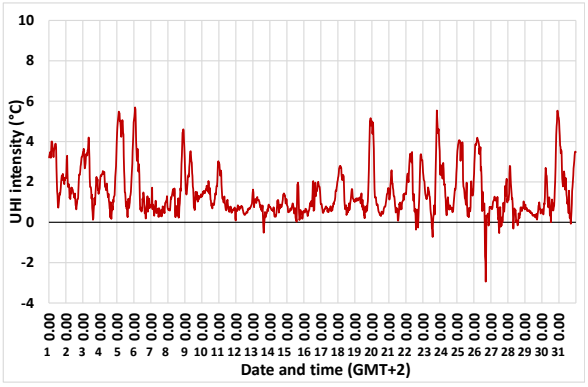

Figure 59. UHI intensity between Kauppatori and Niuskala during March 2021.

month. Additionally, both periods included a stable phase during which UHI intensity remained relatively constant at around 1 °C between the 11th and 16th in 2021, and between the 18th and 29th in 2023.

Monthly summaries

In March 2021, the air quality index peaked during the 15.00–17.00 time period, with values exceeding 1.7, which coincides with typical afternoon traffic rush hours (Figure 64). Respirable particle concentrations also peaked during this time, reaching approximately 23 µg/m³. In contrast, nitrogen dioxide and nitrogen monoxide exhibited peak values during the morning hours between 07.00 and 10.00, which similarly align with morning traffic rush hours. Nitrogen dioxide concentrations reached up to 25 µg/m³, while nitrogen monoxide remained relatively low, with peak values of around 7 µg/m³. Minor peaks in the air quality index and respirable particles were also observed during the morning hours.

The air quality summary for March 2023 indicates that the highest values for all measured variables occurred predominantly in the morning between 07.00 and 10.00. During this period, the air quality index ranged from 1.07 to 1.72; nitrogen dioxide concentrations ranged from 8.76 to 24.55 µg/m³; nitrogen monoxide from 0.88 to 10.12 µg/m³; respirable particles from 6.17 to 15.44 µg/m³; and fine particles from 3.44 to 5.14 µg/m³, on average.

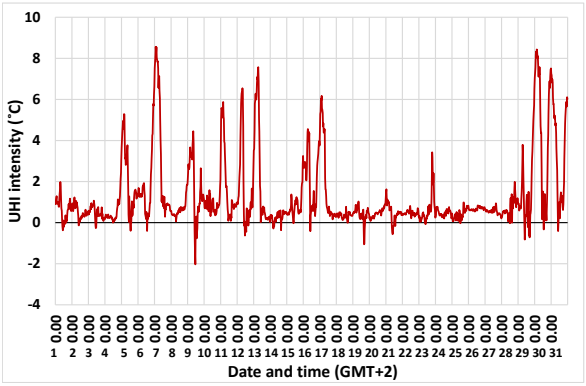

Figure 60. UHI intensity between Betel and Kurala during March 2023.

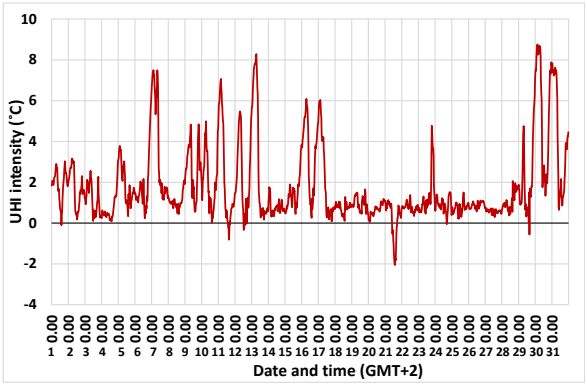

Figure 61. UHI intensity between Betel and Niuskala during March 2023.

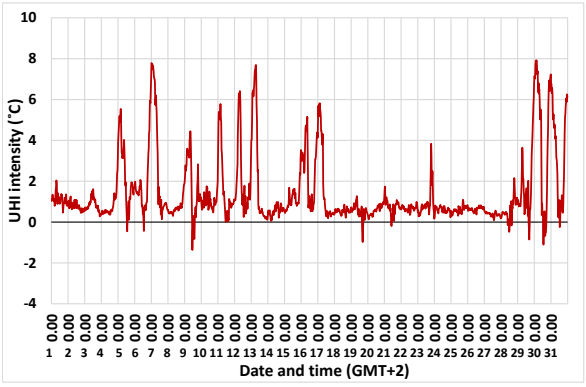

Figure 62. UHI intensity between Kauppatori and Kurala during March 2023.

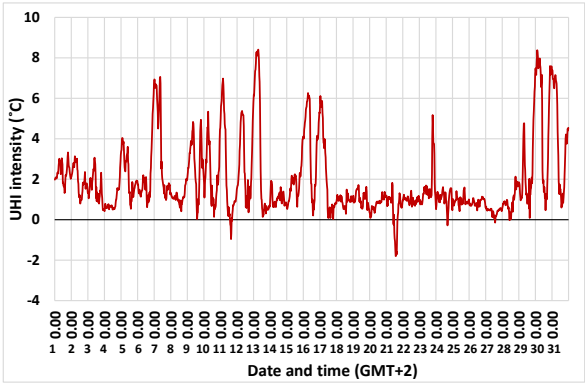

Figure 63. UHI intensity between Kauppatori and Niuskala during March 2023.

In both 2021, the UHI reached its peak during the nighttime hours (Figure 65), with average values ranging from approximately 1.1 to 1.3 °C. During daytime hours, the UHI remained lower, averaging between 0.4 and 0.7 °C.

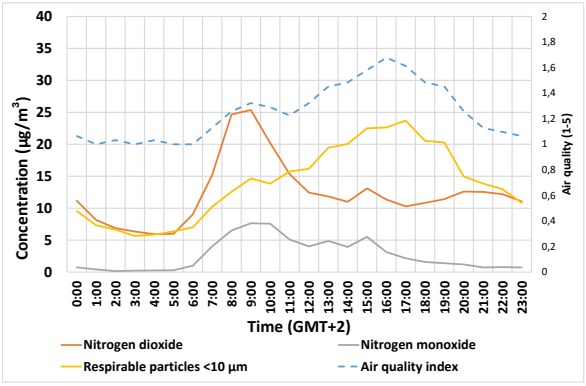

Figure 64. Hourly averages of air quality observations in March 2021.

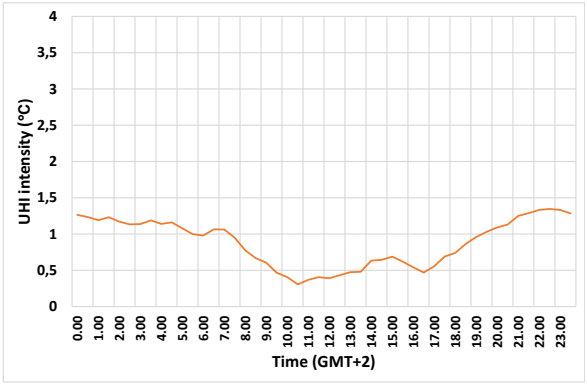

Figure 65. Hourly average UHI intensity between Kauppatori and Kurala in March 2021.

The correlations between the UHI and air quality

In 2021, the UHI effect showed a strong correlation with nitrogen dioxide during the 07.00–08.00 time period, as indicated by both Pearson and Spearman correlation coefficients (Table 27). Additionally, nitrogen monoxide and respirable particles exhibited moderate correlations in the Spearman analysis during the same hour. In the subsequent hour (08.00–09.00), statistically significant correlations were observed with the air quality index, nitrogen dioxide, and nitrogen monoxide. All of these were of moderate strength, except with nitrogen dioxide which was strong. The corresponding Spearman correlations followed a similar pattern, although all coefficients were slightly weaker. In the afternoon, the only statistically significant correlation was between UHI and nitrogen dioxide in the Spearman correlation at 16.00–17.00, which was of moderate strength.

In 2023, between 07.00 and 08.00, the UHI between Betel and Kurala correlated strongly and positively with all measured air quality variables except respirable and fine particles which were of moderate strength (Table 28). Among these, the weakest correlation was with fine particles, while the strongest was with nitrogen dioxide. During the subsequent hour (08.00–09.00), the correlations remained relatively stable. At 15.00–16.00, a statistically significant correlation was observed only with nitrogen monoxide, which was positive and of moderate strength. Between 16.00 and 17.00, no statistically significant correlations were detected, except for a weak Spearman correlation with nitrogen monoxide.

For the Betel–Niuskala pair in 2021, the correlation pattern closely resembles that of the Betel–Kurala pair (Table 29). No statistically significant correlations were observed during the afternoon, with all notable correlations occurring in the morning hours. Between 07.00 and 08.00, only nitrogen dioxide exhibited a statistically significant correlation in the Pearson analysis, whereas in the Spearman analysis, nitrogen monoxide and respirable particles also showed significant correlations. The correlation coefficient for nitrogen dioxide was rel-

Table 27. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in March 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.188	0.311	**0.445***	0.012	0.068	0.716	-0.114	0.542
	Nitrogen dioxide	**0.625****	<0.001	**0.642****	<0.001	0.246	0.182	0.341	0.061
	Nitrogen monoxide	0.351	0.053	**0.475****	0.007	0.346	0.056	0.123	0.508
	Respirable particles	0.170	0.361	-0.049	0.793	0.247	0.180	0.035	0.851
	Fine particles								
Spearman	Air quality index	0.313	0.086	**0.386***	0.032	0.025	0.893	0.025	0.892
	Nitrogen dioxide	**0.758****	<0.001	**0.529****	0.002	0.333	0.067	**0.525****	0.002
	Nitrogen monoxide	**0.465****	0.008	**0.401***	0.025	0.349	0.055	0.273	0.137
	Respirable particles	**0.459****	0.009	0.180	0.333	0.252	0.171	0.166	0.373
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 28. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in March 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.617****	<0.001	**0.662****	<0.001	0.079	0.680	0.228	0.235
	Nitrogen dioxide	**0.721****	<0.001	**0.670****	<0.001	0.292	0.118	0.267	0.162
	Nitrogen monoxide	**0.601****	<0.001	**0.592****	<0.001	**0.507****	0.004	0.320	0.090
	Respirable particles	**0.582****	<0.001	**0.595****	<0.001	0.247	0.189	0.303	0.110
	Fine particles	**0.497****	0.006	**0.497****	0.006	0.009	0.963	0.103	0.594
Spearman	Air quality index	**0.492****	0.007	**0.633****	<0.001	0.113	0.551	0.287	0.131
	Nitrogen dioxide	**0.563****	0.001	**0.611****	<0.001	0.336	0.069	0.193	0.317
	Nitrogen monoxide	**0.478****	0.009	**0.518****	0.004	**0.538****	0.002	**0.385***	0.039
	Respirable particles	0.348	0.064	**0.427***	0.021	0.343	0.064	0.313	0.098
	Fine particles	0.294	0.121	0.311	0.101	0.129	0.497	0.232	0.226

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 29. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in March 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.261	0.156	**0.655****	<0.001	-0.134	0.474	0.096	0.606
	Nitrogen dioxide	**0.694****	<0.001	**0.793****	<0.001	0.244	0.186	0.159	0.391
	Nitrogen monoxide	0.318	0.081	**0.613****	<0.001	0.208	0.262	0.199	0.282
	Respirable particles	0.239	0.196	0.279	0.128	0.017	0.926	0.055	0.769
	Fine particles								
Spearman	Air quality index	0.288	0.116	**0.633****	<0.001	-0.129	0.489	0.045	0.812
	Nitrogen dioxide	**0.745****	<0.001	**0.717****	<0.001	0.332	0.068	0.166	0.372
	Nitrogen monoxide	**0.408***	0.023	**0.559****	0.001	0.243	0.188	0.220	0.235
	Respirable particles	**0.361***	0.046	**0.575****	<0.001	0.024	0.897	0.034	0.855
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

atively strong, while those for the other variables were weaker. During the subsequent hour (08.00–09.00), all variables except respirable particles displayed strong correlations in the Pearson analysis. In the Spearman analysis, respirable particles also showed a statistically significant correlation, with coefficients ranging from strong to moderate in strength. All correlations were positive.

In 2023, the UHI between Betel and Niuskala correlated positively with all measured air quality variables during the 07.00–08.00 period (Table 30). Nitrogen dioxide nitrogen monoxide and air quality index showed a strong

Table 30. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in March 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.621****	<0.001	**0.661****	<0.001	0.115	0.544	0.034	0.861
	Nitrogen dioxide	**0.800****	<0.001	**0.783****	<0.001	-0.094	0.620	0.053	0.784
	Nitrogen monoxide	**0.613****	<0.001	**0.610****	<0.001	0.174	0.357	0.198	0.303
	Respirable particles	**0.597****	<0.001	**0.564****	0.001	0.143	0.451	0.226	0.239
	Fine particles	**0.505****	0.005	**0.469***	0.010	0.186	0.324	0.063	0.744
Spearman	Air quality index	**0.503****	0.005	**0.647****	<0.001	0.159	0.403	0.060	0.758
	Nitrogen dioxide	**0.614****	<0.001	**0.704****	<0.001	-0.102	0.590	-0.007	0.972
	Nitrogen monoxide	**0.519****	0.004	**0.627****	<0.001	0.014	0.939	0.059	0.760
	Respirable particles	**0.482****	0.008	**0.527****	0.003	0.234	0.213	0.288	0.129
	Fine particles	**0.387***	0.038	**0.375***	0.045	0.237	0.207	0.145	0.454

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

correlation, while the remaining variables demonstrated moderately strong correlations. A similar pattern was observed during the following hour, although correlation coefficients decreased slightly. All air quality variables also correlated significantly in the Spearman analysis during the morning hours. No statistically significant correlations were observed during the afternoon period.

In the case of Kauppatori and Kurala in 2021, nitrogen dioxide exhibited a relatively strong and nitrogen monoxide medium-strength Pearson correlations during the 07.00–08.00 time period (Table 31). In the Spearman analysis, all air quality variables except fine particles showed statistically significant correlations, with nitrogen dioxide demonstrating a strong correlation and the air quality index the weakest. During the 08.00–09.00 interval, all variables except respirable particles were significantly correlated in the Pearson analysis, with most showing strong correlations; the air quality index, however, showed a weaker association. In the Spearman analysis, only nitrogen dioxide and nitrogen monoxide were significantly correlated, with strong and medium-strength correlations, respectively. In the afternoon, at 15.00–16.00, nitrogen monoxide showed a moderate correlation in the Spearman analysis, and at 16.00–17.00, a Spearman correlation with nitrogen dioxide was observed.

In 2023, the UHI between Kauppatori and Kurala exhibited medium to strong positive correlations with all air quality variables during the 07.00–08.00 period (Table 32), with nitrogen dioxide again showing the strongest correlation. During the 08.00–09.00 interval, the correlation coefficients remained relatively consistent. The Spearman correlations closely followed the Pearson results, with the exception that respirable and fine particles did not show statistically significant correlations at 07.00–08.00. Additionally, the Spearman coefficients were consistently weaker than those of the Pearson analysis. No statistically significant correlations were observed during the afternoon hours.

Table 31. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in March 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.168	0.367	**0.422***	0.018	0.228	0.217	-0.133	0.476
	Nitrogen dioxide	**0.641****	<0.001	**0.711****	<0.001	0.202	0.276	0.331	0.069
	Nitrogen monoxide	**0.421***	0.018	**0.624****	<0.001	0.345	0.057	0.088	0.638
	Respirable particles	0.133	0.477	-0.023	0.901	0.193	0.298	-0.054	0.773
	Fine particles								
Spearman	Air quality index	**0.363***	0.045	0.347	0.056	0.297	0.105	-0.040	0.830
	Nitrogen dioxide	**0.823****	<0.001	**0.720****	<0.001	0.198	0.286	**0.449***	0.011
	Nitrogen monoxide	**0.555****	0.001	**0.525****	0.002	**0.417***	0.019	0.208	0.261
	Respirable particles	**0.408***	0.023	0.293	0.109	0.312	0.087	0.028	0.880
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 32. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in March 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.574****	0.001	**0.648****	<0.001	-0.053	0.782	0.095	0.625
	Nitrogen dioxide	**0.697****	<0.001	**0.666****	<0.001	-0.145	0.444	0.087	0.652
	Nitrogen monoxide	**0.537****	0.003	**0.584****	<0.001	-0.236	0.210	-0.136	0.482
	Respirable particles	**0.519****	0.004	**0.555****	0.002	-0.110	0.563	0.079	0.685
	Fine particles	**0.435***	0.018	**0.461***	0.012	-0.240	0.201	-0.033	0.865
Spearman	Air quality index	**0.475****	0.009	**0.595****	<0.001	-0.136	0.474	0.000	1.000
	Nitrogen dioxide	**0.516****	0.004	**0.594****	<0.001	-0.171	0.367	0.029	0.880
	Nitrogen monoxide	**0.423***	0.022	**0.508****	0.005	-0.184	0.330	-0.112	0.564
	Respirable particles	0.365	0.052	**0.475****	0.009	-0.219	0.245	-0.165	0.392
	Fine particles	0.294	0.121	**0.382***	0.041	-0.295	0.114	-0.140	0.469

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

In 2021, the UHI between Kauppatori and Niuskala correlated with nitrogen dioxide and nitrogen monoxide during the 07.00–08.00 period (Table 33). Nitrogen dioxide exhibited a strong positive correlation, while nitrogen monoxide showed a weak correlation. In the subsequent hour (08.00–09.00), the air quality index also showed a statistically significant correlation, and all correlations during this period were relatively strong. In the Spearman analysis, respirable particles additionally showed a statistically significant correlation. During the afternoon hours, no statistically significant correlations were observed, except for a me-

Table 33. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in March 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.251	0.173	**0.615****	<0.001	-0.022	0.906	-0.133	0.476
	Nitrogen dioxide	**0.709****	<0.001	**0.799****	<0.001	0.236	0.202	0.331	0.069
	Nitrogen monoxide	**0.365***	0.043	**0.671****	<0.001	0.233	0.207	0.088	0.638
	Respirable particles	0.217	0.241	0.278	0.130	-0.010	0.957	-0.054	0.773
	Fine particles								
Spearman	Air quality index	0.297	0.105	**0.648****	<0.001	0.019	0.920	-0.040	0.830
	Nitrogen dioxide	**0.758****	<0.001	**0.776****	<0.001	0.266	0.148	**0.449***	0.011
	Nitrogen monoxide	**0.420***	0.019	**0.603****	<0.001	0.217	0.240	0.208	0.261
	Respirable particles	0.349	0.064	**0.581****	<0.001	0.006	0.976	0.028	0.880
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 34. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in March 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.582****	<0.001	**0.648****	<0.001	0.027	0.889	-0.067	0.731
	Nitrogen dioxide	**0.782****	<0.001	**0.772****	<0.001	**-0.387***	0.035	-0.084	0.665
	Nitrogen monoxide	**0.556****	0.002	**0.600****	<0.001	-0.322	0.082	-0.168	0.385
	Respirable particles	**0.541****	0.002	**0.532****	0.003	-0.095	0.618	0.064	0.743
	Fine particles	**0.450***	0.014	**0.440***	0.017	0.007	0.969	-0.045	0.816
Spearman	Air quality index	**0.500****	0.006	**0.590****	<0.001	0.011	0.953	0.072	0.712
	Nitrogen dioxide	**0.616****	<0.001	**0.644****	<0.001	**-0.361***	0.050	-0.099	0.610
	Nitrogen monoxide	**0.524****	0.004	**0.585****	<0.001	**-0.420***	0.021	-0.162	0.401
	Respirable particles	**0.488****	0.007	**0.490****	0.007	-0.127	0.504	0.188	0.328
	Fine particles	**0.381***	0.041	**0.372***	0.047	-0.016	0.934	0.106	0.584

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

dium-strength Spearman correlation with nitrogen dioxide between 16.00 and 17.00. All observed correlations were positive.

In 2023, the UHI between Kauppatori and Niuskala demonstrated a strong positive correlation with nitrogen dioxide during the 07.00–08.00 time period (Table 34). During this time, the remaining air quality variables also showed moderately strong positive correlations. Correlation coefficients remained relatively stable

Table 35. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in March 2021. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index	0.047	0.801
	Nitrogen dioxide	**0.490****	0.005
	Nitrogen monoxide	0.284	0.121
	Respirable particles	-0.114	0.540
	Fine particles		
Spearman	Air quality index	0.206	0.266
	Nitrogen dioxide	**0.501****	0.004
	Nitrogen monoxide	0.304	0.096
	Respirable particles	0.047	0.802
	Fine particles		

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 36. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in March 2023. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index	**0.563****	0.001
	Nitrogen dioxide	0.364	0.636
	Nitrogen monoxide		
	Respirable particles	-0.293	0.573
	Fine particles	0.451	0.702
Spearman	Air quality index	**0.591****	<0.001
	Nitrogen dioxide	-0.400	0.600
	Nitrogen monoxide		
	Respirable particles	-0.406	0.425
	Fine particles	0.000	1.000

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

during the following hour, though they showed a slight decline. At 15.00–16.00, a weak negative correlation with nitrogen dioxide was observed. The Spearman correlations largely mirrored the Pearson results, with an additional weak correlation observed with nitrogen monoxide during the 15.00–16.00 interval. No statistically significant correlations were recorded during the 16.00–17.00 period.

The correlation between the 05.00 UHI and the 08.00 air quality

In March 2021, the UHI recorded at 05.00 showed a statistically significant correlation with nitrogen dioxide measured at 08.00, based on both Pearson and Spearman analyses (Table 35). These correlations were positive and of moderate strength, with the Spearman correlation being slightly stronger than the Pearson.

In 2023, only the air quality index demonstrated a statistically significant correlation with the UHI, according to both Pearson and Spearman correlations (Table 36). Both correlations were positive and of moderate strength, with the Spearman coefficient again being slightly stronger. Correlations between nitrogen monoxide and UHI could not be calculated for this period.

Overall, March 2021 and March 2023 were similar in terms of the number of variables showing statistically significant correlations with UHI. Although the specific variables differed between the two years, the correlation coefficients were of comparable magnitude.

The correlation between the UHI, average wind speed and cloudiness

In March 2021, daytime was defined as the period between 07.00 and 18.30. During this time, a moderate and weak negative correlations were observed between the UHI and average wind speed, while moderately strong negative correlations were found with cloudiness (Table 37). These relationships remained relatively consistent during the nighttime hours, although the correlation coefficients were slightly stronger.

Table 37. Pearson and Spearman correlation coefficients between the wind speed and UHI and between the cloudiness and UHI during daytime and nighttime in March 2021. Four different UHI intensities are calculated based on the Betel, Kurala, Kauppatori and Niuskala observation sites.

			Betel & Kurala Average UHI	Betel & Niuskala Average UHI	Kauppatori & Kurala Average UHI	Kauppatori & Niuskala Average UHI
Day	Pearson	Average wind speed	**-0.413***	-0.304	**-0.512****	**-0.407***
		Average cloudiness	**-0.493****	**-0.485****	**-0.466****	**-0.510****
	Spearman	Average wind speed	**-0.426***	-0.294	**-0.563****	**-0.394***
		Average cloudiness	**-0.525****	**-0.500****	**-0.512****	**-0.585****
Night	Pearson	Average wind speed	**-0.560****	**-0.482****	**-0.573****	**-0.499****
		Average cloudiness	**-0.585****	**-0.579****	**-0.566****	**-0.575****
	Spearman	Average wind speed	**-0.545****	**-0.456****	**-0.576****	**-0.463****
		Average cloudiness	**-0.597****	**-0.576****	**-0.573****	**-0.566****

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

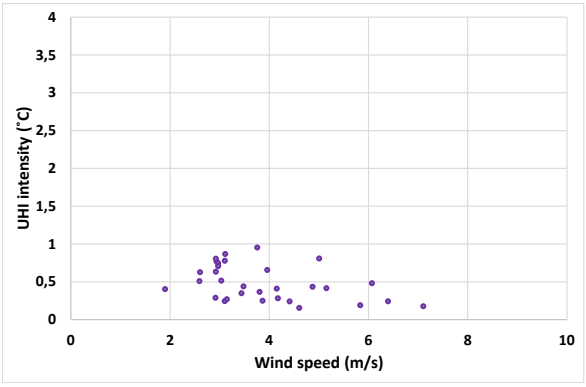

Figure 66. Scatter plot for wind speed and UHI between Betel and Kurala during daytime in March 2021.

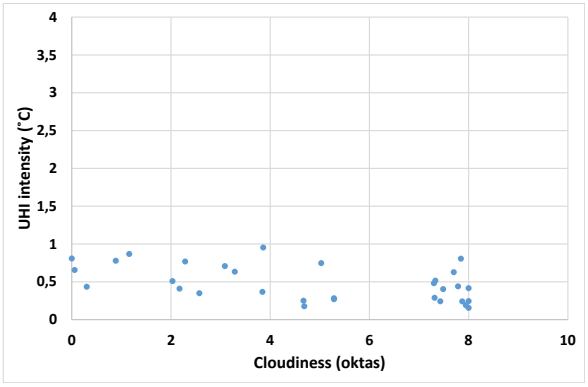

Figure 67. Scatter plot for cloudiness and UHI between Betel and Kurala during daytime in March 2021.

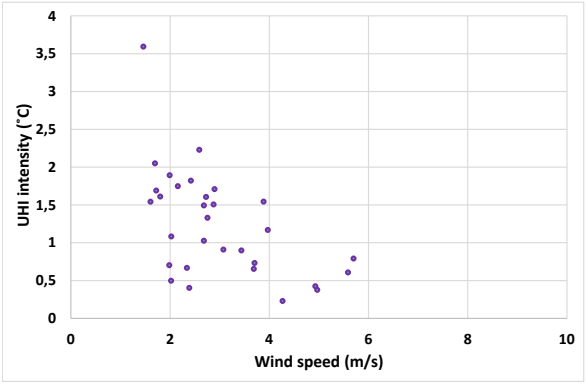

Figure 68. Scatter plot for wind speed and UHI between Betel and Kurala during nighttime in March 2021.

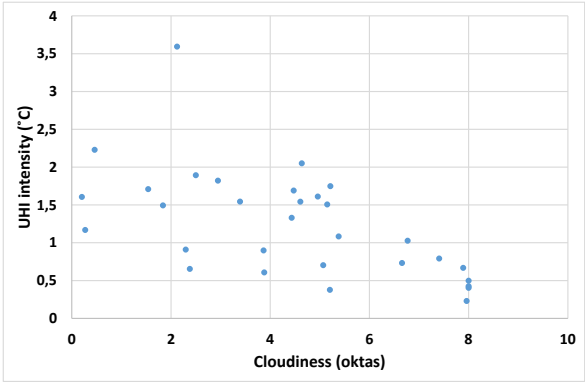

Figure 69. Scatter plot for cloudiness and UHI between Betel and Kurala during nighttime in March 2021.

Table 38. Pearson and Spearman correlations between NAO index and different UHI logger pairs in March 2021.

	UHI	NAO index	Significance level
Pearson	Betel & Kurala	-0.215	0.245
	Betel & Niuskala	-0.163	0.381
	Kauppatori & Kurala	-0.187	0.315
	Kauppatori & Niuskala	-0.140	0.453
	Betel & Ryhmäpuutarha	-0.144	0.439
	Kauppatori & Ryhmäpuutarha	-0.111	0.551
Spearman	Betel & Kurala	-0.100	0.592
	Betel & Niuskala	-0.112	0.547
	Kauppatori & Kurala	-0.036	0.846
	Kauppatori & Niuskala	-0.031	0.870
	Betel & Ryhmäpuutarha	-0.080	0.669
	Kauppatori & Ryhmäpuutarha	-0.037	0.841

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

During the daytime, scatter plots of wind speed and cloudiness in relation to UHI intensity indicate that UHI values remained low, with all measurements below 1 °C (Figures 66–69). Wind speed during this period ranged from 2 to 7 m/s, while cloudiness values varied between 0 and 8. In contrast, during nighttime hours, UHI intensities were generally higher, with most values ranging from 0.5 to 2.0 °C. A few isolated instances showed even higher intensities. Cloudiness values during the night followed a similar range as during the day (0–8), while wind speed values ranged from 1 to 6 m/s, with the majority falling between 2 and 4 m/s.

The correlation between NAO index and UHI

In March the NAO index did not have any statistically significant correlations with any of the UHI logger pairs (Table 38).

5.1.4 April

The UHI intensities

In April 2021, the highest UHI intensity peaks were recorded during the period from the 19th to the 21st (Figures 70–73). During this time, peak values reached approximately 6 °C and occurred during midnight and nighttime across all logger pairs. Toward the end of the month, additional peaks of up to 5 °C were observed, whereas at other times the UHI intensity remained relatively stable, generally staying below 2 °C. Minor negative values, reaching approximately –1 °C, were frequently observed and typically occurred during the daytime, either in the morning or afternoon, indicating the presence of UCIs.

In April 2023, the UHI intensities between the four logger sites ranged on average between 0 °C and 6 °C (Figures 74–77). Overall, UHI values exhibited considerable variability, with the highest intensities occurring during the night and early morning hours. The most stable conditions were observed between the 13th and 16th, as well as toward the end of the month. Minor negative UHI values were observed between Betel and Kurala and between Kauppatori and Kurala, with a distinct minimum of approximately –2 °C recorded on the 26th. Similar minimum values were also seen in the UHI data from Betel and Niuskala and from Kauppatori

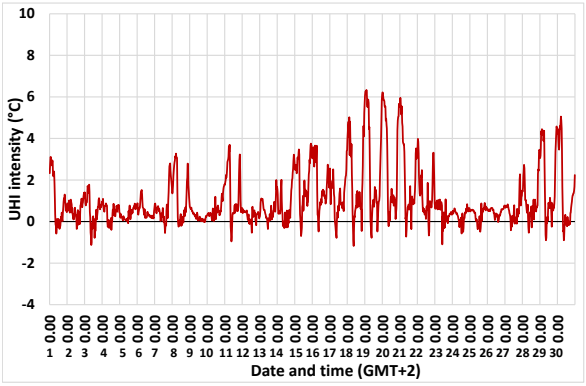

Figure 70. UHI intensity between Betel and Kurala during April 2021.

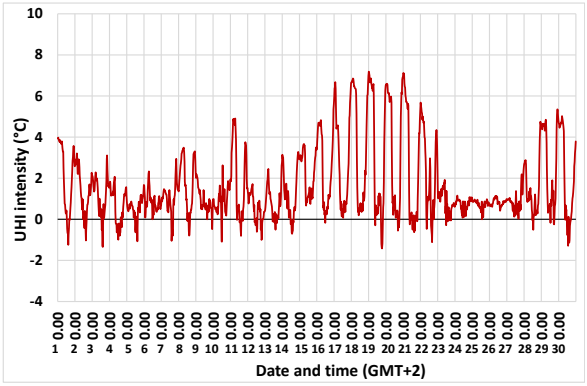

Figure 71. UHI intensity between Betel and Niuskala during April 2021.

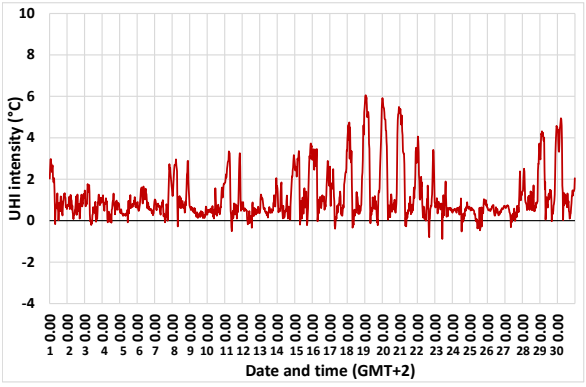

Figure 72. UHI intensity between Kauppatori and Kurala during April 2021.

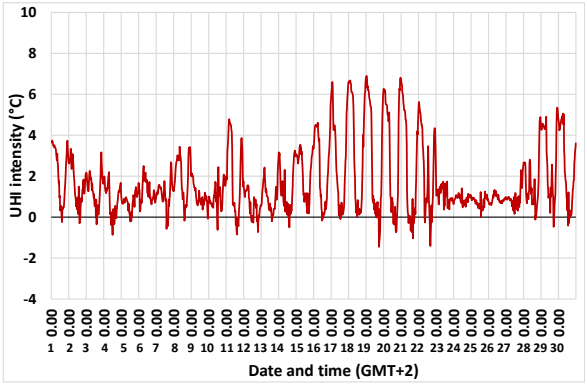

Figure 73. UHI intensity between Kauppatori and Niuskala during April 2021

and Niuskala. These latter pairs showed slightly lower negative values, most of which remained below –2 °C, with a maximum negative peak of approximately –3 °C, also occurring on the 26th.

While April 2021 featured more periods of stable UHI conditions, April 2023 was characterized by frequent high-intensity UHI peaks occurring nearly every day. Although cold island events were more pronounced in 2023, the maximum UHI peaks were of comparable magnitude in both years.

Monthly summaries

In April 2021, air quality exhibited a distinct peak between 07.00 and 08.00 across all measured variables (Figure 78). A secondary, smaller peak was observed in the afternoon between 12.00 and 16.00. During these peak periods, the air quality index reached values of approximately 1.5 in the morning and slightly below 1.4 in the afternoon, while remaining slightly above 1.0 during other parts of the day. Nitrogen dioxide concentrations peaked at 30 µg/m³ and respirable particles at 25 µg/m³ during the 07.00–08.00 interval, with both pollutants remaining around 10 µg/m³ outside of the peak periods. Respirable particles exhibited slightly higher values during the afternoon peak. Nitrogen monoxide concentrations remained close to zero for most of the day, reaching over 10 µg/m³ dur-

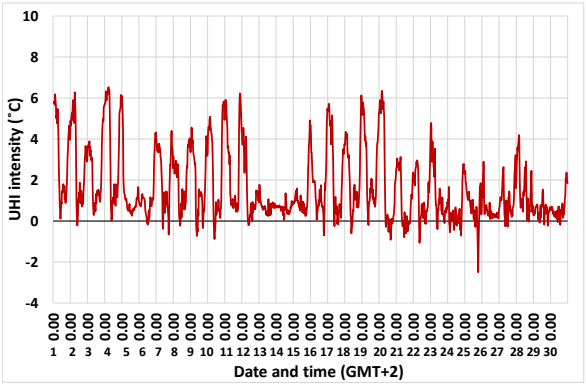

Figure 74. UHI intensity between Betel and Kurala during April 2023.

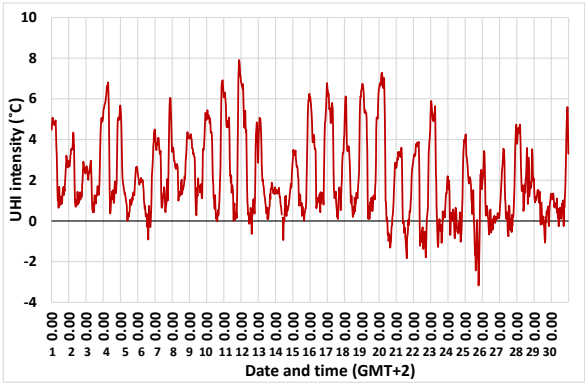

Figure 75. UHI intensity between Betel and Niuskala during April 2023.

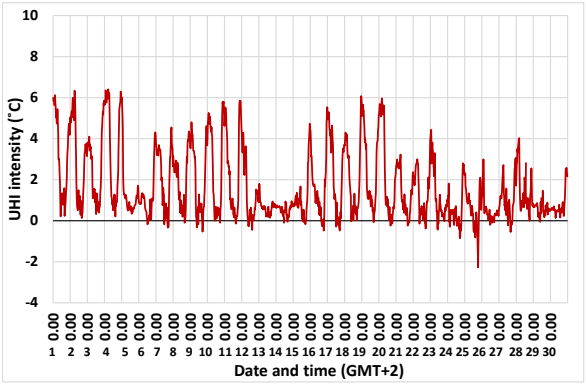

Figure 76. UHI intensity between Kauppatori and Kurala during April 2023.

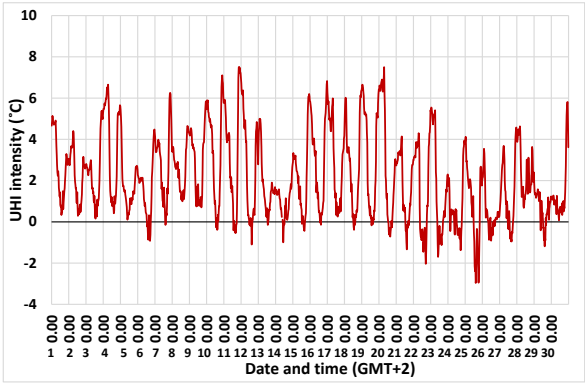

Figure 77. UHI intensity between Kauppatori and Niuskala during April 2023.

ing the morning peak and approximately 5 µg/m³ during the afternoon peak.

In April 2023, air quality peaked during the morning hours, typically between 07.00 and 09.00. During this period, average values were as follows: air quality index ranged from 1.37 to 2.2; nitrogen dioxide from 7.55 to 22.66 µg/m³; nitrogen monoxide from 0.42 to 8.18 µg/m³; respirable particles from 16.04 to 54.32 µg/m³; and fine particles from 6.00 to 10.75 µg/m³.

Regarding the UHI effect, April 2021 showed the strongest intensities during the night, with values ranging from approximately 1.5 °C to 1.9 °C (Figure 79). During the daytime, between 07.00 and 18.00, UHI intensity was significantly weaker, averaging between 0.2 °C and 0.5 °C.

The correlations between the UHI and air quality

For the UHI between Betel and Kurala in 2021, all air quality variables except fine particles exhibited positive and moderately strong Pearson correlations during the 07.00–08.00 time period, with the exception of nitrogen monoxide, which showed a medium-strength correlation (Table 39). In April, the time periods 07.00–08.00 and 15.00–17.00 (local time, GMT+3) were analysed to adapt to the transition to Finnish summertime (GMT+3) at the end of March,

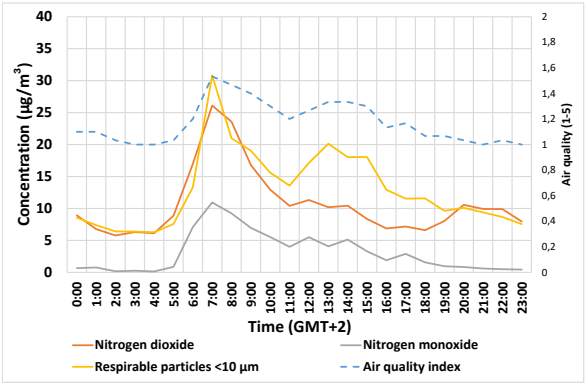

Figure 78. Hourly averages of air quality observations in April 2021.

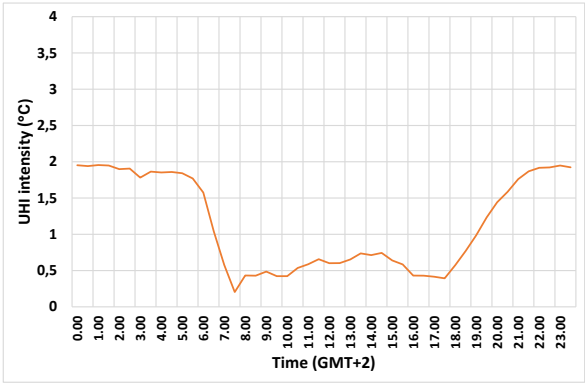

Figure 79. Hourly average UHI intensity between Kauppatori and Kurala in April 2021.

which aligns with local rush hour periods. During the 15.00–16.00 interval, only nitrogen monoxide showed a statistically significant Pearson correlation, which was weak and positive. No other significant correlations were observed during this afternoon period.

In 2023, all air quality variables correlated with UHI during the 07.00–08.00 period, except for fine particles in the Pearson analysis and nitrogen monoxide in the Spearman analysis (Table 40). The strongest correlations were observed with nitrogen dioxide and respirable particles, while the weakest were with nitrogen dioxide in the Pearson correlation and fine particles in the Spearman correlation. During the following hour (08.00–09.00), all variables except nitrogen dioxide in the Spearman analysis showed statistically significant correlations. These were of medium strength or strong overall, with fine particles showing the strongest Pearson correlation and nitrogen dioxide the weakest. In the Spearman analysis, the weakest correlation was with nitrogen monoxide. No

Table 39. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in April 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.665****	<0.001	0.164	0.385	0.228	0.226	0.100	0.600
	Nitrogen dioxide	**0.678****	<0.001	0.287	0.124	0.232	0.217	0.045	0.812
	Nitrogen monoxide	**0.475****	0.008	0.222	0.238	**0.362***	0.049	0.163	0.390
	Respirable particles	**0.631****	<0.001	0.180	0.340	0.155	0.413	0.242	0.198
	Fine particles								
Spearman	Air quality index	**0.609****	<0.001	0.060	0.753	0.236	0.210	0.113	0.551
	Nitrogen dioxide	**0.649****	<0.001	0.261	0.164	0.203	0.281	-0.010	0.960
	Nitrogen monoxide	**0.558****	0.001	0.256	0.172	0.235	0.211	0.065	0.731
	Respirable particles	**0.553****	0.002	-0.016	0.931	0.237	0.207	0.239	0.204
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 40. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in April 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.530****	0.003	**0.547****	0.002	0.182	0.336	0.183	0.332
	Nitrogen dioxide	**0.700****	<0.001	**0.497****	0.005	-0.127	0.502	-0.028	0.884
	Nitrogen monoxide	**0.361***	0.050	**0.579****	<0.001	0.051	0.790	0.217	0.250
	Respirable particles	**0.604****	<0.001	**0.574****	<0.001	0.233	0.215	0.262	0.161
	Fine particles	0.304	0.103	**0.609****	<0.001	0.014	0.941	0.127	0.503
Spearman	Air quality index	**0.543****	0.002	**0.476****	0.008	0.181	0.339	0.233	0.215
	Nitrogen dioxide	**0.763****	<0.001	0.339	0.067	-0.139	0.464	-0.115	0.545
	Nitrogen monoxide	0.295	0.113	**0.372***	0.043	-0.041	0.829	0.040	0.832
	Respirable particles	**0.673****	<0.001	**0.505****	0.004	0.255	0.174	0.314	0.091
	Fine particles	**0.414***	0.023	**0.525****	0.003	0.021	0.911	0.164	0.386

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

statistically significant correlations were found during the afternoon hours.

For the Betel–Niuskala pair in 2021, all air quality variables except fine particles showed statistically significant correlations with UHI during both morning hours (Table 41). At 07.00–08.00, the strongest correlation was observed with the air quality index, while the weakest was with nitrogen monoxide in both Pearson and Spearman analyses. During the 08.00–09.00 period, the strongest Pearson correlation was with respirable particles, while the strongest Spearman correlation was with nitrogen dioxide. In both cases, nitrogen monoxide exhibited the weakest correlation. No statistically significant correlations were observed during the afternoon hours.

In 2023, the air quality index, nitrogen dioxide, and respirable particles all showed statistically significant correlations with the Betel–Niuskala UHI during the 07.00–08.00 time period, in both Pearson and Spearman analyses (Table 42). Additionally, fine particles correlated significantly in the Spearman analysis. During the 08.00–09.00 interval, all variables exhibited medium to strong positive correlations. Fine particles had the strongest Pearson correlation, while the air quality index had the weakest. In the Spearman analysis, the weakest correlation was with nitrogen dioxide. In the afternoon, a single weak positive Spearman correlation was observed with respirable particles during the 15.00–16.00 period.

The UHI between Kauppatori and Kurala in 2021 correlated with all air quality variables except fine particles during the 07.00–08.00 time period (Table 43). The strongest correlation was observed with nitrogen dioxide, while the weakest was with nitrogen monoxide in the Pearson analysis and with respirable particles in the Spearman analysis. In general, the Spearman correlations were stronger than the Pearson correlations. In the afternoon, between 15.00 and 16.00, respirable particles exhibited a moderate Pearson correlation with UHI. No other statistically significant correlations were identified during other time periods.

Table 41. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in April 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.656****	<0.001	**0.670****	<0.001	0.058	0.760	-0.070	0.714
	Nitrogen dioxide	**0.617****	<0.001	**0.670****	<0.001	0.300	0.107	0.127	0.505
	Nitrogen monoxide	**0.419***	0.021	**0.433***	0.017	0.317	0.088	0.092	0.628
	Respirable particles	**0.590****	<0.001	**0.726****	<0.001	-0.033	0.864	-0.073	0.700
	Fine particles								
Spearman	Air quality index	**0.611****	<0.001	**0.533****	0.002	0.054	0.778	-0.011	0.953
	Nitrogen dioxide	**0.585****	<0.001	**0.641****	<0.001	0.238	0.205	0.127	0.502
	Nitrogen monoxide	**0.476****	0.008	**0.417***	0.022	0.229	0.224	0.082	0.665
	Respirable particles	**0.598****	<0.001	**0.623****	<0.001	-0.087	0.646	-0.050	0.793
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 42. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in April 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.519****	0.003	**0.690****	<0.001	0.300	0.108	0.253	0.177
	Nitrogen dioxide	**0.687****	<0.001	**0.714****	<0.001	0.001	0.996	-0.115	0.546
	Nitrogen monoxide	0.260	0.166	**0.740****	<0.001	0.136	0.475	0.126	0.509
	Respirable particles	**0.620****	<0.001	**0.733****	<0.001	0.302	0.105	0.281	0.132
	Fine particles	0.317	0.088	**0.796****	<0.001	0.059	0.756	0.048	0.802
Spearman	Air quality index	**0.556****	0.001	**0.577****	<0.001	0.359	0.052	0.268	0.152
	Nitrogen dioxide	**0.690****	<0.001	**0.461***	0.010	0.010	0.959	-0.105	0.581
	Nitrogen monoxide	0.207	0.272	**0.476****	0.008	0.124	0.513	0.062	0.743
	Respirable particles	**0.645****	<0.001	**0.597****	<0.001	**0.389***	0.034	0.291	0.119
	Fine particles	**0.397***	0.030	**0.656****	<0.001	0.088	0.654	0.140	0.461

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

In 2023, during the 07.00–08.00 period, the air quality index, nitrogen dioxide, and respirable particles showed moderate or strong positive Pearson correlations with the UHI (Table 44). In the Spearman analysis, fine particles also showed a statistically significant, though weak, correlation. During the following hour (08.00–09.00), UHI correlated with all air quality variables, except nitrogen dioxide and nitrogen monoxide, which showed statistically significant correlations only in the Pearson analysis. These correlations were of medium strength, with the strongest observed for fine particles in Pearson and respirable particles in Spearman.

Table 43. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in April 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.550****	0.002	-0.079	0.677	0.352	0.056	0.153	0.420
	Nitrogen dioxide	**0.700****	<0.001	0.309	0.097	0.006	0.975	-0.151	0.427
	Nitrogen monoxide	**0.453***	0.012	0.246	0.189	0.236	0.210	0.003	0.987
	Respirable particles	**0.472****	0.008	-0.093	0.625	**0.476****	0.008	0.333	0.072
	Fine particles								
Spearman	Air quality index	**0.615****	<0.001	-0.062	0.746	0.218	0.248	0.113	0.551
	Nitrogen dioxide	**0.686****	<0.001	0.238	0.205	-0.028	0.882	-0.059	0.757
	Nitrogen monoxide	**0.552****	0.002	0.273	0.145	0.064	0.737	0.073	0.703
	Respirable particles	**0.479****	0.007	-0.133	0.482	0.316	0.089	0.268	0.152
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 44. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in April 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.509****	0.004	**0.522****	0.003	0.112	0.556	-0.012	0.949
	Nitrogen dioxide	**0.693****	<0.001	**0.466****	0.009	-0.083	0.662	0.053	0.780
	Nitrogen monoxide	0.354	0.055	**0.567****	0.001	0.009	0.963	0.358	0.052
	Respirable particles	**0.588****	<0.001	**0.535****	0.002	0.141	0.458	0.008	0.969
	Fine particles	0.296	0.112	**0.570****	0.001	-0.025	0.896	-0.225	0.232
Spearman	Air quality index	**0.465****	0.010	**0.452***	0.012	0.006	0.973	0.069	0.716
	Nitrogen dioxide	**0.696****	<0.001	0.324	0.081	-0.272	0.146	0.051	0.790
	Nitrogen monoxide	0.237	0.208	0.341	0.065	-0.134	0.480	0.307	0.099
	Respirable particles	**0.608****	<0.001	**0.484****	0.007	0.089	0.639	0.087	0.648
	Fine particles	**0.368***	0.045	**0.476****	0.008	-0.211	0.264	-0.106	0.579

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Overall, the Spearman correlation coefficients were weaker than those from Pearson. No statistically significant correlations were found during the afternoon hours.

During the 07.00–08.00 time period, the UHI between Kauppatori and Niuskala correlated with all measured air quality variables (Table 45). Most of these correlations were moderately to strongly positive, with nitrogen monoxide showing a weaker association. In the following hour (08.00–09.00), the same variables continued to correlate with UHI, with generally stronger Pearson coefficients. However, Spearman coefficients mostly weakened dur-

Table 45. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in April 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.614****	<0.001	**0.620****	<0.001	0.086	0.650	-0.078	0.684
	Nitrogen dioxide	**0.633****	<0.001	**0.703****	<0.001	0.145	0.445	0.012	0.951
	Nitrogen monoxide	**0.410***	0.025	**0.458***	0.011	0.194	0.305	-0.041	0.829
	Respirable particles	**0.521****	0.003	**0.669****	<0.001	0.123	0.517	-0.101	0.594
	Fine particles								
Spearman	Air quality index	**0.630****	<0.001	**0.518****	0.003	0.048	0.801	-0.034	0.858
	Nitrogen dioxide	**0.596****	<0.001	**0.654****	<0.001	0.117	0.539	0.044	0.818
	Nitrogen monoxide	**0.490****	0.006	**0.451***	0.012	0.110	0.563	-0.068	0.723
	Respirable particles	**0.629****	<0.001	**0.623****	<0.001	-0.102	0.592	-0.115	0.546
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 46. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in April 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.510****	0.004	**0.651****	<0.001	0.331	0.074	0.173	0.361
	Nitrogen dioxide	**0.696****	<0.001	**0.666****	<0.001	0.027	0.886	-0.095	0.619
	Nitrogen monoxide	0.259	0.167	**0.710****	<0.001	0.142	0.454	0.149	0.432
	Respirable particles	**0.618****	<0.001	**0.681****	<0.001	0.320	0.085	0.164	0.388
	Fine particles	0.317	0.088	**0.742****	<0.001	0.047	0.804	-0.113	0.553
Spearman	Air quality index	**0.546****	0.002	**0.562****	0.001	**0.436***	0.016	0.277	0.138
	Nitrogen dioxide	**0.679****	<0.001	**0.429***	0.018	0.078	0.682	-0.074	0.698
	Nitrogen monoxide	0.189	0.318	**0.443***	0.014	0.150	0.430	0.082	0.668
	Respirable particles	**0.627****	<0.001	**0.578****	<0.001	**0.439***	0.015	0.253	0.177
	Fine particles	**0.382***	0.037	**0.617****	<0.001	0.157	0.406	0.114	0.549

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

ing this period. No statistically significant correlations were observed during the afternoon hours.

In 2023, the 07.00–08.00 correlation pattern for the Kauppatori–Niuskala UHI closely resembled that of the Kauppatori–Kurala and Betel–Niuskala pairs (Table 46). During this period, nitrogen monoxide and fine particles did not show statistically significant Pearson correlations, although fine particles exhibited a weak correlation in the Spearman analysis. The strongest correlation was observed with nitrogen dioxide. In the 08.00–09.00 time period, all variables showed statistically significant correlations, with generally strong coefficients; fine particles exhibited the strongest correlation.

Table 47. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in April 2021. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index	**0.716****	<0.001
	Nitrogen dioxide	**0.683****	<0.001
	Nitrogen monoxide	**0.548****	0.002
	Respirable particles	**0.668****	<0.001
	Fine particles		
Spearman	Air quality index	**0.643****	<0.001
	Nitrogen dioxide	**0.731****	<0.001
	Nitrogen monoxide	**0.586****	<0.001
	Respirable particles	**0.643****	<0.001
	Fine particles		

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 48. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in April 2023. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index	**0.525****	0.003
	Nitrogen dioxide	**0.427***	0.019
	Nitrogen monoxide	**0.481****	0.007
	Respirable particles	**0.553****	0.002
	Fine particles	**0.613****	<0.001
Spearman	Air quality index	**0.424***	0.020
	Nitrogen dioxide	0.252	0.179
	Nitrogen monoxide	0.244	0.194
	Respirable particles	**0.461***	0.010
	Fine particles	**0.504****	0.005

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

During the afternoon (15.00–16.00), only the air quality index and respirable particles demonstrated medium-strength Spearman correlations. No other statistically significant correlations were detected during this time.

The correlation between the 05.00 UHI and the 08.00 air quality

In 2021, all air quality variables exhibited moderately strong positive correlations with UHI in both the Pearson and Spearman analyses (Table 47). The air quality index showed the strongest correlation in the Pearson analysis, while nitrogen monoxide had the weakest. In the Spearman analysis, the strongest correlation was observed with nitrogen dioxide, and the weakest again with nitrogen monoxide.

In 2023, all air quality variables demonstrated statistically significant positive correlations with UHI in the Pearson analysis, with correlations generally of medium strength (Table 48). The strongest correlations were observed with fine particles and respirable particles. In the Spearman analysis, statistically significant correlations were found with the air quality index, respirable particles, and fine particles, with fine particles showing the strongest association. These correlations were all of medium strength and positive.

Overall, all air quality variables correlated with UHI in 2021, and the correlation coefficients were stronger than those observed in 2023.

The correlation between the UHI, average wind speed and cloudiness

In April, daytime extended from 05.00 to 20.00. During this period, the UHI showed a moderately strong negative correlation with cloudiness and a weak negative correlation with average wind speed (Table 49). At nighttime, the UHI exhibited strong negative correlations with both variables, with the correlation with cloudiness being stronger than that with wind speed.

The scatter plots of wind speed and cloudiness against UHI intensity reveal distinct patterns between day and night (Figures 80–83).

Table 49. Pearson and Spearman correlation coefficients between the wind speed and UHI and between the cloudiness and UHI during daytime and nighttime in April 2021. Four different UHI intensities are calculated based on the Betel, Kurala, Kauppatori and Niuskala observation sites.

			Betel & Kurala Average UHI	Betel & Niuskala Average UHI	Kauppatori & Kurala Average UHI	Kauppatori & Niuskala Average UHI
Day	Pearson	Average wind speed	-0.530**	-0.378*	-0.563**	-0.364*
		Average cloudiness	-0.733**	-0.691**	-0.747**	-0.668**
	Spearman	Average wind speed	-0.659**	-0.417*	-0.592**	-0.374*
		Average cloudiness	-0.771**	-0.729**	-0.742**	-0.659**
Night	Pearson	Average wind speed	-0.824**	-0.749**	-0.822**	-0.738**
		Average cloudiness	-0.884**	-0.899**	-0.889**	-0.897**
	Spearman	Average wind speed	-0.872**	-0.791**	-0.867**	-0.774**
		Average cloudiness	-0.899**	-0.889**	-0.907**	-0.896**

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

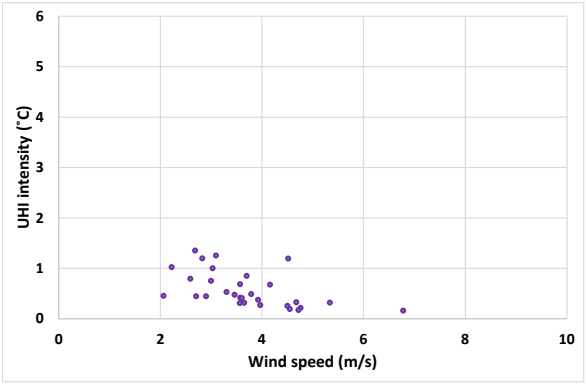

Figure 80. Scatter plot for wind speed and UHI between Betel and Kurala during daytime in April 2021.

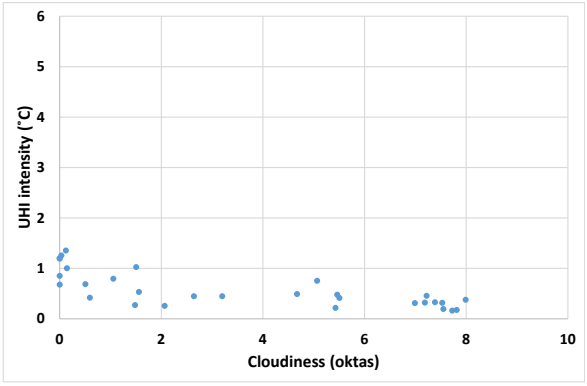

Figure 81. Scatter plot for cloudiness and UHI between Betel and Kurala during daytime in April 2021.

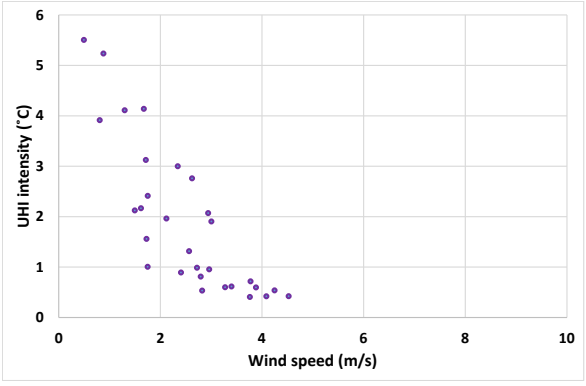

Figure 82. Scatter plot for wind speed and UHI between Betel and Kurala during nighttime in April 2021.

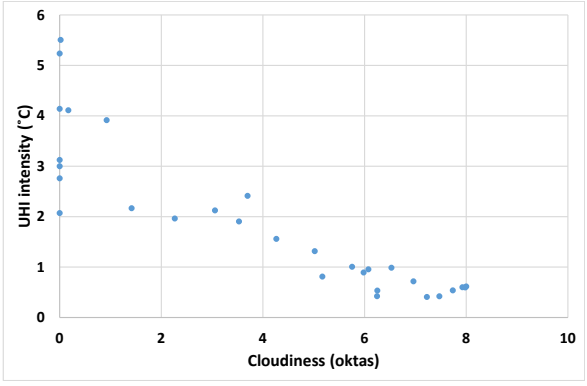

Figure 83. Scatter plot for cloudiness and UHI between Betel and Kurala during nighttime in April 2021.

Table 50. Pearson and Spearman correlations between NAO index and different UHI logger pairs in April 2021.

	UHI	NAO index	Significance level
Pearson	Betel & Kurala	0.346	0.061
	Betel & Niuskala	**0.467****	0.009
	Kauppatori & Kurala	0.341	0.065
	Kauppatori & Niuskala	**0.467****	0.009
	Betel & Ryhmäpuutarha	**0.436***	0.016
	Kauppatori & Ryhmäpuutarha	**0.436***	0.016
Spearman	Betel & Kurala	**0.433***	0.017
	Betel & Niuskala	**0.502****	0.005
	Kauppatori & Kurala	**0.430***	0.018
	Kauppatori & Niuskala	**0.521****	0.003
	Betel & Ryhmäpuutarha	**0.455***	0.011
	Kauppatori & Ryhmäpuutarha	**0.474****	0.008

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

During daytime hours, wind speed values were mostly clustered between 2 and 5 m/s, while UHI intensities remained low, typically between 0 and 1.5 °C. Isolated outliers included one wind speed measurement near 7 m/s, which corresponded with a UHI intensity close to 0 °C. Cloudiness values during the day ranged from 0 to 8, with UHI intensities remaining low across this range. The highest UHI values, around 1.5 °C, occurred under low cloud cover, although the majority of UHI values stayed below 1.0 °C. At night, wind speeds did not exceed 4.5 m/s. A clear inverse relationship between wind speed and UHI intensity was observed, as lower wind speeds were associated with higher UHI values. A similar pattern was evident with cloudiness: higher cloud cover corresponded with lower UHI intensities. Cloudiness values at night also ranged from 0 to 8, and the maximum UHI intensity reached approximately 5.5 °C. This peak UHI value coincided with both the lowest wind speeds and lowest cloudiness levels.

The correlation between NAO index and UHI

In April, all UHI logger pairs demonstrated statistically significant Spearman correlations with the North Atlantic Oscillation (NAO) index (Table 50). All correlation coefficients were of medium strength, with the strongest observed between Kauppatori and Niuskala, and the weakest between Kauppatori and Kurala. In the Pearson analysis, the Betel–Kurala and Kauppatori–Kurala pairs did not show statistically significant correlations with the NAO index. The remaining logger pairs did correlate, though with weaker coefficients compared to the Spearman results. The strongest Pearson correlations were observed for the Betel–Niuskala and Kauppatori–Niuskala pairs, while the weakest were found between Betel–Ryhmäpuutarha and Kauppatori–Ryhmäpuutarha.

5.1.5 May

The UHI intensities

In May 2021, the UHI between Betel–Kurala and Kauppatori–Kurala reached maximum values of approximately 6 °C (Figures 84 & 86). These peaks occurred on the 13th and 30th, while other high values during the month reached around 4 °C. Minor negative values were observed, with minimums around –1 °C. For the Betel–Niuskala and Kauppatori–Niuskala pairs, maximum UHI values approached 8 °C on the 12th and 13th (Figures 85 & 87), with a few negative values exceeding –2 °C on certain days. The most stable period across all logger pairs was recorded between the 18th and 24th. Negative UHI values typically occurred around midday, whereas the highest UHI intensities were generally observed during the early morning hours.

In May 2023, UHI intensity values ranged from approximately –1 °C to nearly 8 °C (Figures 88–91). A distinct period of stability was observed in all logger pairs from the 17th to the 19th. The Betel–Kurala and Kauppatori–Kurala pairs showed lower UHI values than the Betel–Niuskala and Kauppatori–Niuskala pairs, with the former reaching peak values around 6 °C and the latter approaching 8 °C. Minor negative values were observed in the Kauppatori–Niuskala pair, while the other logger pairs showed varying negative values around –1 °C

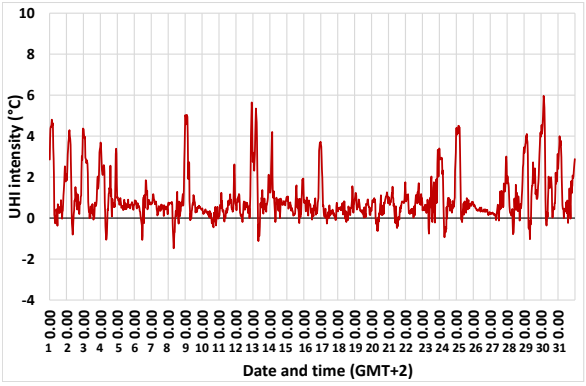

Figure 84. UHI intensity between Betel and Kurala during May 2021.

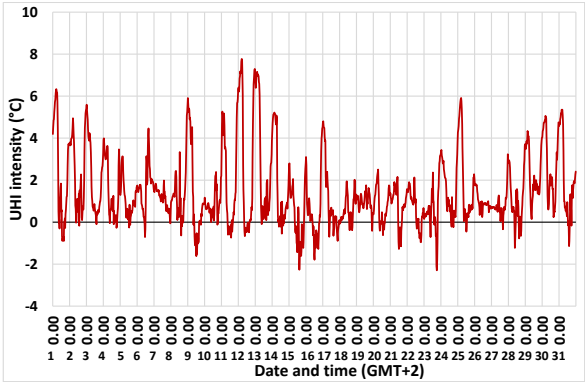

Figure 85. UHI intensity between Betel and Niuskala during May 2021.

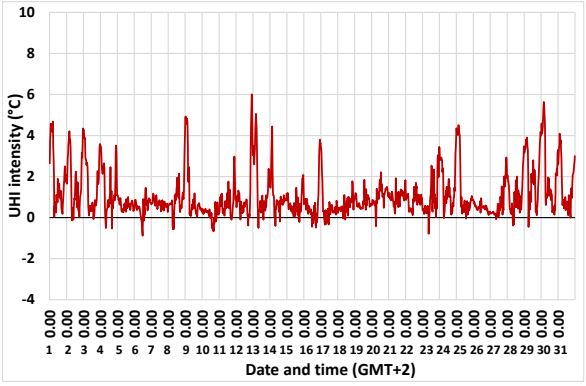

Figure 86. UHI intensity between Kauppatori and Kurala during May 2021.

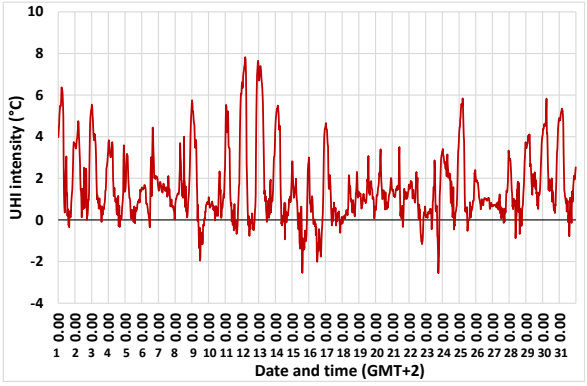

Figure 87. UHI intensity between Kauppatori and Niuskala during May 2021.

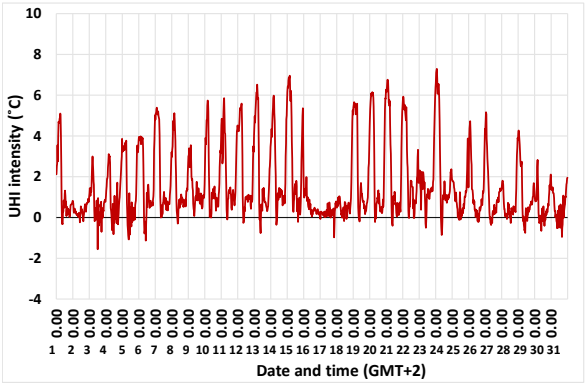

Figure 88. UHI intensity between Betel and Kurala during May 2023.

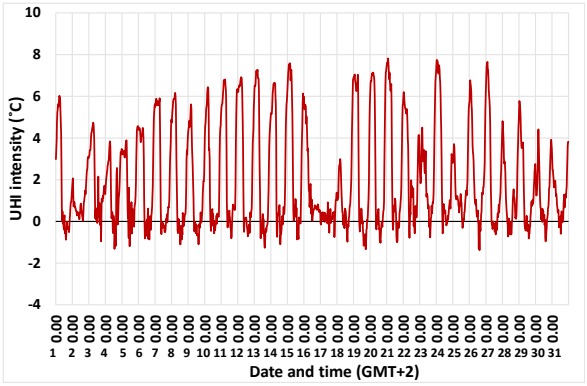

Figure 89. UHI intensity between Betel and Niuskala during May 2023.

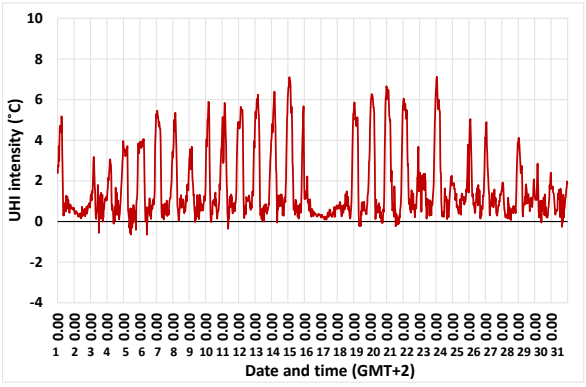

Figure 90. UHI intensity between Kauppatori and Kurala during May 2023.

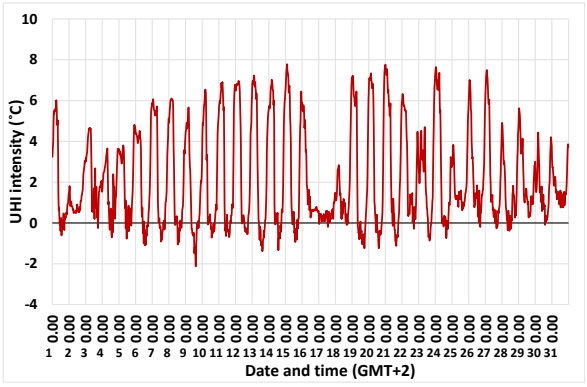

Figure 91. UHI intensity between Kauppatori and Niuskala during May 2023.

on different days. The most pronounced negative value was recorded with Kauppatori–Niuskala, exceeding –2 °C on the 9th. As in 2021, maximum UHI values generally occurred during nighttime and early morning hours, while negative values were concentrated around midday.

Compared to 2021, UHI intensity values in May 2023 exhibited more consistent and pronounced diurnal variability throughout the month. In contrast, 2021 showed smaller UHI values on certain days, without a continuous or patterned trend. Despite these differences, the maximum UHI intensities were similar across both years. Negative values occurred more frequently in both years between the Betel–Niuskala and Kauppatori–Niuskala pairs than between Betel–Kurala and Kauppatori–Kurala.

Monthly summaries

In May 2021, nitrogen monoxide concentrations remained low, close to zero, with higher values occurring during the day. The highest concentrations, reaching 5 µg/m^3, were observed between 06.00–07.00 and 18.00–19.00 (Figure 92). Nitrogen dioxide exhibited a clear concentration peak in the morning between 06.00–08.00, reaching approximately 17 µg/m^3, after which levels declined to around 10 µg/m^3 for the remainder of the day. Respirable particle concentrations were slightly above 5 µg/m^3 overall, increasing to approximately 12 µg/

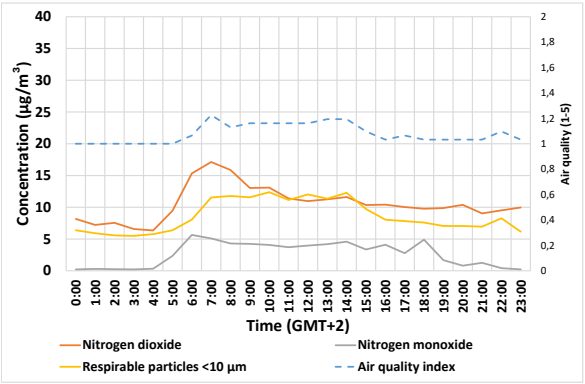

Figure 92. Hourly averages of air quality observations in May 2021.

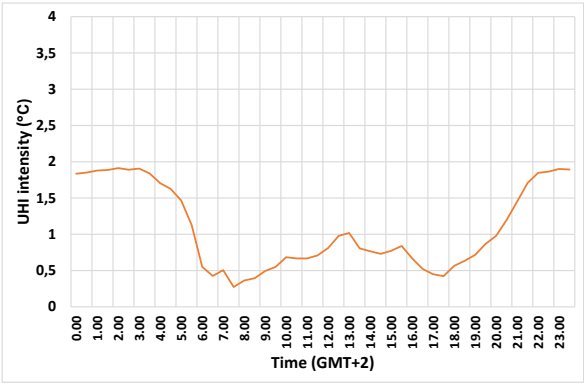

Figure 93. Hourly average UHI intensity between Kauppatori and Kurala in May 2021.

m^3 between 07.00–15.00. The air quality index peaked in the morning at 1.2, remained around 1.1 during the day, and decreased to 1.0 at night.

In 2023, peak air quality values were observed in the morning between 06.00–09.00. During this period, the air quality index ranged from 1.10 to 1.35; nitrogen dioxide concentrations ranged from 6.00 to 16.63 µg/m^3; nitrogen monoxide from 0.44 to 3.24 µg/m^3; respirable particles from 11.11 to 18.27 µg/m^3; and fine particles from 4.56 to 6.72 µg/m^3.

For the UHI in 2021, maximum values occurred during the nighttime, remaining around 1.8 °C (Figure 93). During other hours, UHI values ranged from approximately 0.3 to 0.8 °C. Daytime peak values of around 1.0 °C were recorded between 12.00–14.00.

The correlations between the UHI and air quality

In May 2021, the UHI effect in Betel and Kurala did not exhibit any statistically significant correlations with the air quality variables examined (Table 51).

In 2023, however, a relatively strong positive correlation was observed between UHI and nitrogen dioxide during the 07.00–08.00 time interval (Table 52). Additionally, moderate positive correlations were found with nitrogen monoxide, fine particles and respirable particles. According to Spearman's correlation, all air quality variables except the air quality index showed statistically significant correlations. Nitrogen dioxide displayed a strong correlation, whereas nitrogen monoxide showed a weak one. In the following hour, weak positive correlations were observed with fine particles, and moderate correlations were found with the air quality index, nitrogen dioxide, and respirable particles. However, based on Spearman's method, the correlation with fine particles was not statistically significant. Among these, respirable particles showed the strongest correlation using Pearson's method, while the air quality index had the strongest correlation using Spearman's method. During the afternoon period from 15.00–16.00, a weak positive Spearman correlation was identified with fine particles. In the subsequent hour, moderate positive correlations were observed with nitrogen dioxide, respirable particles, and fine particles.

In the case of Betel and Niuskala, no statistically significant correlations were observed in 2021 (Table 53).

In 2023, however, nitrogen dioxide exhibited a relatively strong positive correlation with the UHI during the 07.00–08.00 period (Table 54). Nitrogen monoxide and respirable particles also showed moderate positive correla-

Table 51. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in May 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	-0.073	0.695	-0.027	0.884	-0.139	0.457	0.072	0.699
	Nitrogen dioxide	0.248	0.178	0.280	0.128	-0.148	0.426	-0.019	0.921
	Nitrogen monoxide	0.115	0.540	0.144	0.439	0.135	0.468	-0.034	0.857
	Respirable particles	-0.005	0.980	-0.045	0.810	-0.033	0.861	0.102	0.586
	Fine particles								
Spearman	Air quality index	-0.155	0.404	-0.022	0.909	-0.110	0.557	0.163	0.380
	Nitrogen dioxide	0.227	0.219	0.241	0.192	-0.034	0.856	-0.084	0.651
	Nitrogen monoxide	0.075	0.687	0.070	0.708	0.110	0.555	-0.036	0.847
	Respirable particles	-0.044	0.816	-0.004	0.983	0.003	0.989	0.289	0.115
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 52. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in May 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.218	0.239	**0.432***	0.015	0.071	0.705	0.253	0.170
	Nitrogen dioxide	**0.698****	<0.001	**0.499****	0.004	-0.102	0.584	**0.422***	0.018
	Nitrogen monoxide	**0.457****	0.010	0.323	0.077	-0.108	0.565	-0.176	0.345
	Respirable particles	**0.562****	0.001	**0.534****	0.002	0.082	0.661	**0.497****	0.004
	Fine particles	**0.420***	0.019	**0.356***	0.049	0.084	0.655	**0.480****	0.006
Spearman	Air quality index	0.206	0.266	**0.401***	0.025	0.043	0.818	0.224	0.225
	Nitrogen dioxide	**0.738****	<0.001	**0.392***	0.029	0.159	0.394	**0.413***	0.021
	Nitrogen monoxide	**0.376***	0.037	0.248	0.179	-0.219	0.235	-0.103	0.581
	Respirable particles	**0.573****	<0.001	**0.362***	0.045	0.303	0.097	**0.405***	0.024
	Fine particles	**0.442***	0.013	0.308	0.092	**0.362***	0.046	**0.520****	0.003

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

tions during this time. No statistically significant correlations were found during the other observation periods.

For the UHI between Kauppatori and Kurala, only nitrogen monoxide exhibited a statistically significant correlation which was a relatively weak negative Pearson correlation during the 15.00–16.00 period (Table 55). No other statistically significant correlations were detected.

In 2023, nitrogen monoxide again showed a relatively strong correlation with UHI during the 07.00–08.00 interval (Table 56), while respirable particles had a moderate correla-

Table 53. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in May 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.232	0.209	-0.016	0.932	-0.009	0.963	0.107	0.567
	Nitrogen dioxide	0.035	0.852	-0.116	0.536	0.137	0.462	-0.017	0.929
	Nitrogen monoxide	-0.010	0.957	-0.153	0.411	0.095	0.609	-0.143	0.442
	Respirable particles	0.320	0.079	-0.116	0.533	-0.105	0.574	0.047	0.801
	Fine particles								
Spearman	Air quality index	0.293	0.109	-0.043	0.818	0.000	1.000	0.204	0.271
	Nitrogen dioxide	0.078	0.676	-0.058	0.757	0.122	0.512	0.036	0.846
	Nitrogen monoxide	0.047	0.800	-0.116	0.535	0.071	0.705	0.024	0.900
	Respirable particles	0.309	0.091	-0.110	0.556	-0.106	0.570	0.019	0.920
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 54. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in May 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.235	0.202	0.253	0.170	0.030	0.873	-0.194	0.297
	Nitrogen dioxide	**0.694****	<0.001	0.300	0.101	-0.077	0.682	-0.122	0.513
	Nitrogen monoxide	**0.512****	0.003	0.332	0.068	-0.084	0.654	-0.192	0.300
	Respirable particles	**0.505****	0.004	0.335	0.065	0.005	0.980	-0.226	0.222
	Fine particles	0.351	0.053	0.111	0.552	0.092	0.623	-0.059	0.752
Spearman	Air quality index	0.256	0.165	0.239	0.195	-0.075	0.687	-0.138	0.459
	Nitrogen dioxide	**0.695****	<0.001	0.236	0.202	-0.152	0.413	-0.031	0.869
	Nitrogen monoxide	**0.514****	0.003	0.255	0.166	0.117	0.530	0.014	0.940
	Respirable particles	**0.467****	0.008	0.242	0.190	0.135	0.471	-0.066	0.724
	Fine particles	0.331	0.069	0.105	0.575	0.172	0.355	-0.142	0.447

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

tion. Additionally, fine particles demonstrated a weak Pearson correlation, and nitrogen monoxide showed a moderate Pearson correlation. At 08.00–09.00, only a weak Pearson correlation was observed with respirable particles. During the afternoon hours, no statistically significant correlations were found.

Regarding the UHI between Kauppatori and Niuskala, no statistically significant correlations with air quality variables were observed in 2021 (Table 57).

In 2023, no statistically significant correlations were found during the 08.00–09.00 and 15.00–16.00 observation periods (Table 58).

Table 55. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in May 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	-0.060	0.749	-0.126	0.501	-0.233	0.208	-0.043	0.818
	Nitrogen dioxide	0.122	0.513	-0.095	0.611	**-0.371***	0.040	-0.205	0.269
	Nitrogen monoxide	0.197	0.288	-0.052	0.779	-0.073	0.696	0.058	0.757
	Respirable particles	-0.098	0.600	-0.257	0.163	-0.143	0.443	-0.215	0.246
	Fine particles								
Spearman	Air quality index	-0.060	0.747	-0.118	0.526	-0.293	0.110	-0.061	0.743
	Nitrogen dioxide	0.142	0.446	-0.097	0.602	-0.338	0.063	-0.221	0.232
	Nitrogen monoxide	0.189	0.309	-0.037	0.845	-0.130	0.485	0.098	0.600
	Respirable particles	-0.127	0.495	-0.234	0.205	-0.115	0.539	-0.273	0.138
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 56. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in May 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.186	0.317	0.298	0.103	-0.238	0.198	-0.137	0.461
	Nitrogen dioxide	**0.670****	<0.001	0.242	0.189	-0.253	0.170	-0.084	0.654
	Nitrogen monoxide	**0.461****	0.009	0.133	0.475	-0.069	0.713	0.064	0.732
	Respirable particles	**0.534****	0.002	**0.368***	0.042	0.075	0.687	0.089	0.636
	Fine particles	**0.366***	0.043	0.109	0.559	-0.156	0.402	-0.116	0.533
Spearman	Air quality index	0.157	0.400	0.208	0.261	-0.247	0.180	-0.173	0.353
	Nitrogen dioxide	**0.643****	<0.001	0.108	0.561	-0.196	0.290	-0.144	0.440
	Nitrogen monoxide	0.352	0.052	0.071	0.703	0.031	0.867	0.078	0.678
	Respirable particles	**0.501****	0.004	0.174	0.349	0.076	0.683	0.085	0.648
	Fine particles	0.342	0.059	-0.025	0.894	-0.192	0.300	-0.206	0.267

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

However, during the 07.00–08.00 period, a relatively strong positive correlation was observed with nitrogen dioxide, while moderate correlations were identified with nitrogen monoxide and respirable particles using both Pearson and Spearman methods. In the afternoon, at 16.00–17.00, nitrogen dioxide, respirable particles, and fine particles showed weak to moderate negative correlations with UHI. According to Spearman's method, respirable particles did not show a statistically significant correlation. All correlations during the 16.00–17.00 period were negative.

Table 57. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in May 2021.

		07.00-08.00		08.00-09.00		15.00-16.00		16.00-17.00	
	Kauppatori & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.230	0.213	-0.041	0.829	-0.054	0.772	0.065	0.728
	Nitrogen dioxide	-0.019	0.918	-0.250	0.174	0.034	0.855	-0.089	0.636
	Nitrogen monoxide	0.001	0.994	-0.185	0.318	-0.016	0.932	-0.111	0.550
	Respirable particles	0.281	0.125	-0.138	0.458	-0.172	0.354	-0.073	0.696
	Fine particles								
Spearman	Air quality index	0.259	0.160	-0.043	0.818	-0.073	0.696	0.163	0.380
	Nitrogen dioxide	-0.043	0.816	-0.159	0.394	-0.003	0.986	-0.047	0.801
	Nitrogen monoxide	-0.015	0.938	-0.141	0.450	-0.144	0.438	0.027	0.887
	Respirable particles	0.230	0.214	-0.127	0.496	-0.255	0.166	-0.158	0.397
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 58. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in May 2023.

		07.00-08.00		08.00-09.00		15.00-16.00		16.00-17.00	
	Kauppatori & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.218	0.240	0.201	0.278	-0.183	0.324	-0.341	0.060
	Nitrogen dioxide	**0.673****	<0.001	0.198	0.285	-0.039	0.835	**-0.360***	0.046
	Nitrogen monoxide	**0.517****	0.003	0.254	0.167	0.034	0.857	-0.013	0.946
	Respirable particles	**0.482****	0.006	0.270	0.142	-0.124	0.505	**-0.401***	0.025
	Fine particles	0.312	0.088	0.014	0.942	-0.062	0.739	**-0.362***	0.046
Spearman	Air quality index	0.264	0.152	0.216	0.243	-0.183	0.325	-0.311	0.089
	Nitrogen dioxide	**0.668****	<0.001	0.141	0.449	-0.005	0.977	**-0.356***	0.050
	Nitrogen monoxide	**0.536****	0.002	0.176	0.345	0.242	0.190	0.116	0.533
	Respirable particles	**0.444***	0.012	0.194	0.296	-0.047	0.803	-0.260	0.158
	Fine particles	0.300	0.102	0.031	0.868	-0.153	0.410	**-0.490****	0.005

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

The correlation between the 05.00 UHI and the 08.00 air quality

In May 2021, none of the 08.00 air quality variables showed a statistically significant correlation with the 05.00 UHI (Table 59).

In 2023, all air quality variables except nitrogen dioxide were positively correlated with the 05.00 UHI according to Pearson's correlation (Table 60). Most of these correlations were of moderate strength, with respirable particles exhibiting the strongest correlation. For Spearman's correlation, moderate positive correlations were observed with the air quality index, respirable particles, and fine particles.

Table 59. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in May 2021. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index	0.288	0.116
	Nitrogen dioxide	0.094	0.616
	Nitrogen monoxide	0.232	0.209
	Respirable particles	0.243	0.189
	Fine particles		
Spearman	Air quality index	0.302	0.099
	Nitrogen dioxide	0.029	0.877
	Nitrogen monoxide	0.081	0.665
	Respirable particles	0.294	0.108
	Fine particles		

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 60. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in May 2023. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index	**0.471****	0.008
	Nitrogen dioxide	0.307	0.093
	Nitrogen monoxide	**0.364***	0.044
	Respirable particles	**0.504****	0.004
	Fine particles	**0.430***	0.016
Spearman	Air quality index	**0.475****	0.007
	Nitrogen dioxide	0.297	0.104
	Nitrogen monoxide	0.328	0.072
	Respirable particles	**0.488****	0.005
	Fine particles	**0.446***	0.012

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

The correlation between the UHI, average wind speed and cloudiness

In May, daytime extended from 04.00 to 21.00. During this period, the UHI exhibited a moderately strong negative correlation with cloudiness (Table 61). At night, the correlation between UHI and cloudiness was very strong and negative on average. Hardly any statistically significant correlations were observed between UHI and average wind speed during either the day or night except.

Wind speed values generally ranged between 2 m/s and 5 m/s during the day, with a few outliers reaching approximately 6 m/s (Figure 94).

Table 61. Pearson and Spearman correlation coefficients between the wind speed and UHI and between the cloudiness and UHI during daytime and nighttime in May 2021. Four different UHI intensities are calculated based on the Betel, Kurala, Kauppatori and Niuskala observation sites.

			Betel & Kurala Average UHI	Betel & Niuskala Average UHI	Kauppatori & Kurala Average UHI	Kauppatori & Niuskala Average UHI
Day	Pearson	Average wind speed	-0.168	-0.100	-0.197	-0.116
		Average cloudiness	**-0.519****	**-0.463****	**-0.633****	**-0.512****
	Spearman	Average wind speed	-0.065	-0.073	-0.139	-0.101
		Average cloudiness	**-0.512****	**-0.445***	**-0.610****	**-0.538****
Night	Pearson	Average wind speed	**-0.430***	-0.300	**-0.425***	-0.287
		Average cloudiness	**-0.747****	**-0.823****	**-0.769****	**-0.818****
	Spearman	Average wind speed	**-0.396***	-0.254	**-0.370***	-0.245
		Average cloudiness	**-0.750****	**-0.820****	**-0.761****	**-0.822****

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

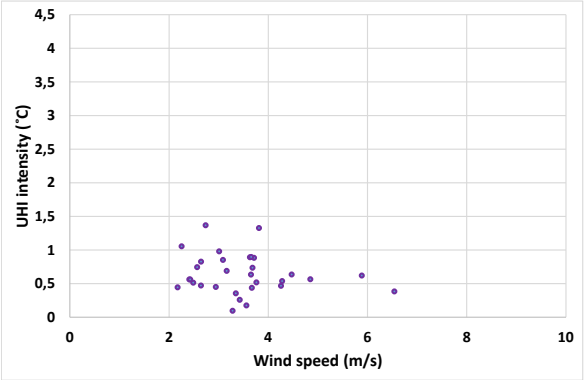

Figure 94. Scatter plot for wind speed and UHI between Betel and Kurala during daytime in May 2021.

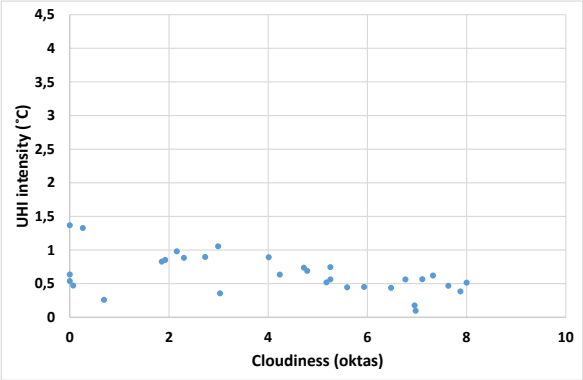

Figure 95. Scatter plot for cloudiness and UHI between Betel and Kurala during daytime in May 2021.

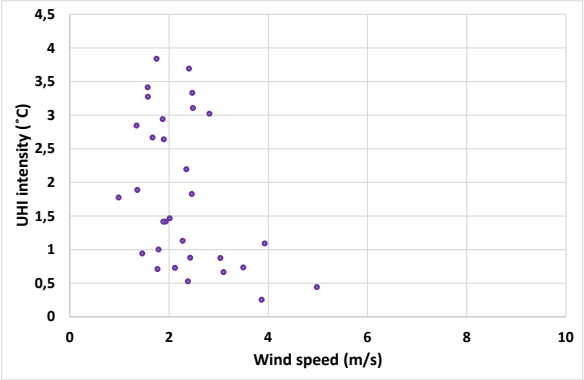

Figure 96. Scatter plot for wind speed and UHI between Betel and Kurala during nighttime in May 2021.

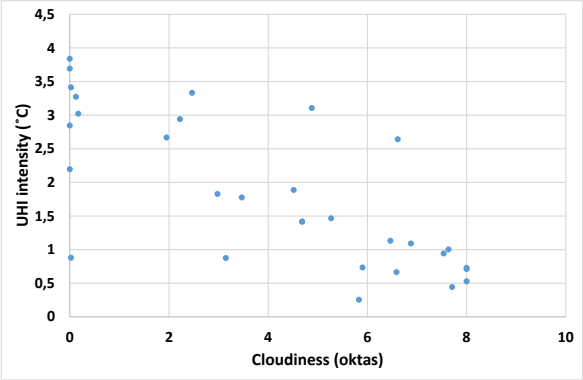

Figure 97. Scatter plot for cloudiness and UHI between Betel and Kurala during nighttime in May 2021.

UHI values ranged from 0 to 1.5 °C during the same period. Cloudiness varied between 0 and 8 oktas, with UHI remaining below 1.5 °C (Figure 95). A slight negative correlation is evident, suggesting a marginally stronger UHI under low cloudiness conditions. At night, wind speed remained low, ranging from 1 to 3 m/s (Figure 96), while UHI values were more variable, ranging from 0.5 °C to nearly 4.0 °C. A somewhat ambiguous pattern is visible between cloudiness and UHI intensity during nighttime. While higher UHI values appear to correspond with lower levels of cloudiness, the relationship is obscured by scattered data points, limiting the clarity of the observed trend (Figure 97).

The correlation between NAO index and UHI

In May 2021, none of the observed logger pairs had a statistically significant correlation with the NAO index (Table 62).

Table 62. Pearson and Spearman correlations between NAO index and different UHI logger pairs in May 2021.

	UHI	NAO index	Significance level
Pearson	Betel & Kurala	0.160	0.389
	Betel & Niuskala	0.002	0.990
	Kauppatori & Kurala	0.160	0.391
	Kauppatori & Niuskala	-0.001	0.997
	Betel & Ryhmäpuutarha	0.220	0.235
	Kauppatori & Ryhmäpuutarha	0.214	0.247
Spearman	Betel & Kurala	-0.080	0.669
	Betel & Niuskala	-0.208	0.260
	Kauppatori & Kurala	-0.072	0.700
	Kauppatori & Niuskala	-0.178	0.339
	Betel & Ryhmäpuutarha	-0.047	0.803
	Kauppatori & Ryhmäpuutarha	-0.047	0.802

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

5.1.6 June

The UHI intensities

In June 2021, the maximum UHI intensity values reached approximately 6 °C and typically occurred during the early morning hours (Figures 98–101). Negative UHI values were relatively frequent, with some falling below –2 °C. These negative values generally occurred around midday or in the evening. A notable peak of nearly 9 °C was recorded on the 8th in the afternoon, observed between Betel–Niuskala and Kauppatori–Niuskala. A clear diurnal pattern is evident, with UHI intensity peaking at night, dropping to negative values, indicative of a cold island around midday, and then gradually increasing again to moderate levels below 2 °C before reaching another peak.

In 2023, higher UHI intensities were recorded between Betel and Niuskala, as well as between Kauppatori and Niuskala (Figures 102–105). On average, UHI values ranged between –1 °C and 8 °C, with notable variability throughout the month. Minor negative values were observed between Kauppatori and Niuskala, although other UHI pairs also exhibited some. The maximum negative value, approximately –2 °C, was recorded in the evening on the 26th between Kauppatori and Kurala. Most of the highest UHI values occurred during the night or early morning, while negative values tended to occur around midday or in the afternoon, again reflecting a clear diurnal pattern.

In 2023, higher peak UHI values occurred more frequently than in 2021. Unlike 2021, no stable period with consistently lower peak values is visible in 2023. In contrast, a relatively stable period appears between the 18th and 24th in 2021. In 2023, smaller peaks were observed between the 22nd and 26th. For both years, the same diurnal pattern is present, with UHI intensities peaking at night and declining to cold island conditions during the day.

Monthly summaries

In June 2021, nitrogen monoxide and nitrogen dioxide exhibited higher concentration peaks in the morning between 07.00–08.00, with a secondary, less pronounced peak occurring

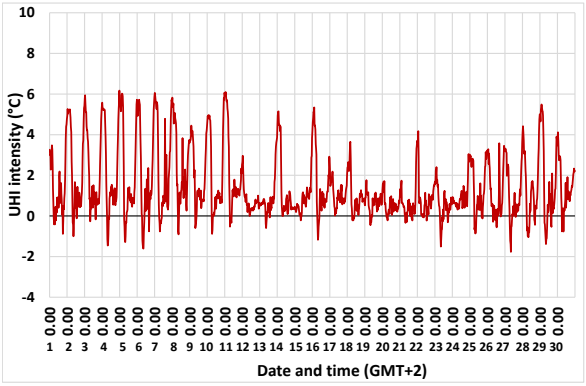

Figure 98. UHI intensity between Betel and Kurala during June 2021.

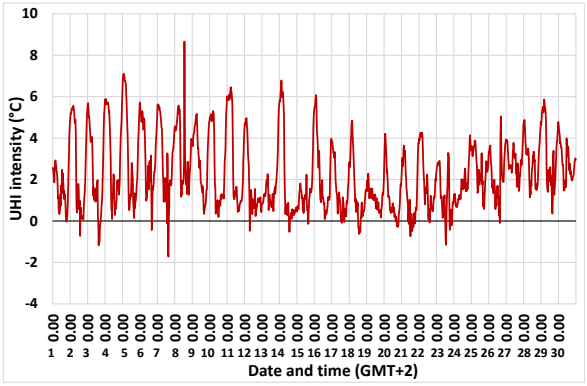

Figure 99. UHI intensity between Betel and Niuskala during June 2021.

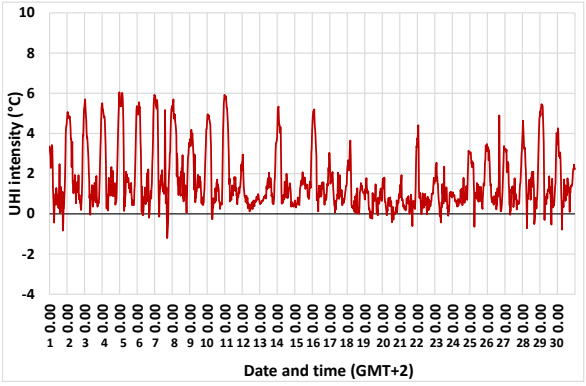

Figure 100. UHI intensity between Kauppatori and Kurala during June 2021.

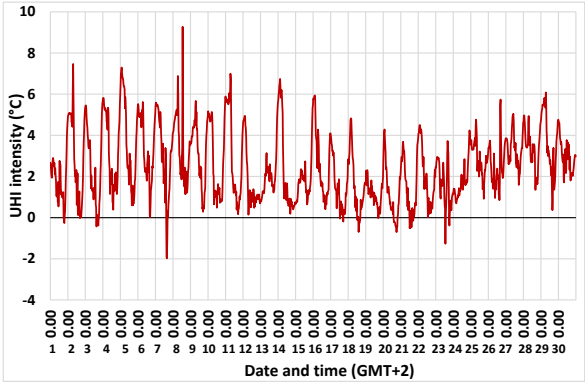

Figure 101. UHI intensity between Kauppatori and Niuskala during June 2021.

in the evening between 18.00–19.00 (Figure 106). Outside of these peak periods, nitrogen monoxide concentrations remained close to 0 µg/m³ and nitrogen dioxide around 10 µg/m³. During the morning peak, concentrations reached approximately 8 µg/m³ for nitrogen monoxide and 17 µg/m³ for nitrogen dioxide. Respirable particles showed their most distinct peak between 13.00–14.00, reaching 20 µg/m³, while remaining close to 10 µg/m³ during other times of the day. The air quality index also exhibited peaks during the morning and between 13.00–14.00, with values around 1.3. At night, the index dropped to approximately 1.0.

Similarly, in 2023, the highest air quality values were recorded during the morning hours between 05.00–10.00. During this period, the air quality index ranged from 1.03 to 1.47, nitrogen dioxide from 5.58 to 12.19 µg/m³, nitrogen monoxide from 0.56 to 3.87 µg/m³, respirable particles from 10.53 to 16.86 µg/m³, and fine particles from 5.03 to 7.29 µg/m³.

In June 2021, the UHI reached its maximum values during the nighttime on average (Figure 107). During the night, UHI values ranged between approximately 3.0 and 3.5 °C, while during the day (from 05.00 to 20.00), values generally ranged between 0.6 and 1.3 °C.

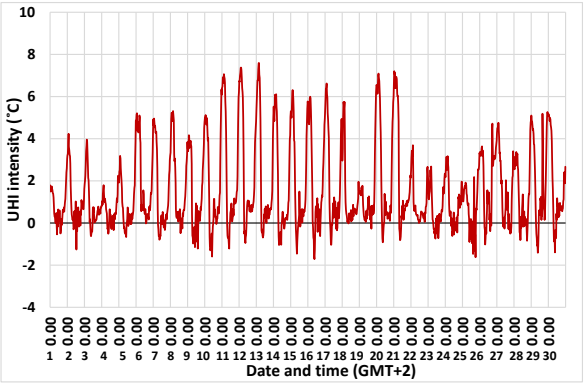

Figure 102. UHI intensity between Betel and Kurala during June 2023.

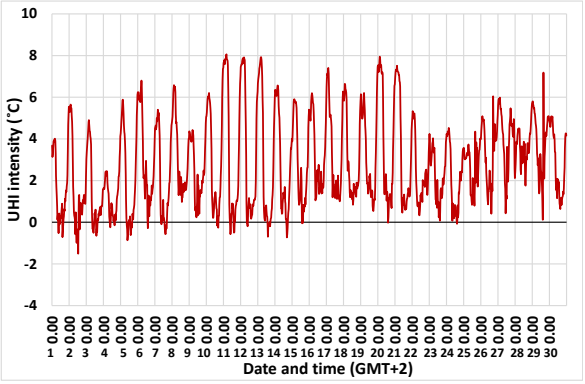

Figure 103. UHI intensity between Betel and Niuskala during June 2023.

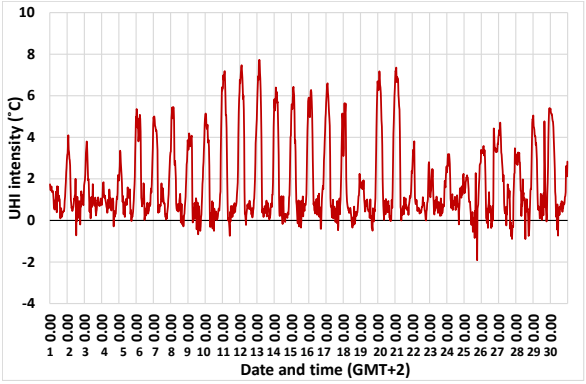

Figure 104. UHI intensity between Kauppatori and Kurala during June 2023.

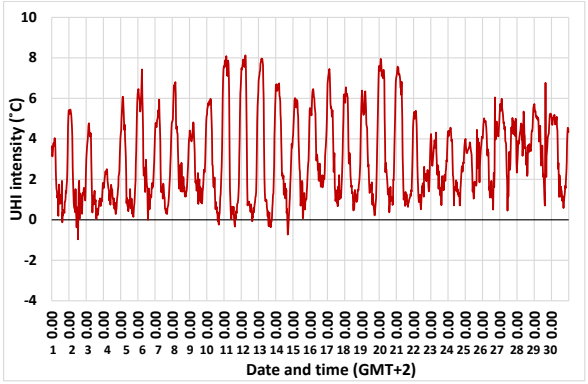

Figure 105. UHI intensity between Kauppatori and Niuskala during June 2023.

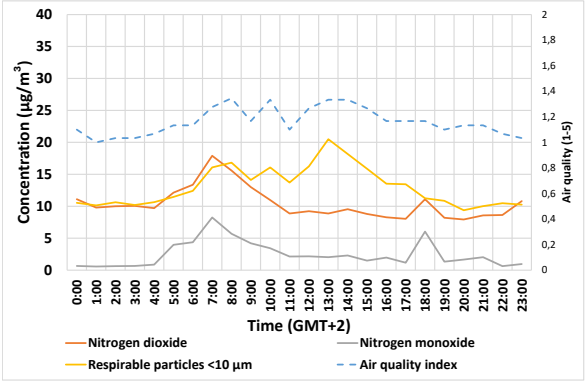

Figure 106. Hourly averages of air quality observations in June 2021.

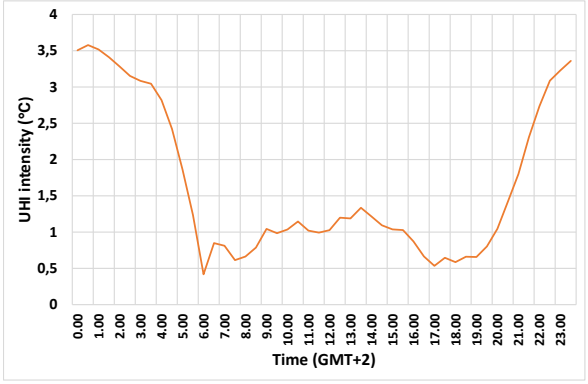

Figure 107. Hourly average UHI intensity between Kauppatori and Kurala in June 2021.

The correlations between the UHI and air quality

The UHI between Betel and Kurala exhibited a positive correlation with the air quality index, nitrogen dioxide, and nitrogen monoxide during the 07.00–08.00 period (Table 63). Among these, nitrogen monoxide showed the strong-

Table 63. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in June 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.403***	0.030	0.177	0.358	-0.004	0.985	-0.195	0.302
	Nitrogen dioxide	**0.544****	0.002	0.014	0.944	**0.517****	0.003	**0.442***	0.014
	Nitrogen monoxide	**0.622****	<0.001	0.083	0.670	0.313	0.093	0.058	0.763
	Respirable particles	0.304	0.109	0.034	0.861	0.209	0.267	-0.007	0.972
	Fine particles								
Spearman	Air quality index	**0.378***	0.043	0.191	0.322	-0.105	0.583	-0.202	0.286
	Nitrogen dioxide	0.210	0.275	0.036	0.852	0.323	0.082	0.083	0.663
	Nitrogen monoxide	0.259	0.175	0.091	0.637	0.253	0.177	**0.423***	0.020
	Respirable particles	0.111	0.568	0.018	0.927	0.025	0.897	0.035	0.854
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 64. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in June 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.323	0.082	0.042	0.826	0.227	0.228	-0.049	0.796
	Nitrogen dioxide	**0.494****	0.005	0.042	0.827	0.323	0.088	0.204	0.279
	Nitrogen monoxide	0.000	0.999	-0.140	0.462	0.263	0.169	-0.095	0.619
	Respirable particles	**0.403***	0.027	-0.084	0.658	**0.391***	0.032	0.238	0.206
	Fine particles	0.205	0.278	-0.076	0.691	**0.443***	0.014	0.269	0.150
Spearman	Air quality index	0.278	0.137	0.044	0.818	0.305	0.101	0.036	0.850
	Nitrogen dioxide	**0.390***	0.033	-0.067	0.725	0.321	0.090	0.255	0.173
	Nitrogen monoxide	0.291	0.119	-0.176	0.351	0.093	0.632	-0.051	0.789
	Respirable particles	0.336	0.069	-0.088	0.642	**0.427***	0.018	0.188	0.319
	Fine particles	0.235	0.211	-0.089	0.639	**0.447***	0.013	0.263	0.161

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

est correlation, while the air quality index showed the weakest. According to Spearman's correlation, only the air quality index demonstrated a statistically significant relationship. In the afternoon, nitrogen dioxide correlated with UHI during both 15.00–16.00 and 16.00–17.00, with moderate correlation coefficients. Additionally, at 16.00–17.00, nitrogen monoxide also showed a moderate Spearman correlation with UHI.

In 2023, the UHI was moderately correlated with nitrogen dioxide and respirable particles during the 07.00–08.00 period (Table 64). According to Spearman's method, only nitro-

Table 65. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in June 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.217	0.259	0.115	0.553	**-0.432***	0.017	**-0.416***	0.022
	Nitrogen dioxide	**0.646****	<0.001	**0.427***	0.021	0.093	0.624	-0.311	0.094
	Nitrogen monoxide	**0.547****	0.002	0.366	0.051	0.219	0.245	-0.125	0.510
	Respirable particles	0.310	0.102	0.021	0.913	-0.347	0.060	**-0.401***	0.028
	Fine particles								
Spearman	Air quality index	0.175	0.363	0.043	0.823	**-0.488****	0.006	**-0.419***	0.021
	Nitrogen dioxide	**0.506****	0.005	0.210	0.275	-0.099	0.601	-0.252	0.179
	Nitrogen monoxide	**0.506****	0.005	0.148	0.443	0.163	0.390	-0.069	0.718
	Respirable particles	0.222	0.247	-0.026	0.892	**-0.487****	0.006	**-0.533****	0.002
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 66. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in June 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.204	0.279	**0.396***	0.030	0.320	0.084	-0.069	0.717
	Nitrogen dioxide	**0.630****	<0.001	**0.618****	<0.001	**0.599****	<0.001	**0.512****	0.004
	Nitrogen monoxide	0.228	0.226	**0.385***	0.036	**0.457***	0.013	0.013	0.945
	Respirable particles	**0.406***	0.026	**0.562****	0.001	**0.394***	0.031	0.232	0.216
	Fine particles	0.184	0.329	**0.392***	0.032	**0.568****	0.001	**0.419***	0.021
Spearman	Air quality index	0.229	0.224	**0.428***	0.018	0.360	0.051	0.016	0.935
	Nitrogen dioxide	**0.680****	<0.001	**0.614****	<0.001	**0.651****	<0.001	**0.378***	0.039
	Nitrogen monoxide	**0.557****	0.001	**0.493****	0.006	**0.381***	0.041	0.018	0.926
	Respirable particles	**0.438***	0.015	**0.553****	0.002	**0.459***	0.011	0.194	0.305
	Fine particles	0.267	0.154	**0.492****	0.006	**0.561****	0.001	**0.493****	0.006

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

gen dioxide correlated, and this correlation was weaker than that observed using Pearson's method. No statistically significant correlations were found between UHI and any air quality variables during the 08.00–09.00 or 16.00–17.00 periods. However, during 15.00–16.00, respirable particles and fine particles demonstrated moderate and weak positive correlations with UHI, with the correlation for fine particles being stronger.

For the UHI between Betel and Niuskala in 2021, nitrogen dioxide and nitrogen monoxide showed strong to medium positive correlations during the 07.00–08.00 period (Table 65). In the

Table 67. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in June 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.345	0.067	0.095	0.625	0.036	0.850	**-0.370***	0.044
	Nitrogen dioxide	**0.668****	<0.001	0.321	0.089	0.234	0.214	-0.205	0.276
	Nitrogen monoxide	**0.758****	<0.001	0.249	0.193	0.075	0.693	0.030	0.873
	Respirable particles	0.334	0.076	-0.010	0.957	0.184	0.330	-0.267	0.154
	Fine particles								
Spearman	Air quality index	0.166	0.389	0.000	1.000	-0.061	0.749	-0.243	0.196
	Nitrogen dioxide	0.234	0.221	0.148	0.445	0.101	0.597	-0.242	0.198
	Nitrogen monoxide	0.285	0.134	0.124	0.523	-0.014	0.940	0.259	0.167
	Respirable particles	-0.052	0.788	-0.106	0.585	-0.083	0.665	-0.176	0.353
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 68. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in June 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.337	0.068	0.202	0.285	-0.021	0.914	-0.206	0.274
	Nitrogen dioxide	**0.590****	<0.001	0.309	0.096	-0.044	0.821	0.109	0.565
	Nitrogen monoxide	0.117	0.537	0.118	0.535	0.092	0.635	-0.265	0.158
	Respirable particles	**0.452***	0.012	0.185	0.328	0.045	0.814	0.032	0.865
	Fine particles	0.238	0.206	0.081	0.671	0.122	0.520	0.089	0.638
Spearman	Air quality index	0.327	0.078	0.156	0.411	0.032	0.867	-0.274	0.143
	Nitrogen dioxide	**0.515****	0.004	0.240	0.202	-0.120	0.537	-0.010	0.958
	Nitrogen monoxide	**0.416***	0.022	0.221	0.241	-0.085	0.663	-0.182	0.335
	Respirable particles	**0.410***	0.024	0.148	0.437	0.026	0.893	-0.153	0.421
	Fine particles	0.297	0.110	0.112	0.555	0.066	0.729	-0.034	0.859

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

following hour, only nitrogen dioxide demonstrated a positive Pearson correlation, which was weaker than in the previous hour. In the afternoon, between 15.00–16.00, the air quality index exhibited a moderate negative correlation, while Spearman's method also revealed a moderate negative correlation with respirable particles. The 16.00–17.00 period showed a similar pattern; however, according to Pearson's method, respirable particles also correlated negatively. All afternoon correlations were negative.

In 2023, a relatively strong positive correlation was observed between UHI and nitro-

Table 69. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in June 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.167	0.386	0.042	0.829	**-0.422***	0.020	**-0.452***	0.012
	Nitrogen dioxide	**0.605****	<0.001	**0.387***	0.038	-0.070	0.714	**-0.570****	0.001
	Nitrogen monoxide	**0.530****	0.003	0.295	0.120	0.088	0.643	-0.121	0.522
	Respirable particles	0.279	0.142	-0.002	0.990	**-0.374***	0.042	**-0.475****	0.008
	Fine particles								
Spearman	Air quality index	0.138	0.474	0.061	0.754	**-0.479****	0.007	**-0.574****	<0.001
	Nitrogen dioxide	**0.481****	0.008	0.258	0.177	-0.229	0.223	**-0.412***	0.024
	Nitrogen monoxide	**0.477****	0.009	0.208	0.280	0.047	0.807	-0.049	0.795
	Respirable particles	0.204	0.288	0.015	0.939	**-0.575****	<0.001	**-0.680****	<0.001
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

gen dioxide, and a moderate one with respirable particles during the 07.00–08.00 period (Table 66). According to Spearman's method, nitrogen monoxide also correlated during this time. In the following hour, both nitrogen dioxide and respirable particles showed relatively strong correlations with UHI, while other air quality variables exhibited weak positive correlations. At 15.00–16.00, all variables except the air quality index correlated with UHI, with nitrogen dioxide showing the strongest Pearson correlation. Respirable particles had the weakest Pearson correlation, while nitrogen monoxide had the weakest correlation according to Spearman. During the 16.00–17.00 interval, only nitrogen dioxide and fine particles correlated with UHI, both with generally moderate coefficients.

For the UHI between Kauppatori and Kurala in 2021, nitrogen dioxide and nitrogen monoxide exhibited strong positive Pearson correlations during the 07.00–08.00 period (Table 67). In the afternoon, a weak negative Pearson correlation was observed with the air quality index.

In 2023, positive correlations were found between UHI and both nitrogen dioxide and respirable particles during the 07.00–08.00 interval, with correlations of moderate strength (Table 68). Additionally, nitrogen monoxide showed a statistically significant correlation according to Spearman's method. No statistically significant correlations between UHI and any air quality variables were observed during the other examined time periods.

The UHI between Kauppatori and Niuskala exhibited a positive correlation with nitrogen dioxide and nitrogen monoxide during the 07.00–08.00 period in 2021, with strengths ranging from moderate to relatively strong (Table 69). In the following hour, only nitrogen dioxide showed a weak positive Pearson correlation. In the afternoon, both the air quality index and respirable particles demonstrated moderate to weak negative correlations. At 16.00–17.00, nitrogen diox-

Table 70. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in June 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.188	0.321	**0.397***	0.030	0.241	0.199	-0.136	0.473
	Nitrogen dioxide	**0.629****	<0.001	**0.629****	<0.001	**0.499****	0.006	**0.495****	0.005
	Nitrogen monoxide	0.279	0.135	**0.445***	0.014	**0.438***	0.017	-0.051	0.791
	Respirable particles	**0.394***	0.031	**0.602****	<0.001	0.274	0.143	0.147	0.437
	Fine particles	0.184	0.330	**0.415***	0.022	**0.488****	0.006	0.356	0.053
Spearman	Air quality index	0.221	0.241	**0.483****	0.007	0.241	0.199	-0.098	0.606
	Nitrogen dioxide	**0.699****	<0.001	**0.642****	<0.001	**0.457***	0.013	0.287	0.124
	Nitrogen monoxide	**0.620****	<0.001	**0.543****	0.002	0.292	0.125	0.058	0.761
	Respirable particles	**0.457***	0.011	**0.651****	<0.001	0.296	0.113	0.082	0.666
	Fine particles	0.305	0.102	**0.585****	<0.001	**0.460***	0.011	**0.366***	0.047

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

ide also correlated negatively with moderate strength. All afternoon correlations were negative.

In 2023, the UHI showed a relatively strong positive correlation with nitrogen dioxide and a weaker positive correlation with respirable particles during the 07.00–08.00 period (Table 70). At the same time, nitrogen monoxide displayed a strong Spearman correlation. During the 08.00–09.00 interval, nitrogen dioxide and respirable particles continued to exhibit relatively strong positive correlations, while the remaining air quality variables showed moderate positive correlations. At 15.00–16.00, nitrogen dioxide and fine particles both demonstrated moderate Pearson correlations, and nitrogen monoxide also showed a statistically significant Pearson correlation. During the 16.00–17.00 period, nitrogen dioxide continued to correlate positively with moderate strength according to Pearson's method, while fine particles showed a weaker correlation using Spearman's method.

The correlation between the 05.00 UHI and the 08.00 air quality

In June 2021, nitrogen dioxide and nitrogen monoxide showed moderate positive Pearson correlations with the 05.00 UHI (Table 71). Using Spearman's method, the correlation with nitrogen dioxide was weaker, while the correlation with nitrogen monoxide was stronger. Respirable particles also correlated with the UHI according to Spearman's method, though no significant correlation was found using Pearson. This correlation was weaker than those observed with nitrogen dioxide and nitrogen monoxide.

In 2023, all air quality variables at the 08.00 mark showed positive Pearson correlations with the 05.00 UHI (Table 72). Among these, nitrogen dioxide had the strongest correlation and fine particles the weakest. According to Spearman's method, all variables except the air quality index also correlated positively, with most correlations being of moderate strength. As with the Pearson results, the strongest Spearman correlation was observed

Table 71. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in June 2021. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index	0.137	0.479
	Nitrogen dioxide	**0.507****	0.005
	Nitrogen monoxide	**0.407***	0.029
	Respirable particles	0.352	0.061
	Fine particles		
Spearman	Air quality index	0.175	0.363
	Nitrogen dioxide	**0.470***	0.010
	Nitrogen monoxide	**0.432***	0.019
	Respirable particles	**0.402***	0.031
	Fine particles		

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 72. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in June 2023. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index	**0.382***	0.037
	Nitrogen dioxide	**0.622****	<0.001
	Nitrogen monoxide	**0.474****	0.008
	Respirable particles	**0.589****	<0.001
	Fine particles	**0.379***	0.039
Spearman	Air quality index	0.355	0.054
	Nitrogen dioxide	**0.648****	<0.001
	Nitrogen monoxide	**0.587****	<0.001
	Respirable particles	**0.578****	<0.001
	Fine particles	**0.380***	0.038

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

with nitrogen dioxide and the weakest with fine particles.

Overall, more variables had statistically significant correlations in 2023, and the correlation coefficients were generally stronger compared to those in 2021.

The correlation between the UHI, average wind speed and cloudiness

In June, daytime extended from 03.00 to 22.00, making it the month with the longest daylight period in Finland. During daytime hours, the UHI showed a moderate to weak negative correlation with average wind speed, while cloudiness did not exhibit any statistically significant corre-

Table 73. Pearson and Spearman correlation coefficients between the wind speed and UHI and between the cloudiness and UHI during daytime and nighttime in June 2021. Four different UHI intensities are calculated based on the Betel, Kurala, Kauppatori and Niuskala observation sites.

			Betel & Kurala Average UHI	Betel & Niuskala Average UHI	Kauppatori & Kurala Average UHI	Kauppatori & Niuskala Average UHI
Day	Pearson	Average wind speed	**-0.464****	**-0.559****	**-0.395***	**-0.473****
		Average cloudiness	-0.108	-0.168	-0.194	-0.204
	Spearman	Average wind speed	**-0.480****	**-0.585****	**-0.504****	**-0.507****
		Average cloudiness	-0.098	-0.228	-0.183	-0.224
Night	Pearson	Average wind speed	**-0.712****	**-0.647****	**-0.704****	-0.054
		Average cloudiness	**-0.434***	**-0.419***	**-0.438***	-0.044
	Spearman	Average wind speed	**-0.711****	**-0.690****	**-0.707****	-0.246
		Average cloudiness	**-0.369***	**-0.366***	**-0.396***	-0.099

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

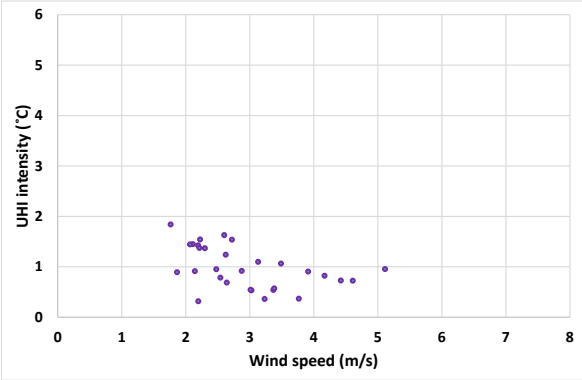

Figure 108. Scatter plot for wind speed and UHI between Betel and Kurala during daytime in June 2021.

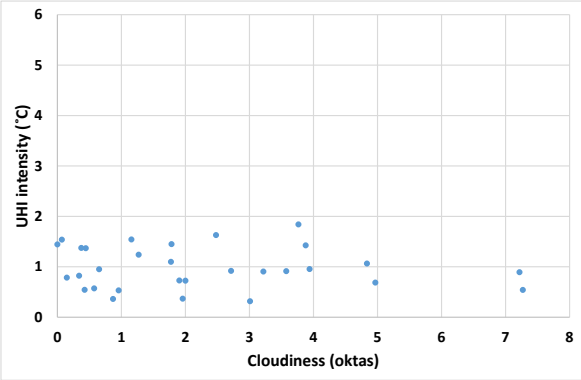

Figure 109. Scatter plot for cloudiness and UHI between Betel and Kurala during daytime in June 2021.

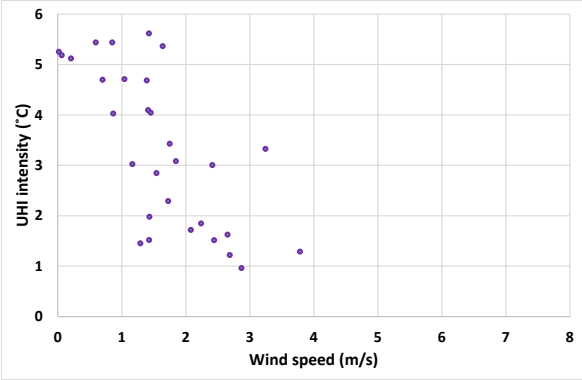

Figure 110. Scatter plot for wind speed and UHI between Betel and Kurala during nighttime in June 2021.

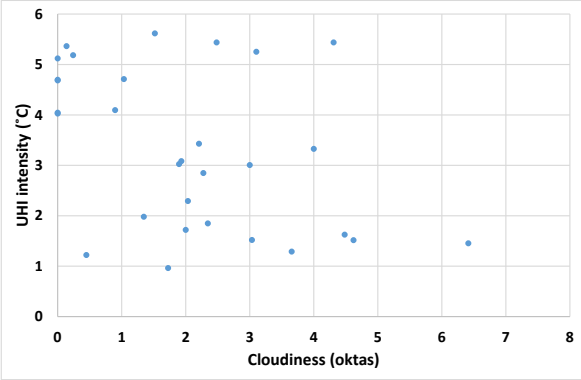

Figure 111. Scatter plot for cloudiness and UHI between Betel and Kurala during nighttime in June 2021.

lation (Table 73). At night, wind speed showed strong negative correlations with the UHI while the correlations with cloudiness were weak.

The scatter plots for daytime wind speed and cloudiness resemble those from the previous month (Figures 108 and 109). Wind speeds generally ranged from 2 to 5 m/s, while UHI values remained below 2.0 °C. Cloudiness typically ranged from 0 to 5 oktas, with a few isolated values reaching 7 oktas. UHI values stayed under 2.0 °C during these periods. At night, a visible negative correlation can be observed between wind speed and UHI (Figure 110), where higher wind speeds correspond with lower UHI intensity. Wind speeds at night ranged between 0 and 3 m/s, while UHI values varied between 1.0 °C and nearly 6.0 °C. In contrast, cloudiness values during the night appeared randomly dispersed, with no discernible pattern or correlation with UHI (Figure 111).

The correlation between NAO index and UHI

In June 2021, no statistically significant correlations occurred with any of the observed logger pairs (Table 74).

Heatwave period review

In July 2021, three heatwave periods occurred, lasting three and five days each, taking place on July 6–8, 19–23, and 25–29. During the first heatwave (July 6–8), UHI intensity reached its peak values primarily at night, decreasing into cold island conditions during the day (Figures

Table 74. Pearson and Spearman correlations between NAO index and different UHI logger pairs in June 2021.

	UHI	NAO index	Significance level
Pearson	Betel & Kurala	0.086	0.652
	Betel & Niuskala	-0.035	0.855
	Kauppatori & Kurala	0.073	0.703
	Kauppatori & Niuskala	-0.055	0.773
	Betel & Ryhmäpuutarha	0.068	0.720
	Kauppatori & Ryhmäpuutarha	0.050	0.793
Spearman	Betel & Kurala	0.021	0.913
	Betel & Niuskala	-0.132	0.488
	Kauppatori & Kurala	0.008	0.996
	Kauppatori & Niuskala	-0.144	0.446
	Betel & Ryhmäpuutarha	-0.032	0.866
	Kauppatori & Ryhmäpuutarha	-0.054	0.777

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

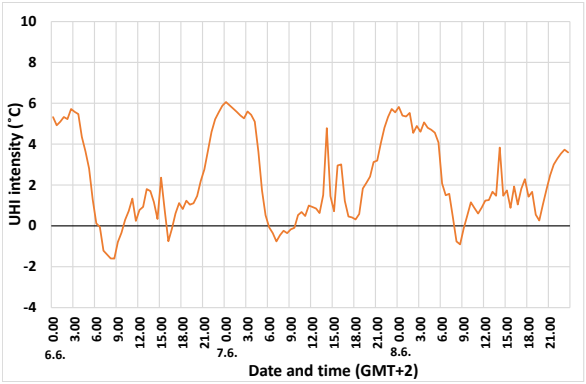

Figure 112. UHI intensity between Betel and Kurala during the heatwave period on the 6th-8th of June in 2021.

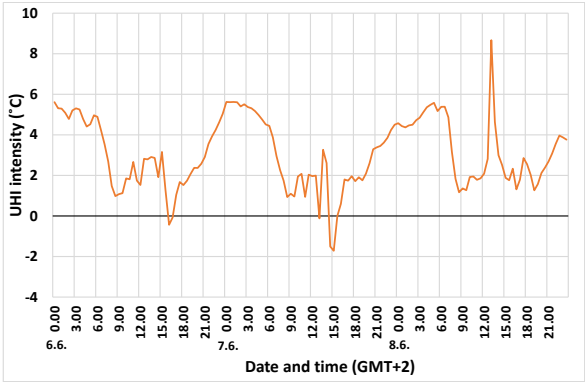

Figure 113. UHI intensity between Betel and Niuskala during the heatwave period on the 6th-8th of June in 2021.

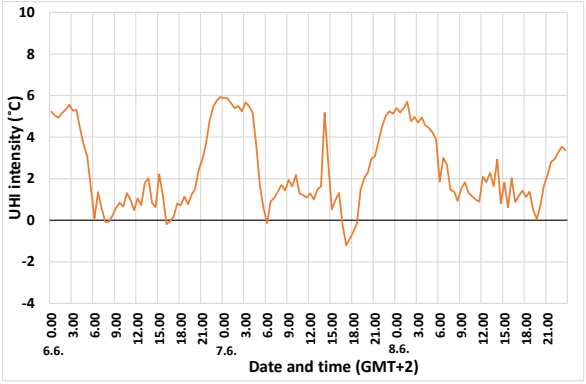

Figure 114. UHI intensity between Kauppatori and Kurala during the heatwave period on the 6th-8th of June in 2021.

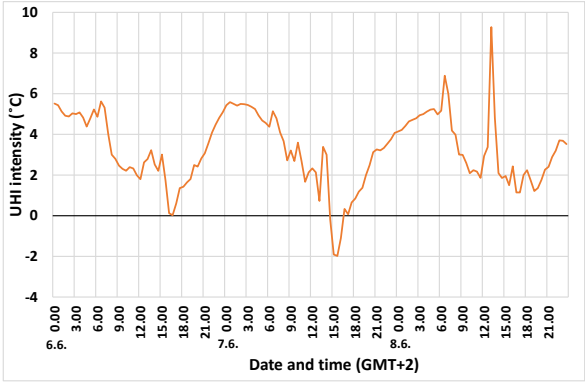

Figure 115. UHI intensity between Kauppatori and Niuskala during the heatwave period on the 6th-8th of June in 2021.

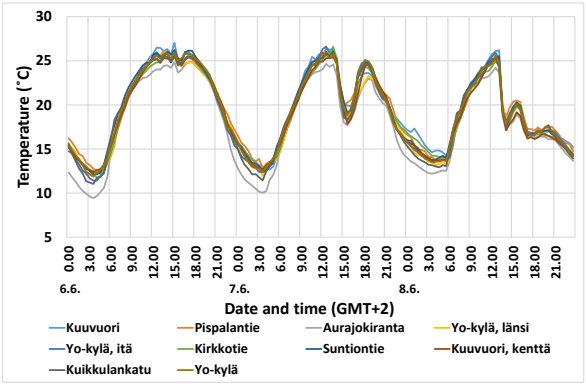

Figure 116. Turku Student Village temperatures during the heatwave period on the 6th-8th of June in 2021.

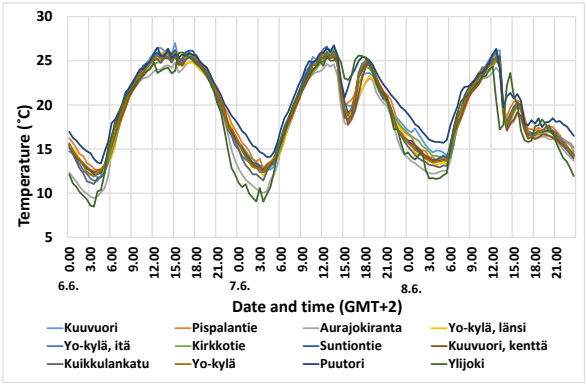

Figure 117. Turku Student Village, Puutori and Ylijoki temperatures during the heatwave period on the 6th-8th of June in 2021.

112–115). Peak intensities reached nearly 6 °C, with the exception of a brief peak between the Betel–Niuskala and Kauppatori–Niuskala station pairs, where values approached 9 °C. Some smaller UHI peaks were also observed during the afternoon, particularly between 14.00–16.00. Cold islands were most prominent in the morning around 08.00, and on the afternoon of July 7 around 16.00. Cold island intensities generally remained below –2 °C, while UHI values during other periods stayed around 1.5 °C.

Temperatures during the July 6–8 heatwave ranged between 10 and 25 °C (Figure 116). Observations from the Student Village did not differ substantially from each other, although Aurajokiranta consistently recorded the lowest temperatures, both during the coldest nighttime hours and during peak daytime temperatures. None of the loggers consistently recorded the highest temperatures, though Kuuvuori slightly stood out as the warmest location during peak temperature periods. When comparing Puutori and Ylijoki to the other sites, Ylijoki recorded even lower temperatures than Aurajokiranta and was especially distinct during colder periods (Figure 117). Puutori, on the other hand, recorded consistently higher temperatures during colder moments, distinguishing it from the other loggers.

During the July 19–23 heatwave period, UHI intensity remained moderate, with the Betel–Kurala and Kauppatori–Kurala logger pairs generally recording values below 2 °C (Figures 118–121). A single notable peak occurred at midnight on the 22nd, when the UHI exceeded 4 °C. For the Betel–Niuskala and Kauppatori–Niuskala logger pairs, UHI intensity peaks were more pronounced, each reaching approximately 4 °C. These peaks consistently occurred around midnight on each day, with UHI values remaining near 1 °C during other times. Cold islands were also present, the most significant appearing on the morning of the 23rd. Depending on the logger pair, this cold island reached up to –1.5 °C, while others during the period remained below –1.0 °C.

Temperatures at the Student Village sites remained relatively consistent throughout the heatwave (Figure 122). No single site consistently recorded the highest temperatures, although Aurajokiranta stood out as the coldest location on several occasions during the nighttime hours. Kuuvuori kenttä also appeared as a relatively cooler site, alongside Aurajokiranta. Puutori did not record the highest temper-

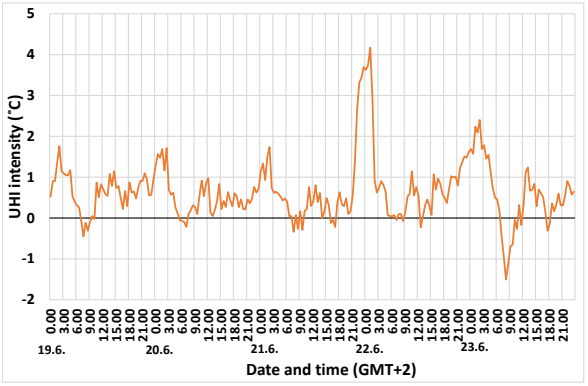

Figure 118. UHI intensity between Betel and Kurala during the heatwave period on the 19th-23rd of June in 2021.

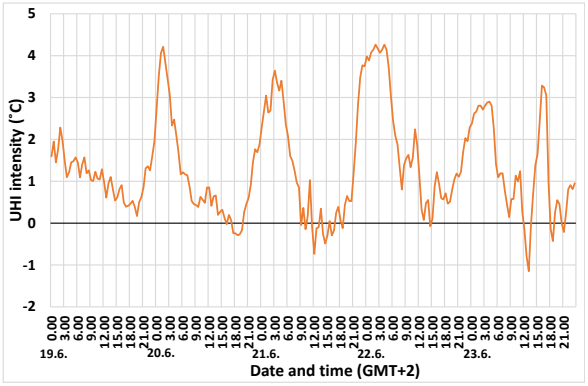

Figure 119. UHI intensity between Betel and Niuskala during the heatwave period on the 19th-23rd of June in 2021.

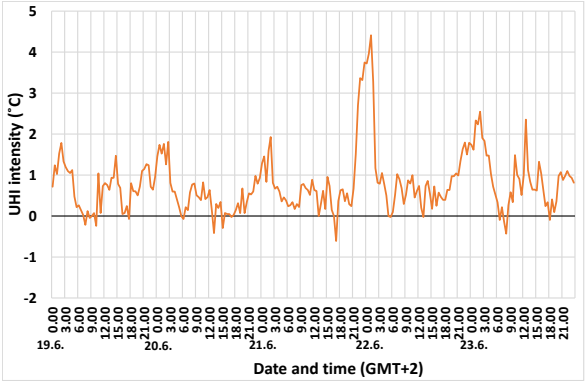

Figure 120. UHI intensity between Kauppatori and Kurala during the heatwave period on the 19th-23rd of June in 2021.

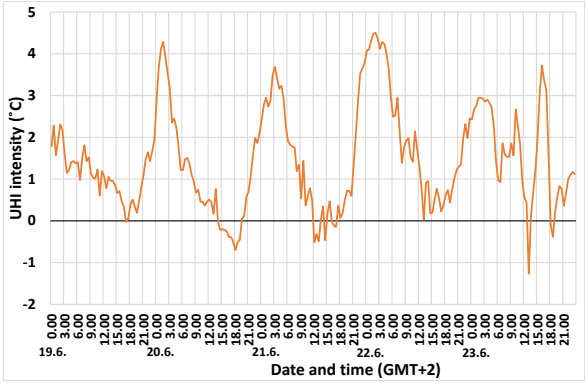

Figure 121. UHI intensity between Kauppatori and Niuskala during the heatwave period on the 19th-23rd of June in 2021.

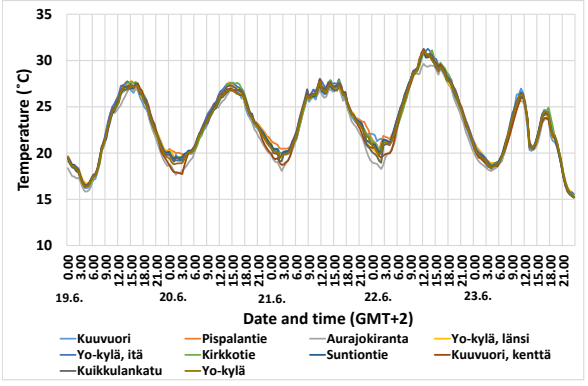

Figure 122. Turku Student Village temperatures during the heatwave period on the 19th-23rd of June in 2021.

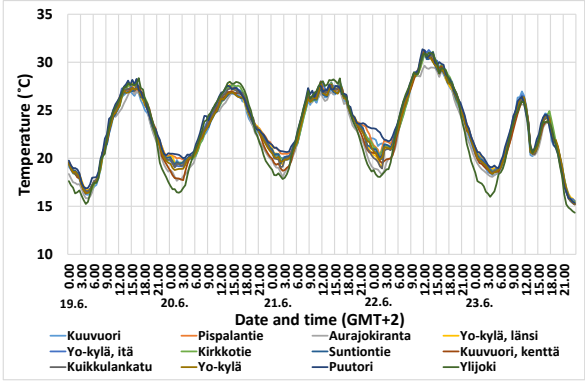

Figure 123. Turku Student Village, Puutori and Ylijoki temperatures during the heatwave period on the 19th-23rd of June in 2021.

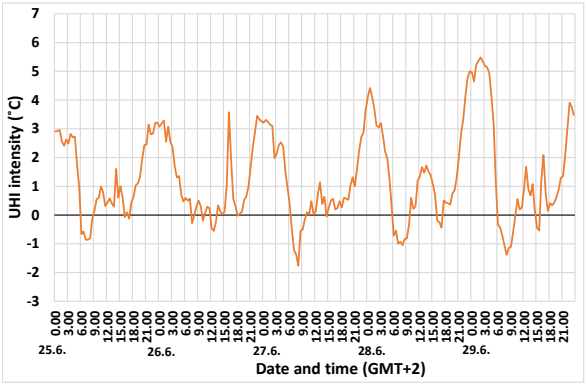

Figure 124. UHI intensity between Betel and Kurala during the heatwave period on the 25th-29th of June in 2021.

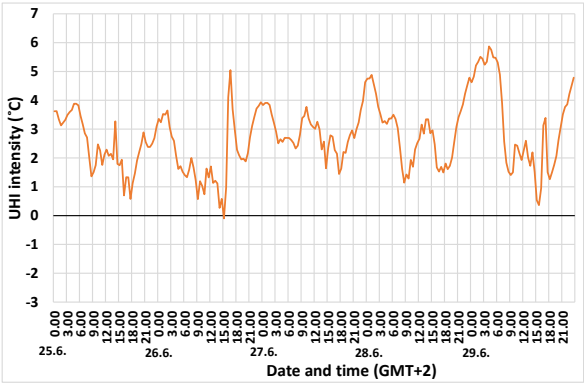

Figure 125. UHI intensity between Betel and Niuskala during the heatwave period on the 25th-29th of June in 2021.

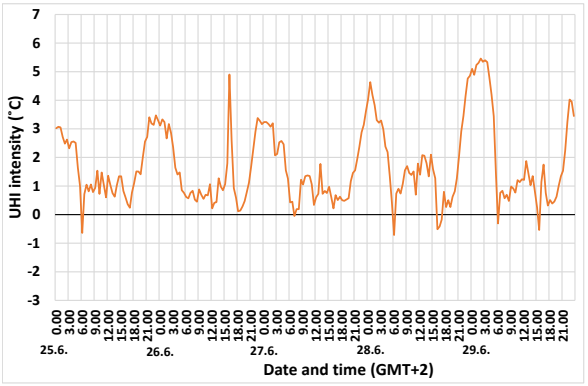

Figure 126. UHI intensity between Kauppatori and Kurala during the heatwave period on the 25th-29th of June in 2021.

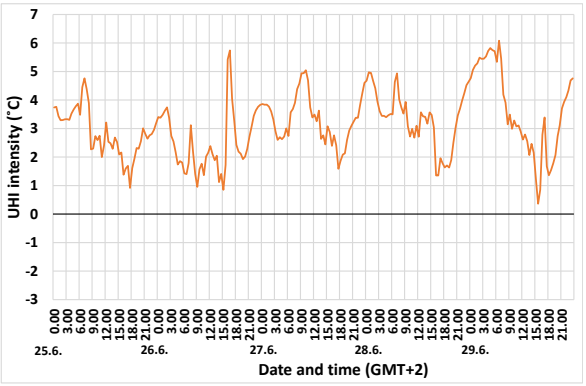

Figure 127. UHI intensity between Kauppatori and Niuskala during the heatwave period on the 25th-29th of June in 2021.

atures compared to the Student Village loggers but showed similar readings to most of them (Figure 123). Ylijoki, however, clearly stood out as the coldest location during colder periods, recording temperatures even lower than those at Aurajokiranta. Exceptionally high temperatures were recorded during this heatwave, exceeding 30 °C on the 22nd.

During the July 25–29 heatwave period, UHI intensity peaks occurred primarily around midnight (Figures 124–127). These major peaks reached up to 6 °C, depending on the logger pair observed. Smaller peaks were recorded around midday, typically reaching only up to approximately 2 °C. Cold islands were also detected across all logger pairs except for Kauppatori–Niuskala. These cold islands mainly occurred in the morning and occasionally in the late afternoon, between the larger nighttime and smaller daytime UHI peaks. Most of these cold islands remained below –1 °C, with one instance exceeding –1.5 °C in the case of the Betel–Kurala pair.

When examining the Student Village temperatures during this heatwave, the recorded values did not differ substantially between the sites (Figure 128). Aurajokiranta appeared to consistently record the lowest tempera-

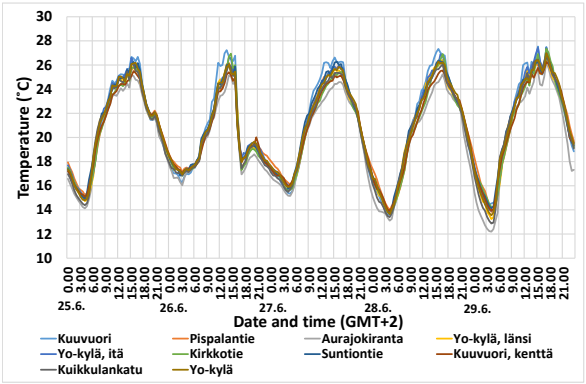

Figure 128. Turku Student Village temperatures during the heatwave period on the 25th–29th of June in 2021.

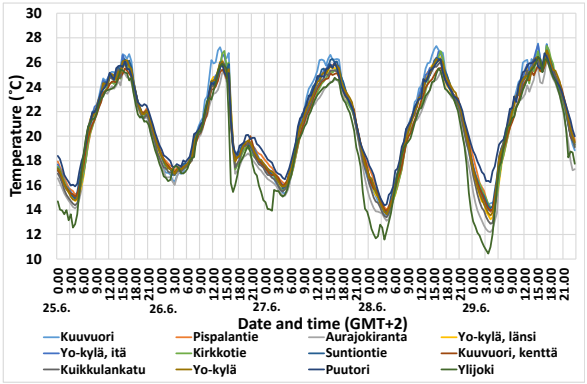

Figure 129. Turku Student Village, Puutori and Ylijoki temperatures during the heatwave period on the 25th–29th of June in 2021.

tures, both during cooler and warmer periods. Kuuvuori recorded slightly higher values compared to the other sites during peak temperature periods but also showed lower values during colder hours. However, these differences were not significant. Among Puutori and Ylijoki, the latter stood out clearly as the coldest site during nighttime, particularly during the cooler periods (Figure 129). In contrast to earlier months, Puutori did not consistently record higher temperatures except during the night of the 29th, when it recorded the highest temperature among all sites during a colder period.

5.1.7 July

The UHI intensities

In July 2021, peak UHI intensity values occurred sporadically throughout the month, with the final days exhibiting relatively stable conditions (Figures 130–133). These peak values generally ranged between 5 and 6 °C. Between the Betel–Niuskala and Kauppatori–Niuskala pairs, almost no negative values were recorded, whereas the Betel–Kurala and Kauppatori–Kurala pairs exhibited near-daily negative values, some exceeding –1 °C. UHI intensity maximums typically occurred during midnight and early morning hours, while UCIs were observed in the morning, indicating a consistent diurnal pattern.

In 2023, UHI intensities reached an average maximum of approximately 6 °C (Figures 134–137). Minor negative values, around –1 °C, were observed across all UHI site pairs. The early part of the month represented the most stable period in terms of both UHI intensity and variability between sites. A distinct maximum occurred on the night of July 13, with UHI values fluctuating slightly below or above 7 °C, depending on the site. Lower UHI values were recorded during the daytime, while the highest intensities consistently occurred at night or in the early morning.

Overall, July 2021 and 2023 exhibited similar UHI intensity patterns, with the primary distinction being the timing of stable periods: late July in 2021 and early July in 2023. A diurnal pattern, similar to that observed in June, was present in both years.

Monthly summaries

In June 2021, nitrogen monoxide concentrations remained relatively stable, with no pronounced peaks observed throughout

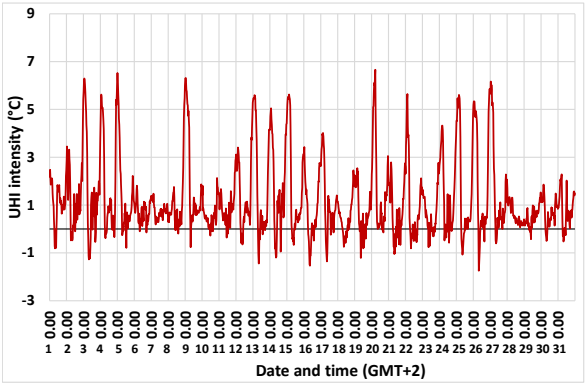

Figure 130. UHI intensity between Betel and Kurala during July 2021.

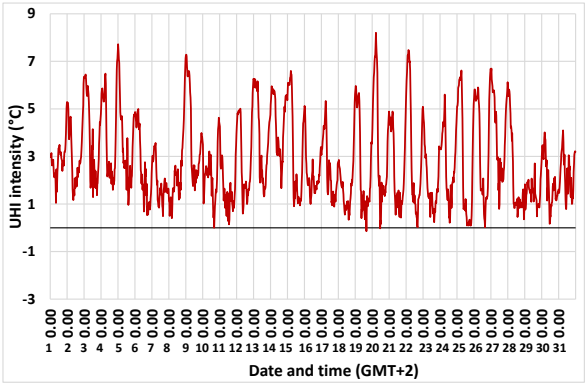

Figure 131. UHI intensity between Betel and Niuskala during July 2021.

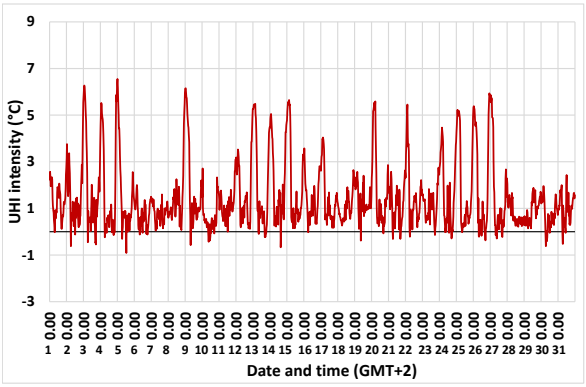

Figure 132. UHI intensity between Kauppatori and Kurala during July 2021.

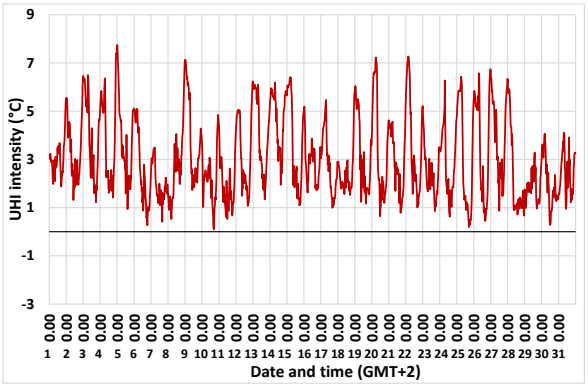

Figure 133. UHI intensity between Kauppatori and Niuskala during July 2021.

the day (Figure 138). Values remained below 5 µg/m³, with modest increases occurring in the morning around 07.00 and in the evening after 18.00. Similar morning peaks were also observed for nitrogen dioxide and respirable particles, although these were relatively low. Concentrations for both variables generally hovered around 10 µg/m³, with peak values reaching approximately 17 µg/m³ for nitrogen dioxide and 13 µg/m³ for respirable particles. The air quality index remained fairly stable, fluctuating between 1.0 and 1.2.

In June 2023, peaks in air quality variables were primarily observed in the early morning, between 05.00 and 07.00. Additionally, nitrogen dioxide concentrations exhibited nighttime peaks. During this month, the air quality index ranged from 1.00 to 1.03, nitrogen dioxide from 5.42 to 11.57 µg/m³, nitrogen monoxide from 0.47 to 3.56 µg/m³, respirable particles from 6.72 to 8.89 µg/m³, and fine particles from 3.58 to 4.14 µg/m³.

The UHI reached its maximum values during the nighttime and early morning hours, specifically between 22.00 and 04.30 (Figure 139). During this period, UHI intensities ranged between 2.4 and 3.0 °C. At other times of the day, values remained lower, between 0.4 and 0.8 °C, with a modest secondary peak observed in the afternoon around 14.00–15.00.

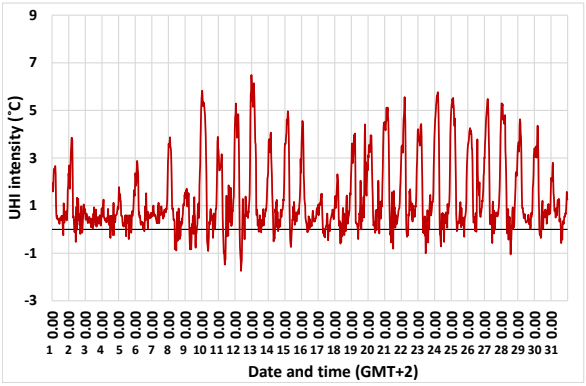

Figure 134. UHI intensity between Betel and Kurala during July 2023.

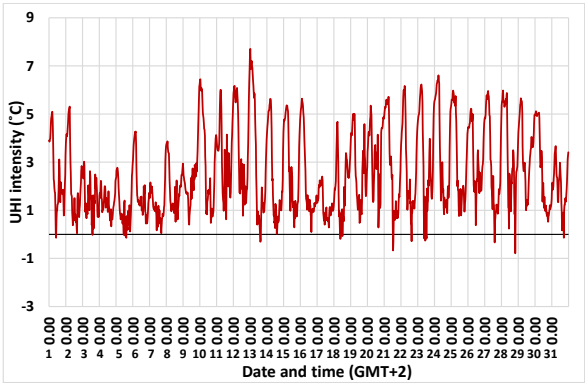

Figure 135. UHI intensity between Betel and Niuskala during July 2023.

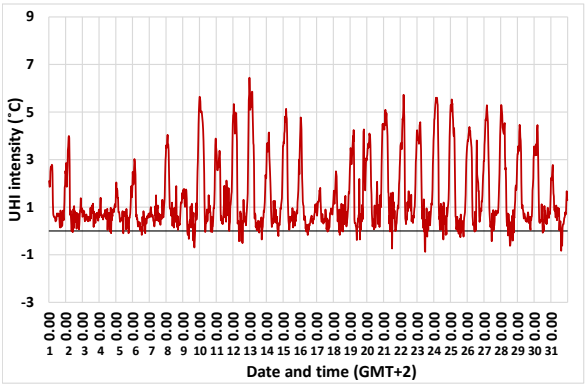

Figure 136. UHI intensity between Kauppatori and Kurala during July 2023.

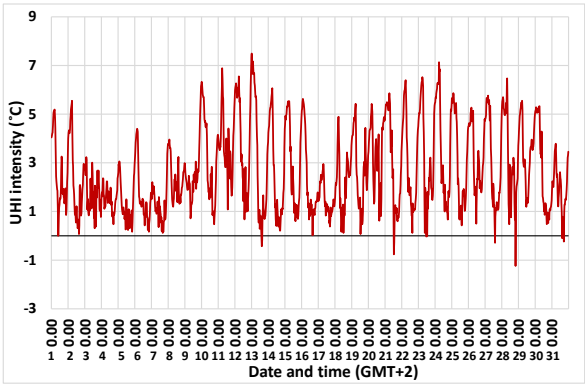

Figure 137. UHI intensity between Kauppatori and Niuskala during July 2023.

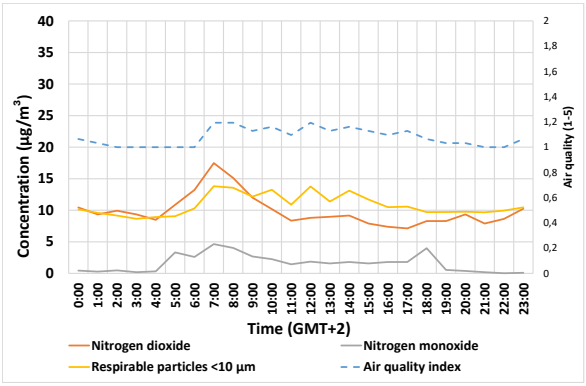

Figure 138. Hourly averages of air quality observations in July 2021.

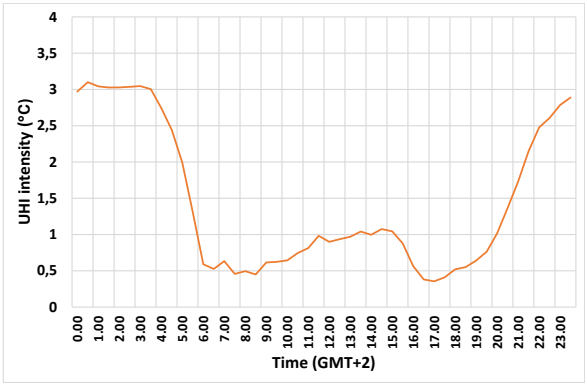

Figure 139. Hourly average UHI intensity between Kauppatori and Kurala in July 2021.

The correlations between the UHI and air quality

The UHI between Betel and Kurala in 2021 exhibited a positive Pearson correlation with nitrogen dioxide during the 07.00–08.00 observation period in 2021 (Table 75). This correlation was of moderate strength. The only other sta-

Table 75. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in July 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.227	0.218	-0.188	0.310	0.085	0.648	0.014	0.941
	Nitrogen dioxide	**0.449***	0.011	0.043	0.817	0.110	0.556	0.341	0.060
	Nitrogen monoxide	0.287	0.117	-0.278	0.129	-0.111	0.554	0.119	0.523
	Respirable particles	0.133	0.477	-0.102	0.586	0.194	0.296	0.061	0.742
	Fine particles								
Spearman	Air quality index	0.265	0.150	-0.188	0.312	0.054	0.774	0.012	0.948
	Nitrogen dioxide	0.303	0.098	-0.065	0.730	0.180	0.333	**0.459****	0.009
	Nitrogen monoxide	0.099	0.596	-0.270	0.143	-0.076	0.686	0.310	0.090
	Respirable particles	0.166	0.372	-0.054	0.771	0.097	0.605	-0.054	0.771
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 76. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in July 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index								
	Nitrogen dioxide	**0.731****	<0.001	0.318	0.082	-0.077	0.682	0.202	0.276
	Nitrogen monoxide	**0.563****	<0.001	0.128	0.491	0.035	0.851	-0.076	0.686
	Respirable particles	0.251	0.173	0.113	0.545	-0.080	0.668	0.267	0.146
	Fine particles	0.070	0.710	0.039	0.836	-0.102	0.587	0.136	0.467
Spearman	Air quality index								
	Nitrogen dioxide	**0.717****	<0.001	0.323	0.076	-0.046	0.804	0.083	0.657
	Nitrogen monoxide	**0.394***	0.028	0.123	0.511	0.067	0.721	-0.196	0.292
	Respirable particles	0.332	0.068	0.127	0.497	-0.055	0.769	0.143	0.442
	Fine particles	0.136	0.466	0.069	0.711	-0.024	0.896	0.036	0.849

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

tistically significant correlation observed was a positive Spearman correlation with nitrogen dioxide during the 16.00–17.00 period.

In 2023, statistically significant correlations occurred exclusively during the 07.00–08.00 period, involving nitrogen dioxide and nitrogen monoxide (Table 76). The correlation with nitrogen dioxide was strong, while the Pearson correlation with nitrogen monoxide was of moderate strength; the Spearman correlation with nitrogen monoxide was weaker. All correlations were positive.

For the Betel–Niuskala UHI in 2021, no statistically significant correlations were observed with air quality variables during the 07.00–08.00 time period (Table 77). In the following hour, a positive but relatively weak correlation was found with the air quality index. During the af-

Table 77. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in July 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.093	0.620	**0.382***	0.034	**0.359***	0.047	-0.105	0.574
	Nitrogen dioxide	0.267	0.146	0.283	0.123	0.206	0.265	**0.407***	0.023
	Nitrogen monoxide	0.292	0.111	0.166	0.373	-0.034	0.856	0.032	0.864
	Respirable particles	0.165	0.375	0.275	0.135	**0.364***	0.044	0.124	0.508
	Fine particles								
Spearman	Air quality index	0.119	0.525	**0.434***	0.015	0.301	0.100	-0.098	0.601
	Nitrogen dioxide	0.190	0.307	0.352	0.052	0.331	0.069	**0.447***	0.012
	Nitrogen monoxide	0.257	0.164	0.161	0.388	0.101	0.588	0.228	0.218
	Respirable particles	0.283	0.123	0.305	0.095	0.179	0.336	0.065	0.730
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 78. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in July 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index								
	Nitrogen dioxide	**0.707****	<0.001	**0.451***	0.011	-0.216	0.244	0.061	0.744
	Nitrogen monoxide	**0.380***	0.035	0.280	0.127	0.044	0.815	-0.075	0.687
	Respirable particles	0.256	0.164	**0.417***	0.019	-0.186	0.316	-0.064	0.734
	Fine particles	0.208	0.261	0.067	0.722	-0.110	0.554	-0.127	0.496
Spearman	Air quality index								
	Nitrogen dioxide	**0.767****	<0.001	**0.421***	0.018	-0.093	0.619	0.020	0.913
	Nitrogen monoxide	0.348	0.055	0.354	0.051	0.029	0.876	-0.040	0.831
	Respirable particles	0.259	0.160	0.339	0.062	-0.152	0.415	-0.083	0.656
	Fine particles	0.207	0.264	0.031	0.868	-0.101	0.589	-0.222	0.230

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

ternoon period of 15.00–16.00, both the air quality index and respirable particles exhibited weak positive Pearson correlations. In the final observation hour, nitrogen dioxide showed a moderate positive correlation with the UHI.

In 2023, the UHI displayed a strong positive correlation with nitrogen dioxide during the 07.00–08.00 period (Table 78). A weaker Pearson correlation was also observed with nitrogen monoxide. In the subsequent hour, a positive correlation was again found with nitrogen dioxide, along with a positive Pearson correlation with respirable particles. No statistically significant correlations were observed during the afternoon periods.

For the Kauppatori–Kurala UHI, only two statistically significant correlations were observed in 2021, both occurring during the first observation period (7.00–8.00) with nitrogen dioxide and ni-

Table 79. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in July 2021.

		07.00-08.00		08.00-09.00		15.00-16.00		16.00-17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.145	0.437	-0.217	0.242	-0.130	0.486	-0.243	0.188
	Nitrogen dioxide	**0.464****	0.009	0.047	0.800	-0.237	0.200	-0.193	0.297
	Nitrogen monoxide	**0.373***	0.039	-0.024	0.900	-0.068	0.716	-0.234	0.205
	Respirable particles	0.175	0.348	-0.177	0.341	0.053	0.775	-0.236	0.201
	Fine particles								
Spearman	Air quality index	0.091	0.625	-0.342	0.059	-0.129	0.489	-0.256	0.164
	Nitrogen dioxide	0.350	0.054	-0.182	0.326	-0.158	0.395	-0.253	0.170
	Nitrogen monoxide	0.297	0.105	-0.087	0.640	0.059	0.754	-0.145	0.436
	Respirable particles	0.265	0.150	-0.298	0.103	0.119	0.524	-0.098	0.600
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 80. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in July 2023.

		07.00-08.00		08.00-09.00		15.00-16.00		16.00-17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index								
	Nitrogen dioxide	**0.734****	<0.001	0.269	0.144	-0.243	0.189	0.142	0.446
	Nitrogen monoxide	**0.598****	<0.001	0.038	0.838	-0.090	0.631	-0.165	0.374
	Respirable particles	0.240	0.194	0.350	0.054	-0.090	0.630	0.217	0.240
	Fine particles	0.077	0.679	0.042	0.824	-0.075	0.687	0.040	0.831
Spearman	Air quality index								
	Nitrogen dioxide	**0.802****	<0.001	0.196	0.291	-0.208	0.263	0.067	0.720
	Nitrogen monoxide	**0458****	0.010	0.037	0.845	-0.119	0.523	-0.177	0.341
	Respirable particles	0.336	0.065	0.280	0.128	-0.010	0.958	0.176	0.344
	Fine particles	0.184	0.322	0.111	0.554	0.014	0.942	0.065	0.727

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

trogen monoxide (Table 79). These Pearson correlations ranged from weak to moderate in strength and did not appear in the Spearman analysis.

In 2023, the same two air quality variables correlated with the UHI during the same time period, but the correlation coefficients were stronger than those in 2021 (Table 80). Additionally, both nitrogen dioxide and nitrogen monoxide also exhibited statistically significant Spearman correlations. In both years, the correlation with nitrogen dioxide was stronger than with nitrogen monoxide.

For the Kauppatori–Niuskala UHI in 2021, only one statistically significant correlation was identified, occurring during the 08.00–09.00

Table 81. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in July 2021.

		07.00-08.00		08.00-09.00		15.00-16.00		16.00-17.00	
	Kauppatori & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.050	0.788	**0.359***	0.047	0.268	0.145	-0.294	0.108
	Nitrogen dioxide	0.240	0.193	0.239	0.196	0.024	0.899	0.171	0.357
	Nitrogen monoxide	0.298	0.104	0.260	0.158	-0.009	0.963	-0.184	0.323
	Respirable particles	0.168	0.366	0.238	0.198	0.312	0.088	-0.034	0.855
	Fine particles								
Spearman	Air quality index	0.027	0.884	**0.405***	0.024	0.247	0.180	-0.207	0.263
	Nitrogen dioxide	0.135	0.468	0.229	0.215	0.111	0.552	0.152	0.414
	Nitrogen monoxide	0.266	0.147	0.212	0.253	0.133	0.475	0.024	0.897
	Respirable particles	0.284	0.121	0.277	0.131	0.218	0.239	0.078	0.675
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 82. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in July 2023.

		07.00-08.00		08.00-09.00		15.00-16.00		16.00-17.00	
	Kauppatori & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index								
	Nitrogen dioxide	**0.662****	<0.001	0.347	0.056	-0.288	0.117	0.028	0.882
	Nitrogen monoxide	**0.367***	0.042	0.207	0.263	-0.023	0.903	-0.118	0.528
	Respirable particles	0.235	0.204	**0.413***	0.021	-0.180	0.334	-0.087	0.642
	Fine particles	0.203	0.274	0.055	0.769	-0.092	0.632	-0.171	0.358
Spearman	Air quality index								
	Nitrogen dioxide	**0.714****	<0.001	**0.357***	0.049	-0.166	0.372	-0.007	0.972
	Nitrogen monoxide	0.315	0.085	0.303	0.097	-0.049	0.792	-0.076	0.685
	Respirable particles	0.232	0.209	**0.380***	0.035	-0.116	0.534	-0.070	0.709
	Fine particles	0.205	0.268	0.065	0.730	-0.064	0.732	-0.222	0.230

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

observation period with the air quality index (Table 81). This correlation was positive but relatively weak. No other statistically significant correlations were found.

In 2023, none of the air quality variables exhibited statistically significant correlations with the UHI during the afternoon hours (Table 82). However, during the 07.00–08.00 period, nitrogen dioxide showed a strong positive correlation in both Pearson and Spearman analyses, while nitrogen monoxide correlated weakly and only in the Pearson analysis. During the 08.00–09.00 period, respirable particles displayed a positive correlation in both Pearson

Table 83. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in July 2021. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index	0.142	0.448
	Nitrogen dioxide	0.328	0.071
	Nitrogen monoxide	**0.382***	0.034
	Respirable particles	0.129	0.490
	Fine particles		
Spearman	Air quality index	0.164	0.377
	Nitrogen dioxide	0.271	0.141
	Nitrogen monoxide	0.269	0.143
	Respirable particles	0.185	0.320
	Fine particles		

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 84. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in July 2023. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index		
	Nitrogen dioxide	**0.425***	0.017
	Nitrogen monoxide	**0.485****	0.006
	Respirable particles	**0.483****	0.006
	Fine particles	0.292	0.111
Spearman	Air quality index		
	Nitrogen dioxide	**0.392***	0.029
	Nitrogen monoxide	**0.468****	0.008
	Respirable particles	**0.495****	0.005
	Fine particles	0.241	0.192

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

and Spearman analyses. Additionally, nitrogen dioxide had a weak positive Spearman correlation during this time.

The correlation between the 05.00 UHI and the 08.00 air quality

In July 2021, only nitrogen monoxide exhibited a statistically significant Pearson correlation with the 05.00 UHI (Table 83). This correlation was positive but relatively weak.

In contrast, in 2023, statistically significant Pearson correlations were observed for nitrogen dioxide, nitrogen monoxide, and respirable particles (Table 84). All correlations were positive and generally of medium strength, with nitrogen monoxide showing the strongest association and nitrogen dioxide the weakest. The same variables also showed statistically significant Spearman correlations; however, the strength of the correlation decreased for nitrogen dioxide and nitrogen monoxide, while it increased for respirable particles. Correlations with the air quality index could not be calculated.

Overall, more air quality variables correlated with the UHI in 2023 than in 2021, and the correlation coefficients were slightly stronger.

The correlation between the UHI, average wind speed and cloudiness

In July, daytime extended from approximately 03.30 in the morning until 21.30 in the evening. During this period, a quite strong negative correlation was observed between the UHI intensity and average wind speed (Table 85). A weaker negative correlation also emerged with cloudiness. At night, statistically significant correlations appeared for both variables with wind speed having stronger coefficients than cloudiness. All of these correlations were negative.

Daytime wind speeds typically ranged between 2 and 4 m/s, while UHI intensities remained around 1 °C (Figure 140). Cloudiness values during the day were generally low, mostly falling between 0 and 4, with occasional higher values exceeding 4 (Figure 141). At night,

Table 85. Pearson and Spearman correlation coefficients between the wind speed and UHI and between the cloudiness and UHI during daytime and nighttime in July 2021. Four different UHI intensities are calculated based on the Betel, Kurala, Kauppatori and Niuskala observation sites.

			Betel & Kurala Average UHI	Betel & Niuskala Average UHI	Kauppatori & Kurala Average UHI	Kauppatori & Niuskala Average UHI
Day	Pearson	Average wind speed	**-0.643****	**-0.708****	**-0.481****	**-0.676****
		Average cloudiness	-0.137	-0.333	**-0.387***	**-0.457****
	Spearman	Average wind speed	**-0.659****	**-0.680****	**-0.551****	**-0.628****
		Average cloudiness	-0.216	-0.337	-0.332	**-0.418***
Night	Pearson	Average wind speed	**-0.847****	**-0.672****	**-0.843****	0.242
		Average cloudiness	**-0.628****	**-0.466****	**-0.614****	-0.070
	Spearman	Average wind speed	**-0.837****	**-0.606****	**-0.822****	0.211
		Average cloudiness	**-0.707****	**-0.488****	**-0.695****	-0.106

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

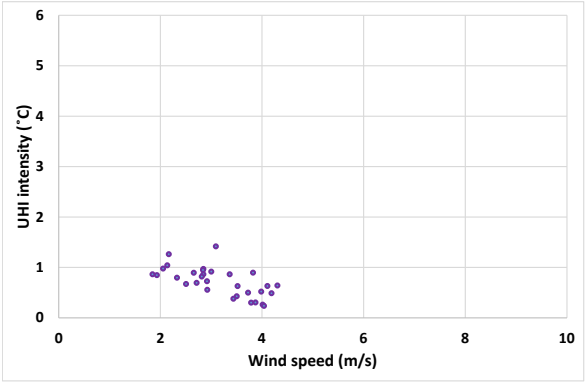

Figure 140. Scatter plot for wind speed and UHI between Betel and Kurala during daytime in July 2021.

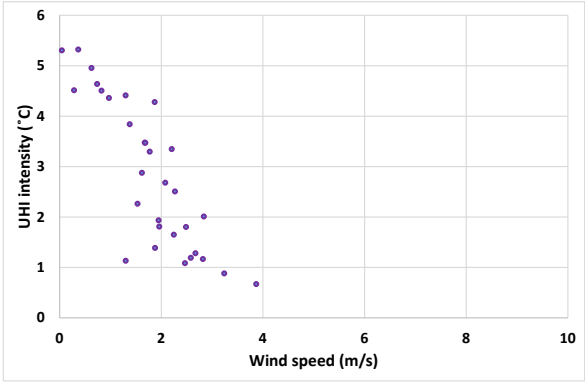

Figure 141. Scatter plot for cloudiness and UHI between Betel and Kurala during daytime in July 2021.

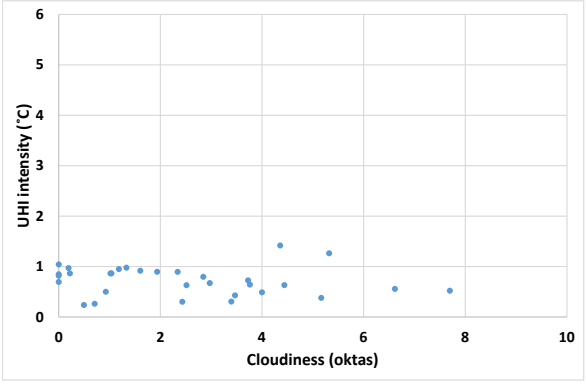

Figure 142. Scatter plot for wind speed and UHI between Betel and Kurala during nighttime in July 2021.

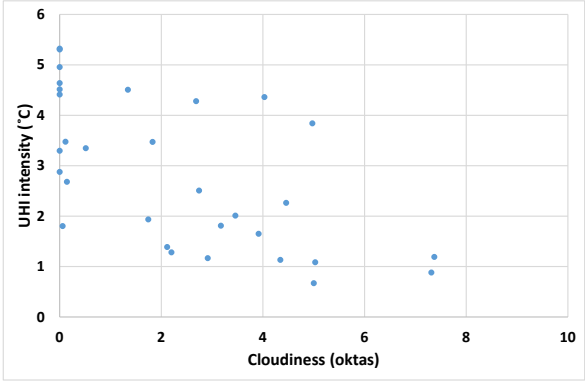

Figure 143. Scatter plot for cloudiness and UHI between Betel and Kurala during nighttime in July 2021.

Table 86. Pearson and Spearman correlations between NAO index and different UHI logger pairs in July 2021.

	UHI	NAO index	Significance level
Pearson	Betel & Kurala	0.209	0.259
	Betel & Niuskala	0.069	0.712
	Kauppatori & Kurala	0.230	0.212
	Kauppatori & Niuskala	0.084	0.651
	Betel & Ryhmäpuutarha	0.253	0.170
	Kauppatori & Ryhmäpuutarha	0.278	0.130
Spearman	Betel & Kurala	0.174	0.350
	Betel & Niuskala	0.034	0.856
	Kauppatori & Kurala	0.152	0.416
	Kauppatori & Niuskala	0.020	0.196
	Betel & Ryhmäpuutarha	0.228	0.217
	Kauppatori & Ryhmäpuutarha	0.237	0.199

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

a visible negative correlation was observed between UHI intensity and wind speed (Figure 142). Higher UHI values corresponded with lower wind speeds, which generally remained below 4 m/s, while UHI intensities ranged from 0 °C to 5 °C. Cloudiness during nighttime appeared randomly distributed without any discernible correlation to UHI intensity (Figure 143).

The correlation between NAO index and UHI

In July 2021 there were no statistically significant correlations between the NAO index and the observed logger pairs (Table 86).

Heatwave period review

In July 2021, three distinct heatwave periods were observed: July 1st–10th, 12th–17th, and 25th–27th. During the first heatwave period (July 1st–10th), UHI intensity peaks were consistently recorded around midnight (Figures 144–147), with some values exceeding 7 °C. A relatively more stable period occurred between July 6th and 8th, during which UHI intensity peaks remained around 2 °C. Minor UHI peaks were also observed during midday, with maximum values reaching approximately 4 °C. Cold island events were recorded between the Betel–Kurala and Kauppatori–Kurala site pairs in the morning hours, reaching intensities of approximately –1 °C. However, no cold islands were observed for the Betel–Niuskala and Kauppatori–Niuskala logger pairs.

The warmest day during this heatwave period was clearly July 10th, with maximum temperatures exceeding 30 °C (Figure 148). On the remaining days, peak temperatures typically ranged between 26 and 29 °C. The Student Village loggers recorded relatively consistent temperature values, although Aurajokiranta stood out as the coldest site on several occasions. On July 8th, during the daytime temperature maximum, Kuuvuori was clearly the warmest location. When examining the additional logger sites of Puutori and Ylijoki, Puutori did not consistently appear as the warmest site. In contrast, Ylijoki was notably the coldest, particularly during nighttime hours (Figure 149).

During the heatwave period from July 12th to 17th, 2021, UHI intensity peaks were again

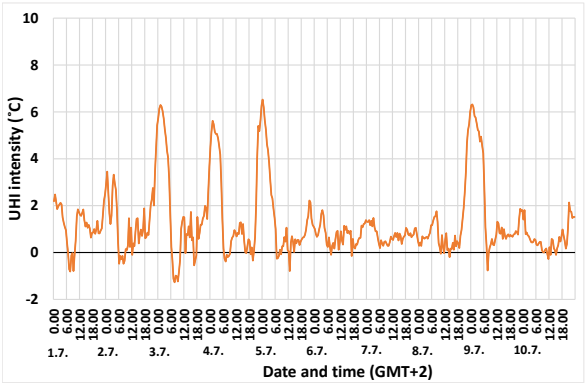

Figure 144. UHI intensity between Betel and Kurala during the heatwave period on the 1st-10th of July in 2021.

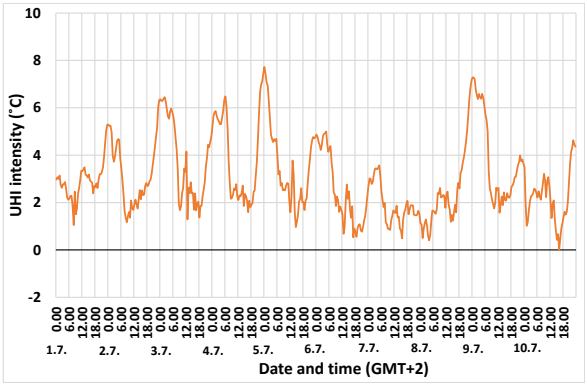

Figure 145. UHI intensity between Betel and Niuskala during the heatwave period on the 1st-10th of July in 2021.

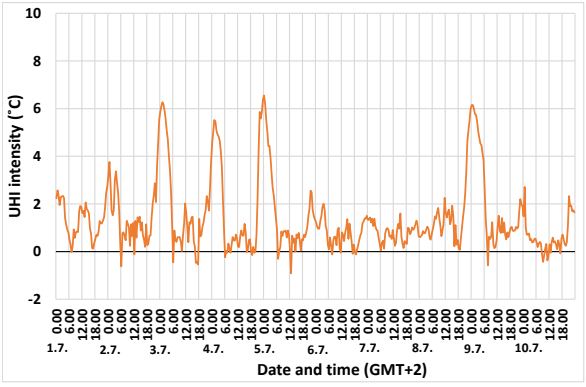

Figure 146. UHI intensity between Kauppatori and Kurala during the heatwave period on the 1st-10th of July in 2021.

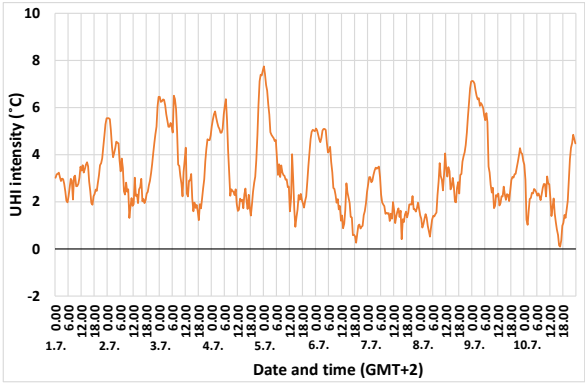

Figure 147. UHI intensity between Kauppatori and Niuskala during the heatwave period on the 1st-10th of July in 2021.

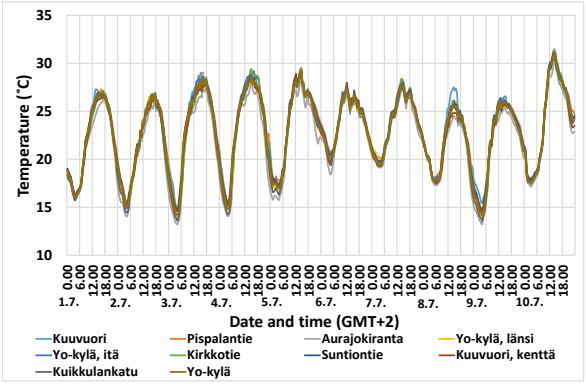

Figure 148. Turku Student Village temperatures during the heatwave period on the 1st-10th of July in 2021.

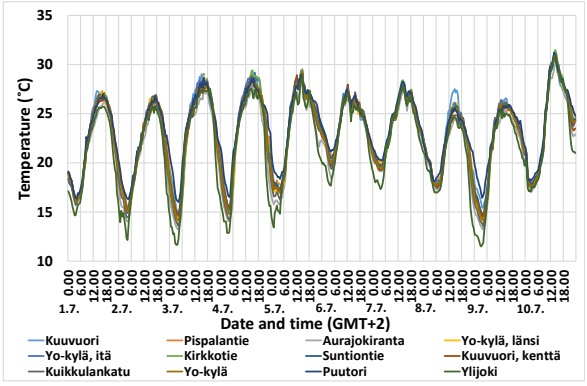

Figure 149. Turku Student Village, Puutori and Ylijoki temperatures during the heatwave period on the 1st-10th of July in 2021.

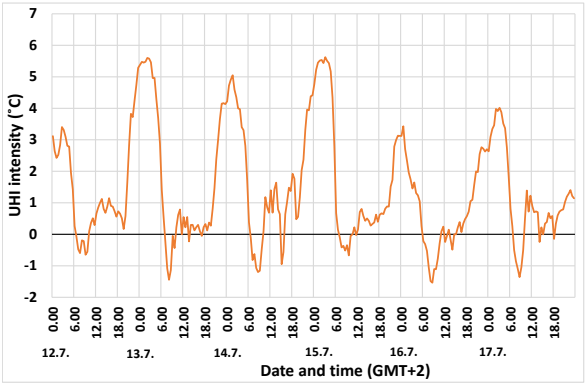

Figure 150. UHI intensity between Betel and Kurala during the heatwave period on the 12th-17th of July in 2021.

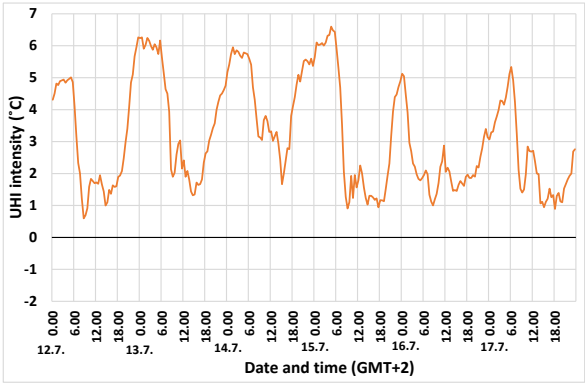

Figure 151. UHI intensity between Betel and Niuskala during the heatwave period on the 12th-17th of July in 2021.

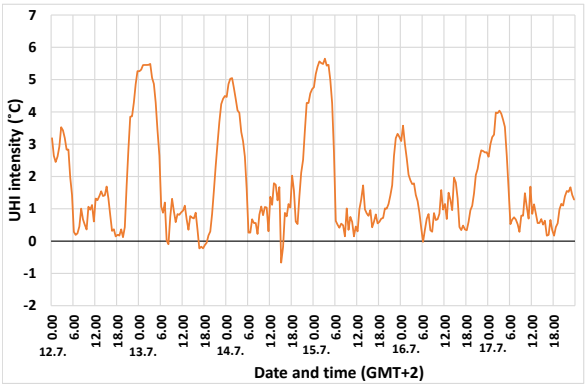

Figure 152. UHI intensity between Kauppatori and Kurala during the heatwave period on the 12th-17th of July in 2021.

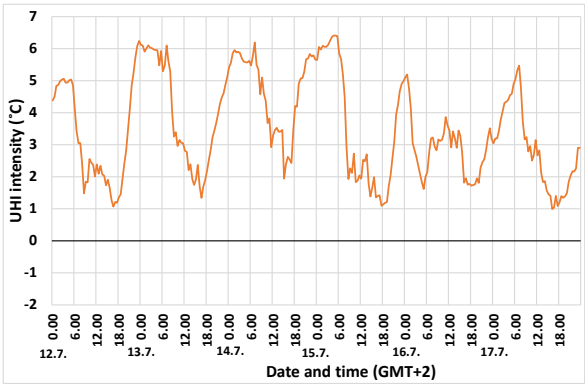

Figure 153. UHI intensity between Kauppatori and Niuskala during the heatwave period on the 12th-17th of July in 2021.

consistently observed around midnight, with values ranging between 5 and 6 °C depending on the logger pair (Figures 150–153). Unlike the previous heatwave period, minor midday peaks were largely absent. However, cold island occurrences were recorded each morning, typically exceeding –1 °C in intensity. These cold islands were observed only between the Betel–Kurala and Kauppatori–Kurala logger pairs; no such events were detected between Betel–Niuskala and Kauppatori–Niuskala.

The highest temperatures recorded by the Student Village loggers during this period occurred on July 14th, with values surpassing 32 °C (Figure 154). Nighttime temperatures were generally elevated throughout the heatwave, with the exception of July 17th, when they dropped below 15 °C. Among the Student Village sites, Aurajokiranta and Kuuvuori occasionally stood out, with Aurajokiranta recording the lowest and Kuuvuori the highest temperatures. The Puutori logger showed similar temperature patterns to those of the Student Village sites, whereas Ylijoki consistently recorded the lowest temperatures, particularly during the night (Figure 155).

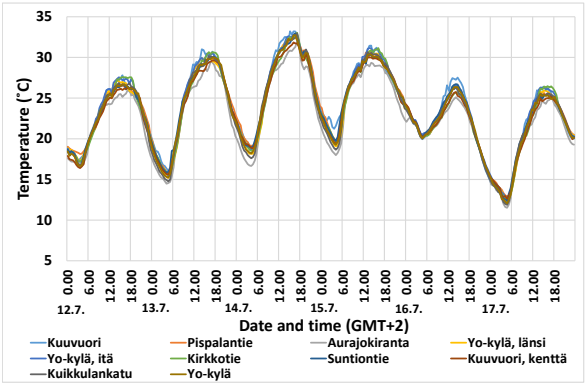

Figure 154. Turku Student Village temperatures during the heatwave period on the 12th-17th of July in 2021.

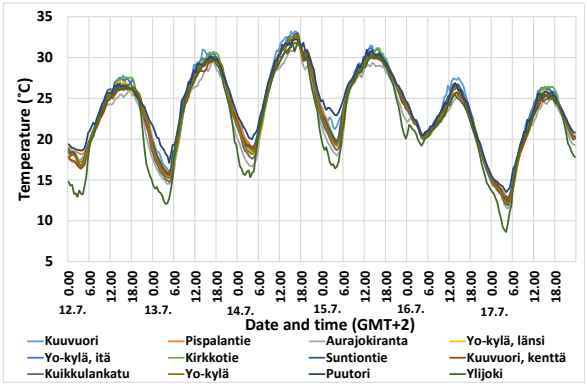

Figure 155. Turku Student Village, Puutori and Ylijoki temperatures during the heatwave period on the 12th-17th of July in 2021.

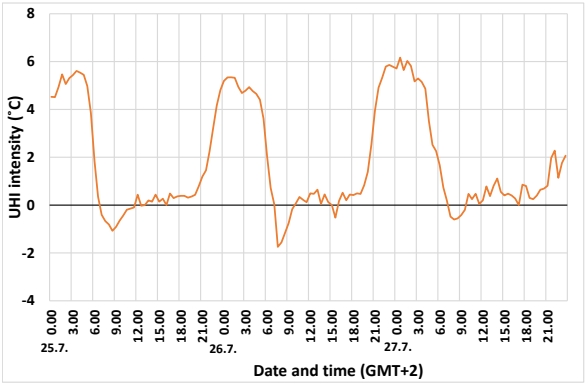

Figure 156. UHI intensity between Betel and Kurala during the heatwave period on the 25th-27th of July in 2021.

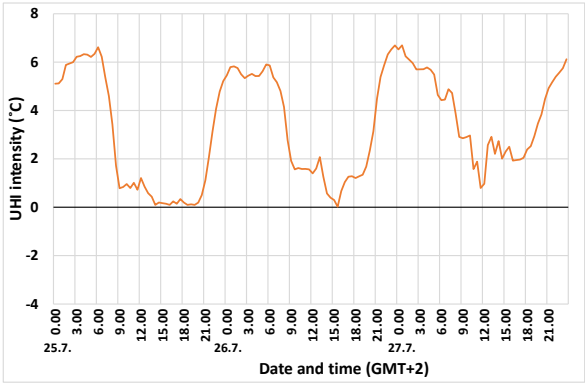

Figure 157. UHI intensity between Betel and Niuskala during the heatwave period on the 25th-27th of July in 2021.

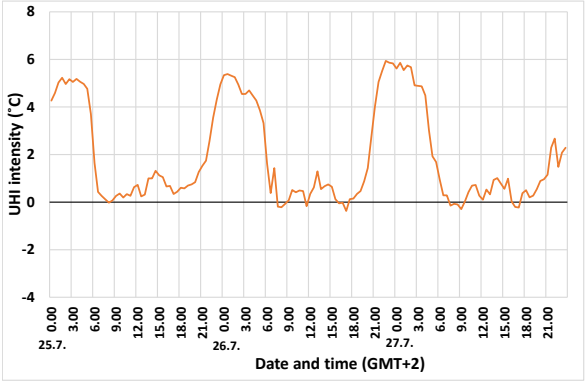

Figure 158. UHI intensity between Kauppatori and Kurala during the heatwave period on the 25th-27th of July in 2021.

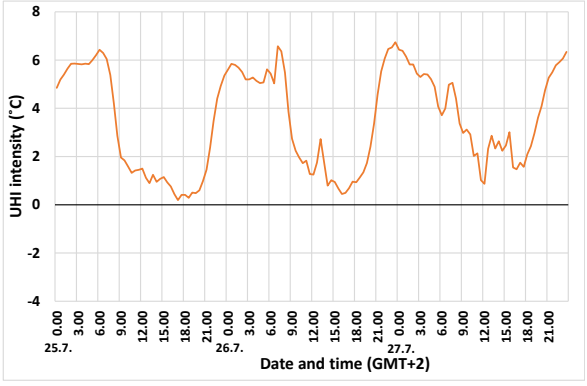

Figure 159. UHI intensity between Kauppatori and Niuskala during the heatwave period on the 25th-27th of July in 2021.

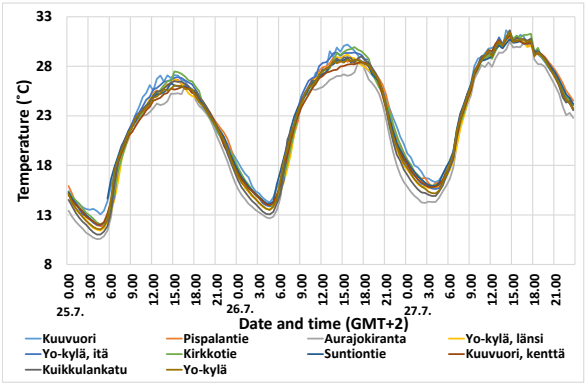

Figure 160. Turku Student Village temperatures during the heatwave period on the 25th-27th of July in 2021.

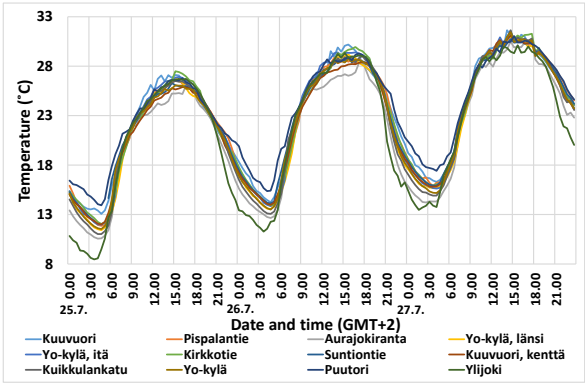

Figure 161. Turku Student Village, Puutori and Ylijoki temperatures during the heatwave period on the 25th-27th of July in 2021.

During the final heatwave period from July 25th to 27th, 2021, UHI intensity peaks were consistently observed each night around midnight, reaching up to 6 °C depending on the logger pair (Figures 156–159). Following these nocturnal peaks, a cold island typically formed in the morning hours most notably between the Betel–Kurala pair where the intensity reached nearly –2 °C. For the other logger pairs, cold island intensities were minimal or not observed. At other times of the day, UHI intensity generally ranged between 0 and 2 °C.

During this same period, the highest temperatures recorded in the Student Village occurred on July 27th, reaching approximately 30 °C (Figure 160). Temperature differences between the loggers were relatively small. Aurajokiranta was slightly colder during nighttime or cooler periods, while Kuuvuori and Kirkkotie occasionally stood out as the warmest sites. Puutori appeared to record higher temperatures during colder periods but aligned closely with the other loggers during the rest of the day. As in previous heatwave periods, Ylijoki remained clearly distinguishable as the coldest site during nighttime and other cool intervals (Figure 161).

5.1.8 August

The UHI intensities

In August 2021, distinct UHI intensity peaks were observed around the 4th–7th, 12th–13th, and during the final days of the month (Figures 162–165). These maximum values, typically occurring at night or in the early morning hours, reached approximately 5–6 °C. At other times, UHI intensity remained mostly below 4 °C. Minor negative values also appeared, generally around –1 °C or lower with a few exceptions, mostly occurring in the morning.

Compared to preceding months, August exhibited lower overall UHI intensities, with maximum values reaching only around 4–5 °C (Figures 166–169). Additionally, UHI intensity in August showed the most stable profile throughout the summer. Negative UHI values were recorded at several sites, with the most notable reaching approximately –1.5 °C between Betel and Niuskala. The most prominent UHI peaks occurred on the 13th and 24th, both during nighttime, while the most significant negative intensities appeared in the afternoon. The weakest UHI intensities were recorded be-

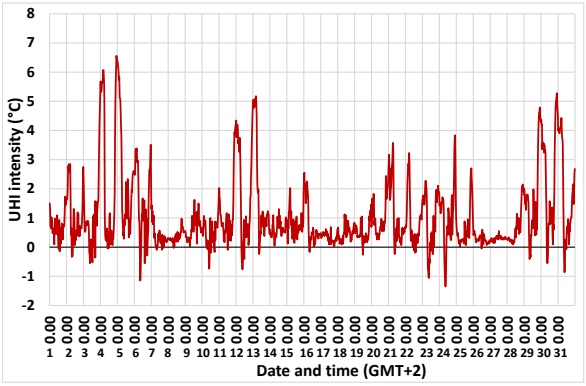

Figure 162. UHI intensity between Betel and Kurala during August 2021.

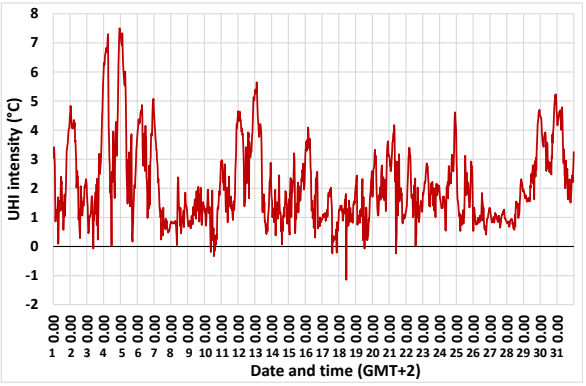

Figure 163. UHI intensity between Betel and Niuskala during August 2021.

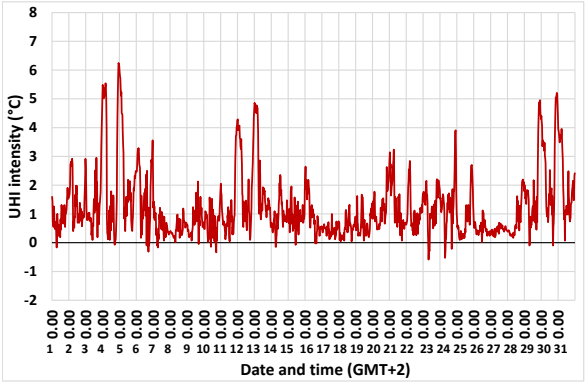

Figure 164. UHI intensity between Kauppatori and Kurala during August 2021.

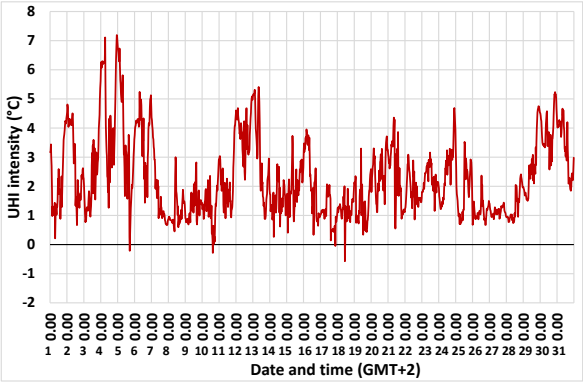

Figure 165. UHI intensity between Kauppatori and Niuskala during August 2021.

tween the Betel–Kurala and Kauppatori–Kurala logger pairs.

In 2023, maximum UHI values were slightly lower than in 2021, while the magnitude of negative values was slightly greater. Notably, in contrast to 2021, when cold islands typically appeared in the morning, several cold island events in 2023 occurred during the afternoon.

Monthly summaries

In August 2021, air quality variable values remained relatively low overall (Figure 170). A more pronounced peak occurred between 06.00–09.00 in the morning, with a smaller one appearing after 18.00. Nitrogen monoxide concentrations were close to 0 µg/m³ during the night and peaked at approximately 11 µg/m³ during the morning. Nitrogen dioxide and respirable particles generally stayed below 10 µg/m³, but during the morning peak, they reached around 18 µg/m³ and 10 µg/m³, respectively. The air quality index remained low throughout the day, typically staying between 1.0 and 1.1.

In 2023, the highest air quality values were again recorded in the morning, around 06.00–09.00. The air quality index ranged from 1.03 to 1.13, nitrogen dioxide from 4.23 to 13.02 µg/m³, nitrogen monoxide from 0.58 to 5.43 µg/m³, respirable particles from 7.66 to 11.82 µg/m³, and fine particles from 4.22 to 5.20 µg/m³.

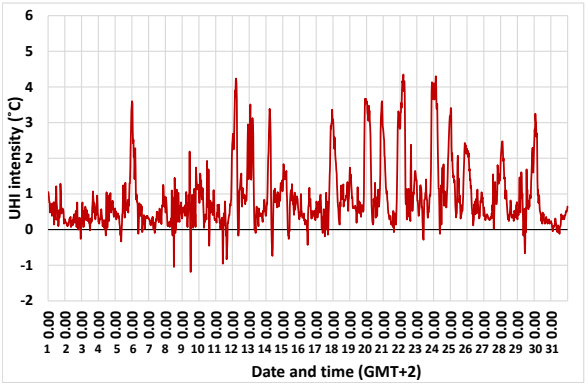

Figure 166. UHI intensity between Betel and Kurala during August 2023.

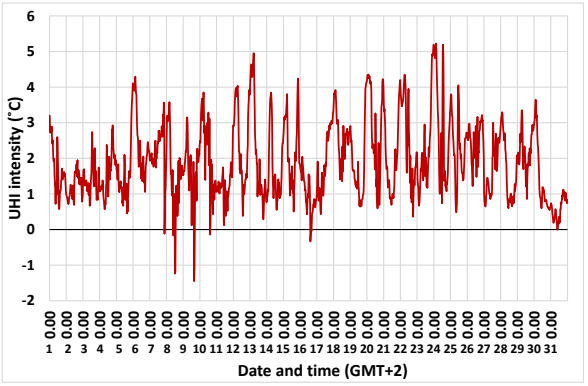

Figure 167. UHI intensity between Betel and Niuskala during August 2023.

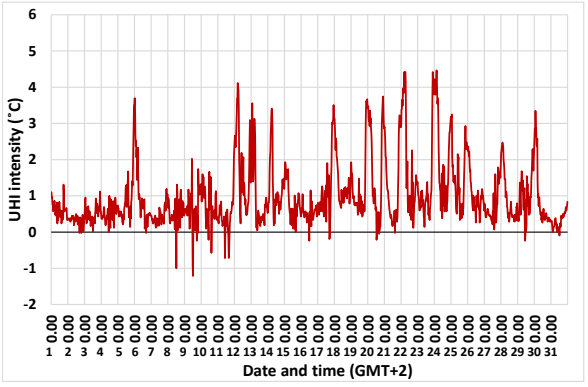

Figure 168. UHI intensity between Kauppatori and Kurala during August 2023.

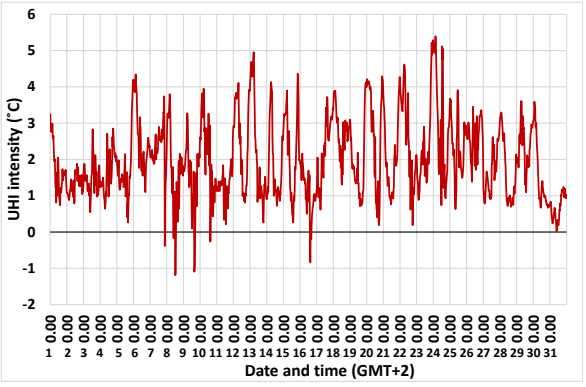

Figure 169. UHI intensity between Kauppatori and Niuskala during August 2023.

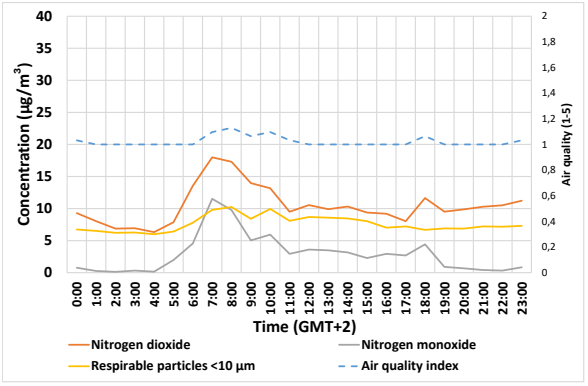

Figure 170. Hourly averages of air quality observations in August 2021.

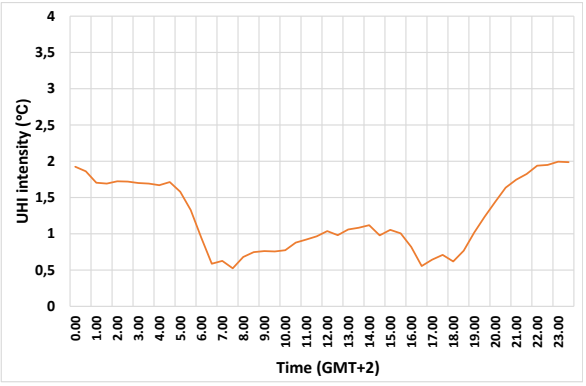

Figure 171. Hourly average UHI intensity between Kauppatori and Kurala in August 2021.

The UHI in August reached its maximum values at night, with intensities ranging between 1.7 and 1.9 °C (Figure 171). During the rest of the day, UHI intensity averaged around 0.5–0.7 °C, with the lowest values occurring at 07.00 and again between 17.00–18.00.

The correlations between the UHI and air quality

At 07.00–08.00 in 2021, the UHI intensity between Betel and Kurala exhibited statistically significant correlations with all observed air quality variables (Table 87). These correlations were strong according to Pearson analysis and of medium strength in the Spearman analysis. Among the variables, respirable particles showed the strongest Pearson correlation, while nitrogen dioxide had the strongest Spearman correlation. During the subsequent hour (08.00–09.00), only the air quality index maintained a statistically significant correlation with UHI, presenting a medium-strength Pearson correlation and a weaker Spearman correlation. No statistically significant correlations were observed during the afternoon hours.

In 2023, the UHI intensity at 07.00–08.00 showed a moderate positive correlation with nitrogen dioxide (Table 88). Additionally, a weaker positive Spearman correlation was observed with nitrogen monoxide. During the 08.00–09.00 period, both nitrogen dioxide and nitrogen monoxide had statistically significant positive correlations in both Pearson and Spearman analyses, with coefficients being stronger in Pearson. Of the two, nitrogen monoxide exhibited the stronger correlation. Similar to 2021, no statistically significant correlations were identified during the afternoon.

For the Betel–Niuskala pair, the UHI intensity at 07.00–08.00 in 2021 showed statistically significant correlations with all air quality variables except fine particles (Table 89). Nitrogen dioxide exhibited the strongest correlation, while the air quality index showed the weakest and did not correlate at all in the Spearman analysis. During the 08.00–09.00 period, all variables again showed statistically significant correlations. Nitrogen dioxide had the strongest Pearson correlation, and nitrogen monoxide the weakest, whereas in the Spearman analysis, the air quality index had the strongest correlation and nitrogen monoxide the weakest. No statistically significant correlations were observed during the afternoon hours.

Table 87. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in August 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.602****	<0.001	**0.535****	0.002				
	Nitrogen dioxide	**0.682****	<0.001	0.219	0.236	0.222	0.229	0.046	0.807
	Nitrogen monoxide	**0.692****	<0.001	0.279	0.128	0.026	0.890	-0.119	0.525
	Respirable particles	**0.728****	<0.001	0.339	0.062	0.044	0.816	0.197	0.289
	Fine particles								
Spearman	Air quality index	**0.464****	0.009	**0.387***	0.031				
	Nitrogen dioxide	**0.559****	0.001	0.078	0.677	0.115	0.539	0.009	0.964
	Nitrogen monoxide	**0.489****	0.005	0.065	0.728	0.081	0.663	0.101	0.588
	Respirable particles	**0.430***	0.016	0.084	0.653	0.162	0.384	0.216	0.243
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 88. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in August 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	-0.252	0.171	0.065	0.728	-0.154	0.409	-0.031	0.869
	Nitrogen dioxide	**0.558****	0.001	**0.498****	0.004	-0.252	0.171	-0.005	0.980
	Nitrogen monoxide	0.308	0.092	**0.513****	0.003	0.064	0.731	-0.142	0.445
	Respirable particles	-0.104	0.577	0.259	0.160	0.029	0.875	0.063	0.738
	Fine particles	-0.135	0.468	0.111	0.553	0.000	0.998	0.069	0.713
Spearman	Air quality index	-0.396*	0.027	-0.033	0.860	-0.163	0.380	-0.061	0.743
	Nitrogen dioxide	**0.564****	<0.001	**0.372***	0.040	-0.217	0.241	-0.051	0.784
	Nitrogen monoxide	**0.375***	0.038	**0.385***	0.032	0.131	0.483	-0.072	0.699
	Respirable particles	-0.004	0.984	0.252	0.172	0.282	0.125	0.198	0.284
	Fine particles	-0.126	0.501	0.217	0.241	0.200	0.281	0.160	0.390

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 89. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in August 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.374***	0.038	**0.527****	0.002				
	Nitrogen dioxide	**0.665****	<0.001	**0.558****	0.001	0.136	0.464	-0.081	0.666
	Nitrogen monoxide	**0.466****	0.008	**0.366***	0.043	0.085	0.650	0.077	0.680
	Respirable particles	**0.517****	0.003	**0.548****	0.001	-0.223	0.228	-0.138	0.458
	Fine particles								
Spearman	Air quality index	0.342	0.060	**0.463****	0.009				
	Nitrogen dioxide	**0.573****	<0.001	**0.440***	0.013	0.105	0.574	-0.066	0.725
	Nitrogen monoxide	**0.448***	0.012	**0.401***	0.025	0.235	0.204	0.136	0.466
	Respirable particles	**0.475****	0.007	**0.438***	0.014	-0.231	0.212	-0.244	0.185
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

In 2023, during the 07.00–08.00 observation period, the UHI intensity correlated only with nitrogen dioxide (Table 90), showing a positive and medium-strength correlation. At 08.00–09.00, none of the air quality variables exhibited statistically significant correlations. During the 15.00–16.00 period, respirable particles showed a weak positive correlation with the UHI, followed by a single weak positive Pearson correlation in the 16.00–17.00 period.

For the Kauppatori–Kurala logger pair, the UHI intensity in 2021 correlated with all air quality variables except fine particles during the 07.00–08.00 time frame (Table 91). All Pearson correlation coefficients were strong, whereas the corresponding Spearman coefficients were notably weaker.

Table 90. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in August 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	-0.080	0.669	-0.023	0.901	0.321	0.078	**0.358***	0.048
	Nitrogen dioxide	**0.444***	0.012	0.139	0.455	0.003	0.985	-0.082	0.660
	Nitrogen monoxide	0.242	0.189	0.077	0.681	0.053	0.776	0.013	0.946
	Respirable particles	-0.060	0.748	-0.009	0.960	**0.371***	0.040	0.347	0.056
	Fine particles	-0.109	0.558	0.040	0.831	0.278	0.130	0.264	0.152
Spearman	Air quality index	-0.015	0.938	0.037	0.844	0.265	0.149	0.286	0.119
	Nitrogen dioxide	**0.421***	0.019	0.097	0.604	0.088	0.637	-0.074	0.694
	Nitrogen monoxide	0.275	0.134	0.045	0.812	0.083	0.656	-0.004	0.981
	Respirable particles	0.075	0.687	0.073	0.698	**0.369***	0.047	0.248	0.178
	Fine particles	-0.044	0.814	-0.005	0.980	0.230	0.213	0.151	0.417

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 91. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calcullated based on the Kauppatori and Kurala observation sites in August 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.622****	<0.001	**0.673****	<0.001				
	Nitrogen dioxide	**0.718****	<0.001	**0.400***	0.026	-0.089	0.632	-0.141	0.450
	Nitrogen monoxide	**0.670****	<0.001	0.342	0.060	-0.049	0.795	-0.112	0.548
	Respirable particles	**0.721****	<0.001	**0.544****	0.002	0.054	0.773	0.180	0.333
	Fine particles								
Spearman	Air quality index	**0.476****	0.007	**0.549****	0.001				
	Nitrogen dioxide	**0.616****	<0.001	0.263	0.152	-0.035	0.851	-0.094	0.615
	Nitrogen monoxide	**0.570****	<0.001	0.317	0.082	0.065	0.729	0.141	0.449
	Respirable particles	**0.492****	0.005	0.276	0.133	0.084	0.653	0.225	0.223
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

During the 08.00–09.00 period, a relatively strong correlation was observed with the air quality index, alongside medium-strength Pearson correlations with nitrogen dioxide and respirable particles. No statistically significant correlations were found during the afternoon hours.

In 2023, at 07.00–08.00, nitrogen monoxide showed a Pearson correlation of medium strength with the UHI (Table 92), while the air quality index exhibited a weak negative Spearman correlation. At 08.00–09.00, nitrogen dioxide and nitrogen monoxide both showed moderate to weak positive Pearson correlations with the UHI, but no corresponding Spearman correlations. No statistically significant correlations were observed during the afternoon periods.

Table 92. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in August 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	-0.234	0.205	-0.033	0.859	-0.167	0.370	-0.099	0.597
	Nitrogen dioxide	**0.514****	0.003	**0.405***	0.024	-0.212	0.253	0.155	0.406
	Nitrogen monoxide	0.276	0.132	**0.368***	0.042	0.090	0.631	0.094	0.614
	Respirable particles	-0.061	0.746	0.138	0.458	-0.056	0.764	-0.016	0.931
	Fine particles	-0.075	0.687	0.016	0.934	-0.117	0.530	-0.032	0.866
Spearman	Air quality index	**-0.367***	0.042	-0.080	0.667	-0.225	0.225	-0.163	0.380
	Nitrogen dioxide	**0.530****	0.002	0.311	0.089	-0.167	0.369	0.111	0.553
	Nitrogen monoxide	0.309	0.090	0.284	0.121	0.205	0.267	0.142	0.447
	Respirable particles	0.087	0.642	0.221	0.232	0.234	0.206	0.035	0.851
	Fine particles	-0.011	0.954	0.165	0.374	0.164	0.377	-0.058	0.757

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

For the Kauppatori–Niuskala logger pair in 2021, nitrogen dioxide, nitrogen monoxide, and respirable particles all exhibited statistically significant correlations with the UHI during the 07.00–08.00 time frame (Table 93). Nitrogen dioxide showed a strong correlation, while nitrogen monoxide and respirable particles had medium-strength correlations. During the 08.00–09.00 period, all air quality variables except nitrogen monoxide, which correlated only in Spearman, had statistically significant correlations with the UHI. These were of medium strength, with respirable particles and the air quality index show-

Table 93. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in August 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.346	0.057	**0.528****	0.002				
	Nitrogen dioxide	**0.653****	<0.001	**0.566****	<0.001	-0.016	0.934	-0.155	0.404
	Nitrogen monoxide	**0.413***	0.021	0.354	0.051	0.037	0.842	0.046	0.805
	Respirable particles	**0.471****	0.007	**0.568****	<0.001	-0.179	0.337	-0.089	0.635
	Fine particles								
Spearman	Air quality index	0.342	0.060	**0.484****	0.006				
	Nitrogen dioxide	**0.606****	<0.001	**0.463****	0.009	-0.055	0.768	-0.123	0.511
	Nitrogen monoxide	**0.477****	0.007	**0.465****	0.008	0.140	0.454	0.144	0.439
	Respirable particles	**0.470****	0.008	**0.477****	0.007	-0.191	0.303	-0.134	0.473
	Fine particles								

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 94. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in August 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	-0.074	0.692	-0.059	0.751	0.268	0.145	0.287	0.118
	Nitrogen dioxide	**0.424***	0.018	0.095	0.612	0.010	0.959	0.005	0.980
	Nitrogen monoxide	0.225	0.225	0.021	0.912	0.061	0.746	0.125	0.502
	Respirable particles	-0.028	0.879	-0.050	0.788	0.288	0.117	0.274	0.136
	Fine particles	-0.065	0.728	-0.003	0.987	0.191	0.302	0.189	0.310
Spearman	Air quality index	-0.015	0.938	0.022	0.907	0.245	0.184	0.286	0.119
	Nitrogen dioxide	**0.392***	0.029	0.049	0.792	0.100	0.592	0.008	0.965
	Nitrogen monoxide	0.217	0.241	-0.006	0.973	0.133	0.475	0.068	0.716
	Respirable particles	0.160	0.391	0.043	0.818	0.286	0.119	0.263	0.153
	Fine particles	0.030	0.873	-0.027	0.887	0.163	0.381	0.178	0.338

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

ing the strongest associations. No statistically significant correlations were observed during the afternoon.

In 2023, the only statistically significant correlation occurred at 07.00–08.00 with nitrogen dioxide, which showed a positive but quite weak correlation with the UHI (Table 94).

The correlation between the 05.00 UHI and the 08.00 air quality

In August 2021, all of the 08.00 air quality variables showed statistically significant correlations with the 05.00 UHI in both Pearson and Spearman analyses (Table 95). Nitrogen dioxide and respirable particles exhibited relatively strong Pearson correlations, while the weakest was with the air quality index, although it still showed a moderate correlation. In the Spearman analysis, the weakest correlation was with respirable particles, while nitrogen dioxide had the strongest. Overall, the Spearman coefficients were weaker than the corresponding Pearson values.

In 2023, only nitrogen dioxide and nitrogen monoxide showed statistically significant Pearson correlations with the 05.00 UHI (Table 96). These were of weak and moderate strength, with nitrogen dioxide displaying the weaker correlation. In the Spearman analysis, nitrogen dioxide was the only variable with a statistically significant correlation, showing a weak positive association with the UHI.

Compared to 2021, fewer variables were significantly correlated in 2023, and the correlation coefficients were generally weaker.

The correlation between the UHI, average wind speed and cloudiness

Daytime in August lasted from 04.30 to 20.30. During the daytime, the UHI correlated strongly and negatively with average wind speed (Table 97). There was also a moderately strong negative correlation with cloudiness. At night, similar correlations were observed, but both coefficients were stronger.

UHI intensity values in August were relatively low, averaging around 1 °C during the

Table 95. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in August 2021. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index	**0.532****	0.002
	Nitrogen dioxide	**0.736****	<0.001
	Nitrogen monoxide	**0.585****	<0.001
	Respirable particles	**0.649****	<0.001
	Fine particles		
Spearman	Air quality index	**0.439***	0.013
	Nitrogen dioxide	**0.699****	<0.001
	Nitrogen monoxide	**0.567****	<0.001
	Respirable particles	**0.426***	0.017
	Fine particles		

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 96. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in August 2023. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index	0.008	0.967
	Nitrogen dioxide	**0.367***	0.042
	Nitrogen monoxide	**0.449***	0.011
	Respirable particles	0.225	0.224
	Fine particles	0.104	0.577
Spearman	Air quality index	-0.039	0.835
	Nitrogen dioxide	**0.360***	0.047
	Nitrogen monoxide	0.350	0.054
	Respirable particles	0.333	0.067
	Fine particles	0.204	0.271

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 97. Pearson and Spearman correlation coefficients between the wind speed and UHI and between the cloudiness and UHI during daytime and nighttime in August 2021. Four different UHI intensities are calculated based on the Betel, Kurala, Kauppatori and Niuskala observation sites.

			Betel & Kurala	Betel & Niuskala	Kauppatori & Kurala	Kauppatori & Niuskala
			Average UHI	Average UHI	Average UHI	Average UHI
Day	Pearson	Average wind speed	**-0.755****	**-0.781****	**-0.705****	**-0.747****
		Average cloudiness	**-0.526****	**-0.620****	**-0.656****	**-0.666****
	Spearman	Average wind speed	**-0.743****	**-0.755****	**-0.656****	**-0.740****
		Average cloudiness	**-0.580****	**-0.650****	**-0.656****	**-0.647****
Night	Pearson	Average wind speed	**-0.873****	**-0.873****	**-0.871****	**-0.850****
		Average cloudiness	**-0.720****	**-0.720****	**-0.734****	**-0.681****
	Spearman	Average wind speed	**-0.890****	**-0.890****	**-0.898****	**-0.833****
		Average cloudiness	**-0.790****	**-0.790****	**-0.788****	**-0.731****

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

day (Figures 172 & 173). Wind speeds ranged between 2–5 m/s, while cloudiness values spanned from 0 to 8. A similar pattern to the previous month emerged during nighttime, with wind speeds mostly remaining below 4 m/s, though a few higher values were recorded (Figure 174). The correlation between wind speed and UHI remained clearly visible at night. For cloudiness, a correlation was also observed, though it was less distinct than that of wind speed (Figure 175). Higher UHI intensities typically occurred under low cloud cover, while cloudier conditions were associated with reduced UHI. Nighttime UHI values varied but consistently remained below 6 °C.

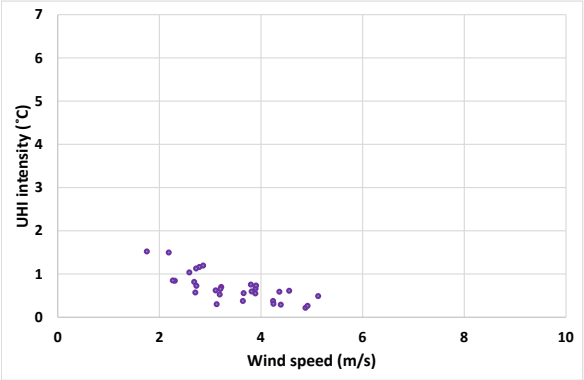

Figure 172. Scatter plot for wind speed and UHI between Betel and Kurala during daytime in August 2021.

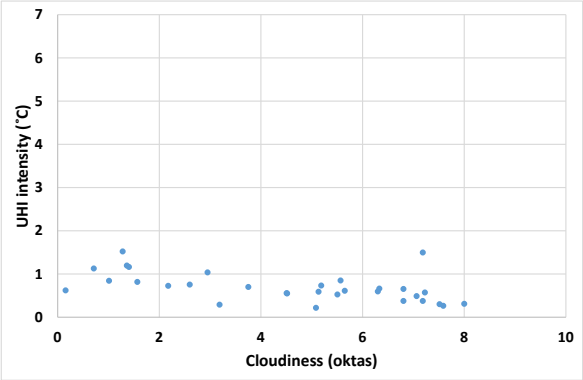

Figure 173. Scatter plot for cloudiness and UHI between Betel and Kurala during daytime in August 2021.

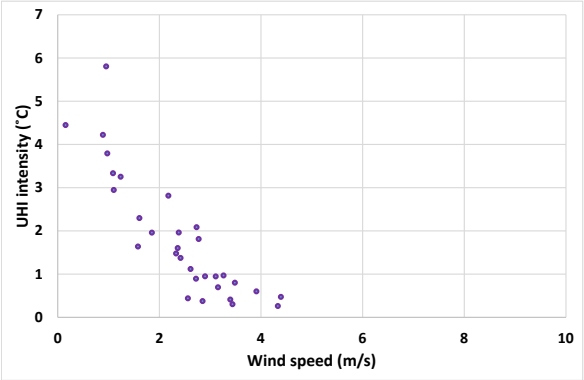

Figure 174. Scatter plot for wind speed and UHI between Betel and Kurala during nighttime in August 2021.

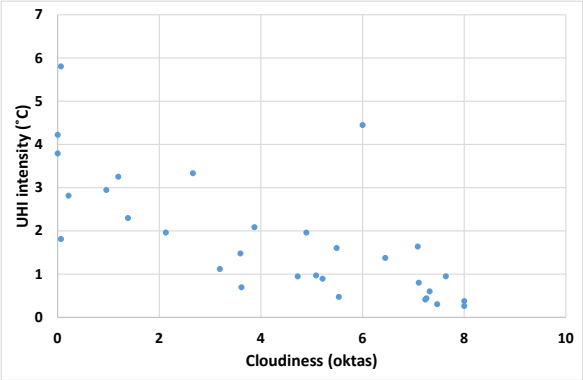

Figure 175. Scatter plot for cloudiness and UHI between Betel and Kurala during nighttime in August 2021.

The correlation between NAO index and UHI

No statistically significant correlations occurred between the NAO index and the observed UHI logger site pairs in August 2021 (Table 98).

Table 98. Pearson and Spearman correlations between NAO index and different UHI logger pairs in August 2021.

	UHI	NAO index	Significance level
Pearson	Betel & Kurala	0.164	0.378
	Betel & Niuskala	0.271	0.141
	Kauppatori & Kurala	0.165	0.376
	Kauppatori & Niuskala	0.279	0.129
	Betel & Ryhmäpuutarha	0.290	0.114
	Kauppatori & Ryhmäpuutarha	0.301	0.100
Spearman	Betel & Kurala	-0.031	0.867
	Betel & Niuskala	0.054	0.773
	Kauppatori & Kurala	0.023	0.902
	Kauppatori & Niuskala	0.071	0.706
	Betel & Ryhmäpuutarha	0.145	0.437
	Kauppatori & Ryhmäpuutarha	0.250	0.175

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

5.1.9 September

The UHI intensities

The UHI intensities reached maximum values of approximately 5–6 °C depending on the logger pair (Figures 176–179). These peaks occurred mostly during nighttime and early morning hours, particularly during the periods of the 4th–7th, 15th–16th, 21st–22nd, and 26th–28th. Between these peak periods, more stable intervals were observed during which the UHI intensity generally remained around or below 2 °C. Negative UHI values were rare for the Betel–Niuskala and Kauppatori–Niuskala pairs, while a few appeared for the Betel–Kurala and Kauppatori–Kurala pairs. These negative values occurred mostly around midday and typically stayed below –1 °C.

In September 2023, UHI conditions were generally stable, with notable exceptions occurring during the periods of the 6th–9th, as well as on the 15th, 18th, 25th, and 27th (Figures 180–183). During these intervals, UHI intensities reached up to approximately 5 °C at Betel, Kurala, and Kauppatori, and 6 °C at both Betel–Niuskala and Kauppatori–Niuskala. All peak intensities occurred during nighttime or early morning hours. The highest UHI values were observed between Kauppatori and Niuskala, nearly exceeding 7 °C. During the more stable periods, UHI values remained around 1 °C, with occasional minor negative values, most-

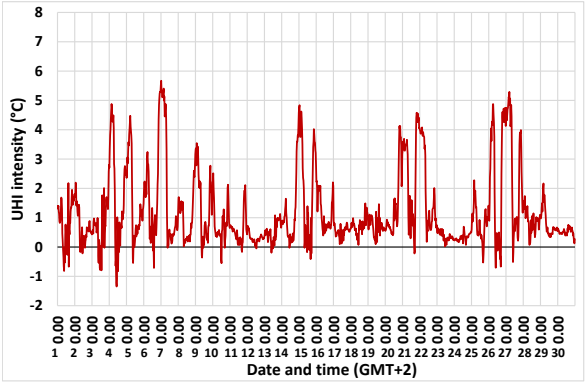

Figure 176. UHI intensity between Betel and Kurala during September 2021.

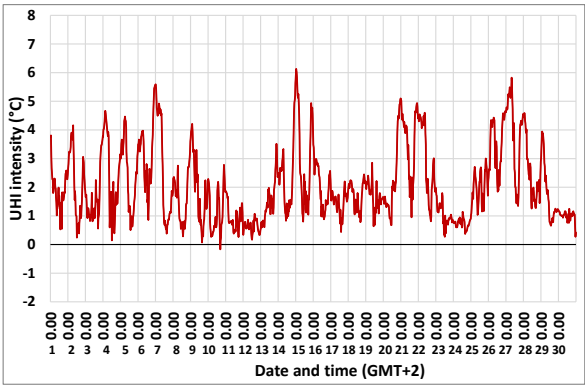

Figure 177. UHI intensity between Betel and Niuskala during September 2021.

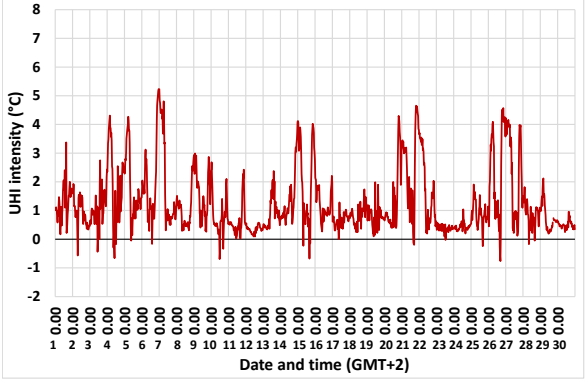

Figure 178. UHI intensity between Kauppatori and Kurala during September 2021.

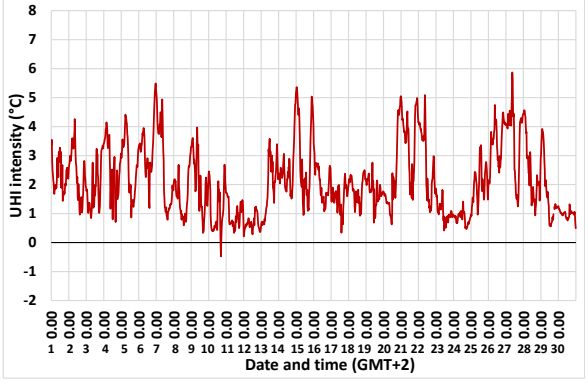

Figure 179. UHI intensity between Kauppatori and Niuskala during September 2021.

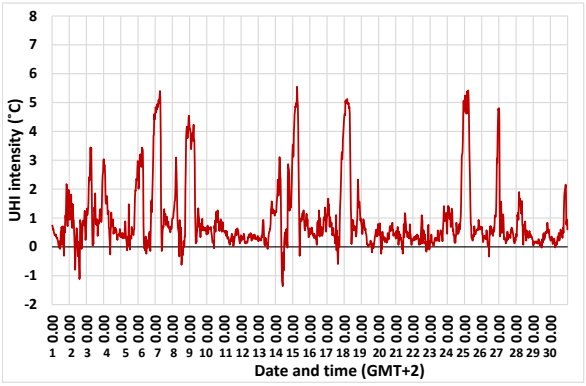

Figure 180. UHI intensity between Betel and Kurala during September 2023.

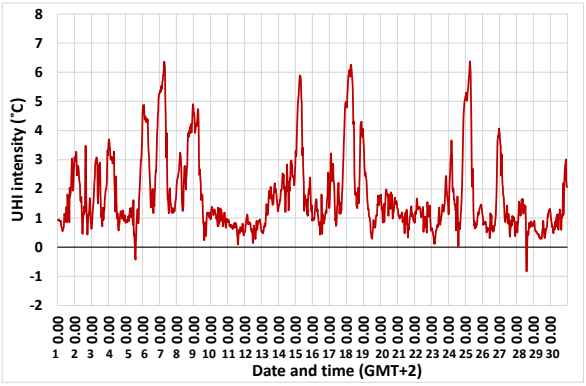

Figure 181. UHI intensity between Betel and Niuskala during September 2023.

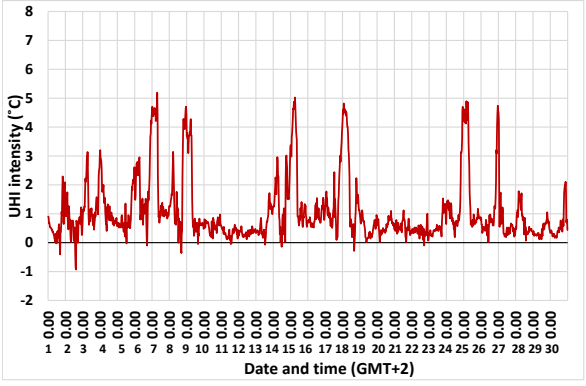

Figure 182. UHI intensity between Kauppatori and Kurala during September 2023.

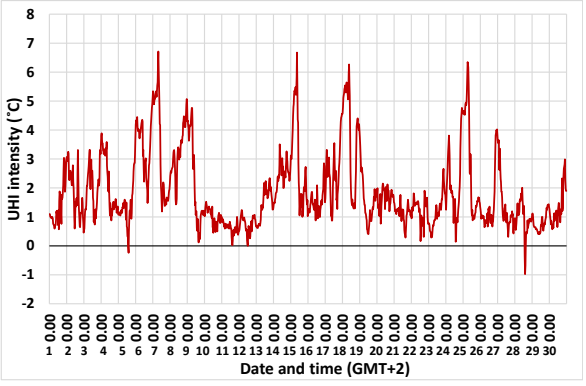

Figure 183. UHI intensity between Kauppatori and Niuskala during September 2023.

ly below –1 °C, particularly between Betel and Kurala around midday.

When comparing the two years, the timing of peak UHI values appears similar in 2021 and 2023. However, peak values were slightly higher in 2023, and more instances of cold islands were also recorded that year.

Monthly summaries

In September 2021, air quality variables exhibited a distinct peak during the morning, with no noticeable rise during the afternoon rush hours (Figure 184). The morning peak occurred between 07.00 and 09.00, with the air quality index reaching 1.3, nitrogen dioxide peaking at 25 µg/m^3, nitrogen monoxide at approximately 19 µg/m^3, and respirable particles nearing 15 µg/m^3. Nitrogen dioxide also displayed a secondary peak in the evening, around 20.00–22.00, with values of about 15 µg/m^3. During calmer nighttime periods, concentrations of all air quality variables mostly remained below 10 µg/m^3. Fine particles stayed mostly under 5 µg/m^3 throughout the day, and nitrogen monoxide dropped to near 0 µg/m^3 during the night.

In 2023, air quality variables also reached their maximum values during the morning, specifically between 05.00 and 09.00. The air quality index ranged from 1.07 to 1.23, nitrogen dioxide peaked at 4.54 µg/m^3, nitrogen monoxide ranged between 0.50 and 10.04 µg/m^3,

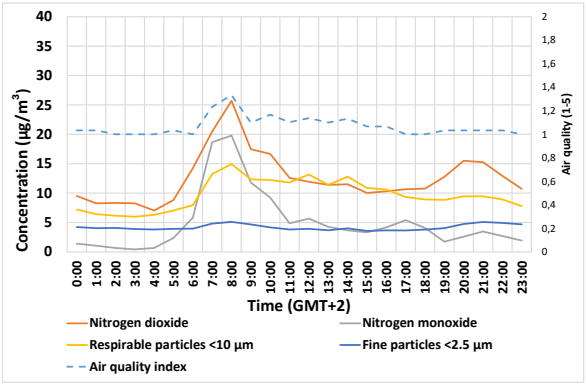

Figure 184. Hourly averages of air quality observations in September 2021.

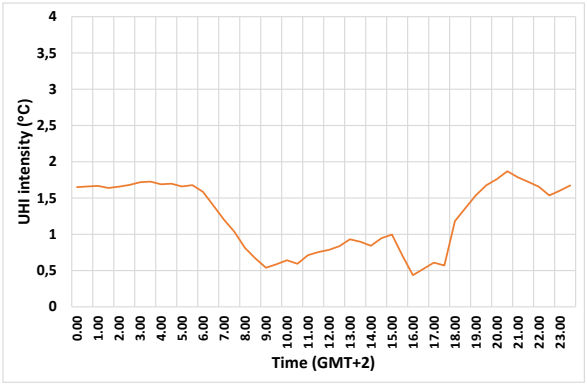

Figure 185. Hourly average UHI intensity between Kauppatori and Kurala in September 2021.

respirable particles between 9.11 and 12.34 µg/m³, and fine particles between 5.10 and 6.10 µg/m³.

The UHI reached its maximum values during nighttime, early morning, and late evening (Figure 185), with intensities ranging from 1.6 to 1.8 °C. During the daytime, UHI values were lower, generally between 0.5 and 0.9 °C.

The correlations between the UHI and air quality

The UHI between Betel and Kurala had a positive Pearson correlation with nitrogen monoxide during 07.00–08.00 (Table 99). In the following hour, all air quality variables except fine particles showed a statistically significant Pearson correlation, while only the air quality index and nitrogen monoxide correlated in the Spearman analysis. The strongest Pearson correlations during this period were observed with the air quality index and nitrogen monoxide. In the afternoon, between 15.00–16.00, respirable particles and fine particles both had positive Pearson correlations with the UHI, with fine particles showing a particularly strong correlation. During the next hour (16.00–17.00), respirable particles continued to correlate positively in Pearson with a coefficient of medium strength.

In 2023, all air quality variables correlated with the UHI at 07.00–08.00, except the air quality index, which did not show a significant Pearson correlation (Table 100). Nitrogen dioxide and nitrogen monoxide had fairly strong positive Pearson correlations, while respirable particles, fine particles, and the air quality index showed negative correlations. In the next hour (08.00–09.00), nitrogen dioxide and nitrogen monoxide continued to correlate positively in Pearson, with nitrogen monoxide showing a strong coefficient. In the afternoon, the only statistically significant correlation observed at 15.00–16.00 was a negative Spearman correlation with nitrogen monoxide.

For the Betel and Niuskala logger pair, the UHI exhibited a positive Pearson correlation with nitrogen monoxide and a Spearman correlation with nitrogen dioxide at 07.00–08.00 (Table 101). During the following hour, all air quality variables except fine particles showed a Pearson correlation, with nitrogen monoxide having the strongest and respirable particles the weakest correlation. In the Spearman analysis, only the air quality index showed a statistically significant correlation, though with a weak coefficient. In the afternoon, none of the variables showed significant correlations.

Table 99. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in September 2021.

		07.00-08.00		08.00-09.00		15.00-16.00		16.00-17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.321	0.084	**0.631****	<0.001	0.344	0.063	0.073	0.703
	Nitrogen dioxide	0.207	0.273	**0.560****	0.001	-0.023	0.903	-0.301	0.106
	Nitrogen monoxide	**0.545****	0.002	**0.734****	<0.001	-0.159	0.402	-0.280	0.134
	Respirable particles	0.217	0.249	**0.421***	0.021	**0.364***	0.048	**0.411***	0.024
	Fine particles					**1.000****	0.005		
Spearman	Air quality index	0.305	0.101	**0.461***	0.010	0.293	0.116	0.062	0.746
	Nitrogen dioxide	0.342	0.064	0.320	0.085	-0.005	0.977	-0.267	0.153
	Nitrogen monoxide	0.263	0.161	**0.365***	0.047	0.017	0.928	-0.056	0.770
	Respirable particles	0.248	0.185	0.293	0.116	0.348	0.059	0.361	0.050
	Fine particles					0.866	0.333		

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 100. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in September 2023.

		07.00-08.00		08.00-09.00		15.00-16.00		16.00-17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	-0.324	0.081	0.287	0.124	0.112	0.555	0.081	0.670
	Nitrogen dioxide	**0.660****	<0.001	**0.530****	0.004	-0.203	0.320	0.082	0.685
	Nitrogen monoxide	**0.739****	<0.001	**0.857****	<0.001	-0.188	0.357	0.148	0.460
	Respirable particles	**-0.373***	0.042	0.299	0.108	-0.128	0.502	-0.103	0.587
	Fine particles	**-0.411***	0.024	-0.138	0.466	-0.121	0.525	-0.111	0.561
Spearman	Air quality index	**-0.512****	0.004	0.029	0.880	-0.032	0.866	-0.079	0.677
	Nitrogen dioxide	**0.640****	<0.001	0.293	0.130	-0.304	0.131	-0.027	0.893
	Nitrogen monoxide	**0.550****	0.003	0.370	0.053	**-0.389***	0.049	0.185	0.357
	Respirable particles	**-0.453***	0.012	0.036	0.849	-0.303	0.103	-0.253	0.177
	Fine particles	**-0.489****	0.006	-0.272	0.146	-0.267	0.154	-0.231	0.219

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

In 2023, all air quality variables correlated with the UHI at 07.00–08.00, with nitrogen dioxide and nitrogen monoxide displaying the strongest positive correlations (Table 102). The remaining variables; respirable particles, fine particles, and the air quality index, showed negative correlations. In the following time frame (08.00–09.00), nitrogen monoxide maintained a strong Pearson correlation, while nitrogen dioxide also showed a Pearson correlation but not in Spearman. During the afternoon, respirable particles and fine particles had negative correlations, with stronger coefficients observed between 16.00–17.00. Additionally, at that time, the air quality index and nitrogen dioxide had negative Spearman correlations.

Table 101. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in September 2021.

		07.00-08.00		08.00-09.00		15.00-16.00		16.00-17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.246	0.190	**0.532****	0.002	0.170	0.369	-0.139	0.464
	Nitrogen dioxide	0.322	0.083	**0.516****	0.004	-0.244	0.193	-0.049	0.796
	Nitrogen monoxide	**0.457***	0.011	**0.647****	<0.001	0.193	0.306	-0.053	0.782
	Respirable particles	0.197	0.297	**0.407***	0.026	-0.084	0.657	-0.083	0.662
	Fine particles					-0.994	0.070		
Spearman	Air quality index	0.260	0.166	**0.377***	0.040	0.170	0.370	-0.139	0.464
	Nitrogen dioxide	**0.371***	0.044	0.348	0.059	-0.213	0.258	-0.105	0.579
	Nitrogen monoxide	0.254	0.175	0.322	0.083	0.322	0.082	-0.011	0.955
	Respirable particles	0.212	0.261	0.263	0.161	-0.068	0.722	-0.051	0.790
	Fine particles					-0.866	0.333		

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 102. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in September 2023.

		07.00-08.00		08.00-09.00		15.00-16.00		16.00-17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**-0.365***	0.047	0.129	0.496	-0.207	0.271	-0.319	0.086
	Nitrogen dioxide	**0.521****	0.005	**0.447***	0.017	-0.260	0.199	-0.376	0.053
	Nitrogen monoxide	**0.723****	<0.001	**0.687****	<0.001	-0.026	0.898	-0.034	0.866
	Respirable particles	**-0.419***	0.021	0.161	0.394	**-0.437***	0.016	**-0.491****	0.006
	Fine particles	**-0.467****	0.009	-0.277	0.138	**-0.477****	0.008	**-0.516****	0.004
Spearman	Air quality index	**-0.481****	0.007	-0.077	0.686	-0.225	0.233	**-0.397***	0.030
	Nitrogen dioxide	**0.571****	0.002	0.143	0.468	-0.307	0.127	**-0.470***	0.013
	Nitrogen monoxide	**0.487****	0.010	**0.424***	0.025	0.004	0.983	-0.096	0.635
	Respirable particles	**-0.443***	0.014	0.043	0.822	**-0.538****	0.002	**-0.674****	<0.001
	Fine particles	**-0.495****	0.005	-0.279	0.135	**-0.621****	<0.001	**-0.702****	<0.001

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

For the Kauppatori and Kurala logger pair, the UHI showed a positive Pearson correlation with nitrogen monoxide and a weaker Spearman correlation with the air quality index at 07.00–08.00 (Table 103). During the following hour, all variables except fine particles had a positive Pearson correlation, with nitrogen monoxide having the strongest coefficient. In the Spearman analysis, only the air quality index and nitrogen monoxide showed statistically significant positive correlations, with the air quality index having the stronger coefficient. In the afternoon, at 15.00–16.00, nitrogen dioxide exhibited a negative Pearson correlation of

Table 103. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in September 2021.

		07.00-08.00		08.00-09.00		15.00-16.00		16.00-17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.314	0.091	**0.567****	0.001	0.048	0.803	-0.046	0.809
	Nitrogen dioxide	0.191	0.311	**0.493****	0.006	**-0.429***	0.018	**-0.589****	<0.001
	Nitrogen monoxide	**0.512****	0.004	**0.686****	<0.001	-0.121	0.523	-0.276	0.140
	Respirable particles	0.195	0.301	**0.393***	0.032	-0.155	0.412	-0.010	0.959
	Fine particles					0.822	0.386		
Spearman	Air quality index	**0.369***	0.045	**0.452***	0.012	0.108	0.570	-0.015	0.935
	Nitrogen dioxide	0.318	0.086	0.358	0.052	**-0.526****	0.003	**-0.589****	<0.001
	Nitrogen monoxide	0.285	0.128	**0.386***	0.035	-0.067	0.726	-0.319	0.086
	Respirable particles	0.231	0.219	0.269	0.151	-0.177	0.350	0.054	0.777
	Fine particles					0.866	0.333		

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 104. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in September 2023.

		07.00-08.00		08.00-09.00		15.00-16.00		16.00-17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	-0.348	0.060	0.295	0.113	-0.189	0.318	-0.251	0.181
	Nitrogen dioxide	**0.656****	<0.001	**0.538****	0.003	**-0.465***	0.017	0.135	0.503
	Nitrogen monoxide	**0.755****	<0.001	**0.777****	<0.001	-0.282	0.162	0.266	0.179
	Respirable particles	**-0.384***	0.036	0.273	0.144	-0.357	0.053	**-0.374***	0.042
	Fine particles	**-0.425***	0.019	-0.174	0.357	**-0.404***	0.027	**-0.409***	0.025
Spearman	Air quality index	**-0.532****	0.002	0.029	0.880	-0.225	0.233	-0.215	0.253
	Nitrogen dioxide	**0.623****	<0.001	0.292	0.132	**-0.534****	0.005	0.187	0.351
	Nitrogen monoxide	**0.560****	0.002	**0.395***	0.037	-0.385	0.052	0.278	0.160
	Respirable particles	**-0.484****	0.007	0.077	0.687	**-0.409***	0.025	-0.279	0.136
	Fine particles	**-0.509****	0.004	-0.235	0.212	**-0.475****	0.008	**-0.375***	0.041

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

medium strength, and at 16.00–17.00, the negative coefficients became stronger.

In 2023, all variables had statistically significant correlations at 07.00–08.00 except for the air quality index, which did not correlate in Pearson (Table 104). Nitrogen dioxide and nitrogen monoxide had relatively strong positive coefficients, while the other variables showed medium-strength negative correlations. During the next hour, nitrogen monoxide maintained a strong Pearson correlation and a weaker Spearman correlation. Nitrogen dioxide also showed a medium-strength Pearson correlation. At 15.00–16.00, both nitrogen dioxide

and fine particles had negative Pearson correlations, and respirable particles had a negative Spearman correlation. In the following hour, fine particles had a moderate negative Pearson correlation, and respirable particles continued to correlate negatively in Pearson as well.

For the Kauppatori and Niuskala logger pair in 2021, the UHI exhibited a positive Pearson correlation with nitrogen monoxide at 07.00–08.00 (Table 105). During the following hour, the air quality index, nitrogen dioxide, and nitrogen monoxide all showed statistically significant positive Pearson correlations of medium strength. At 15.00–16.00, nitrogen dioxide had a negative Pearson correlation, and fine particles displayed a strong negative correlation. No statistically significant correlations were observed during the 16.00–17.00 time frame.

In 2023, all air quality variables showed statistically significant correlations at 07.00–08.00 (Table 106). Nitrogen monoxide had a strong positive Pearson correlation, while the air quality index, respirable particles, and fine particles all had negative correlations. During the next hour, nitrogen monoxide maintained a strong positive Pearson correlation, and nitrogen dioxide also showed a positive Pearson correlation. At 15.00–16.00, respirable particles and fine particles both had negative correlations, with stronger coefficients in the Spearman analysis. These negative correlations intensified in the 16.00–17.00 time frame for both Pearson and Spearman. Additionally, the air quality index also exhibited a negative correlation.

The correlation between the 05.00 UHI and the 08.00 air quality

In September 2021, the air quality index showed a weak Pearson correlation with the 05.00 UHI, while nitrogen monoxide exhibited a Pearson correlation of medium strength (Table 107). All air quality variables had statistically significant Spearman correlations, with coefficients of medium strength. Among these, nitrogen dioxide had the weakest correlation and respirable particles the strongest.

Table 105. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in September 2021.

		07.00-08.00		08.00-09.00		15.00-16.00		16.00-17.00	
	Kauppatori & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.228	0.226	**0.436***	0.016	-0.007	0.969	-0.194	0.304
	Nitrogen dioxide	0.328	0.077	**0.429***	0.018	**-0.501****	0.005	-0.290	0.120
	Nitrogen monoxide	**0.409***	0.025	**0.557****	0.001	0.119	0.530	-0.093	0.625
	Respirable particles	0.171	0.365	0.359	0.051	-0.359	0.052	-0.289	0.122
	Fine particles					**-0.997***	0.050		
Spearman	Air quality index	0.223	0.236	0.335	0.070	-0.015	0.935	-0.201	0.288
	Nitrogen dioxide	0.355	0.054	0.351	0.057	**-0.522****	0.003	-0.300	0.107
	Nitrogen monoxide	0.215	0.253	0.304	0.103	0.089	0.640	-0.138	0.469
	Respirable particles	0.167	0.379	0.237	0.208	-0.346	0.061	-0.273	0.145
	Fine particles					-0.866	0.333		

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 106. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in September 2023.

	Kauppatori & Niuskala	07.00-08.00 UHI	07.00-08.00 Significance level	08.00-09.00 UHI	08.00-09.00 Significance level	15.00-16.00 UHI	15.00-16.00 Significance level	16.00-17.00 UHI	16.00-17.00 Significance level
Pearson	Air quality index	**-0.385***	0.036	0.125	0.510	-0.284	0.128	**-0.417***	0.022
	Nitrogen dioxide	**0.496****	0.009	**0.436***	0.020	-0.303	0.133	-0.329	0.094
	Nitrogen monoxide	**0.723****	<0.001	**0.610****	<0.001	-0.056	0.787	0.020	0.923
	Respirable particles	**-0.427***	0.019	0.134	0.479	**-0.431***	0.017	**-0.558****	0.001
	Fine particles	**-0.478****	0.007	-0.301	0.107	**-0.484****	0.007	**-0.592****	<0.001
Spearman	Air quality index	**-0.553****	0.002	-0.077	0.686	-0.340	0.066	**-0.487****	0.006
	Nitrogen dioxide	**0.558****	0.003	0.170	0.386	-0.288	0.154	-0.350	0.074
	Nitrogen monoxide	**0.475***	0.012	**0.456***	0.015	0.003	0.989	0.038	0.852
	Respirable particles	**-0.518****	0.003	0.037	0.848	**-0.541****	0.002	**-0.706****	<0.001
	Fine particles	**-0.559****	0.001	-0.285	0.126	**-0.632****	<0.001	**-0.760****	<0.001

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 107. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in September 2021. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index	**0.374***	0.042
	Nitrogen dioxide	0.323	0.082
	Nitrogen monoxide	**0.583****	<0.001
	Respirable particles	0.291	0.118
	Fine particles		
Spearman	Air quality index	**0.423***	0.020
	Nitrogen dioxide	**0.408***	0.025
	Nitrogen monoxide	**0.417***	0.022
	Respirable particles	**0.429***	0.018
	Fine particles		

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 108. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in September 2023. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index	-0.015	0.937
	Nitrogen dioxide	-0.965	0.170
	Nitrogen monoxide		
	Respirable particles	0.201	0.287
	Fine particles	-0.167	0.378
Spearman	Air quality index	-0.047	0.807
	Nitrogen dioxide	-0.500	0.667
	Nitrogen monoxide		
	Respirable particles	0.277	0.139
	Fine particles	-0.049	0.795

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

In contrast, in 2023, none of the 08.00 air quality variables displayed statistically significant correlations with the 05.00 UHI (Table 108). Additionally, correlations for nitrogen monoxide could not be calculated.

The correlation between the UHI, average wind speed and cloudiness

In September, daytime lasted from 06.00 in the morning until 19.00 in the evening. During this period, a strong negative correlation was ob-

Table 109. Pearson and Spearman correlation coefficients between the wind speed and UHI and between the cloudiness and UHI during daytime and nighttime in September 2021. Four different UHI intensities are calculated based on the Betel, Kurala, Kauppatori and Niuskala observation sites.

			Betel & Kurala Average UHI	Betel & Niuskala Average UHI	Kauppatori & Kurala Average UHI	Kauppatori & Niuskala Average UHI
Day	Pearson	Average wind speed	**-0.485****	-0.341	-0.193	-0.180
		Average cloudiness	**-0.636****	**-0.739****	**-0.780****	**-0.787****
	Spearman	Average wind speed	**-0.425***	-0.254	-0.171	-0.118
		Average cloudiness	**-0.605****	**-0.705****	**-0.789****	**-0.785****
Night	Pearson	Average wind speed	**-0.733****	**-0.614****	**-0.736****	**-0.598****
		Average cloudiness	**-0.752****	**-0.777****	**-0.728****	**-0.748****
	Spearman	Average wind speed	**-0.736****	**-0.631****	**-0.737****	**-0.629****
		Average cloudiness	**-0.826****	**-0.803****	**-0.790****	**-0.780****

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

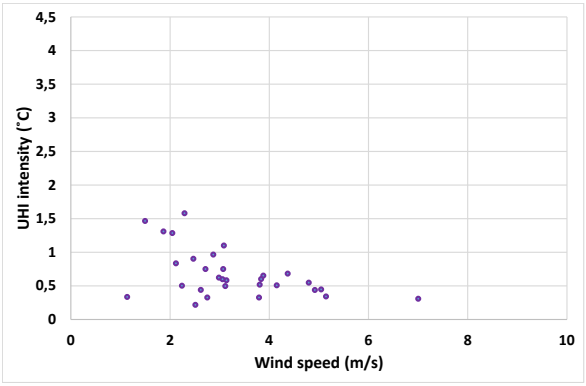

Figure 186. Scatter plot for wind speed and UHI between Betel and Kurala during daytime in September 2021.

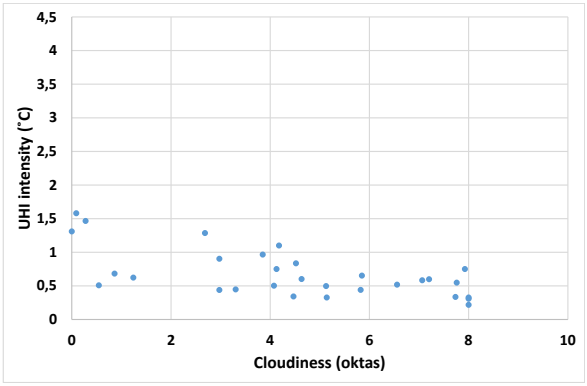

Figure 187. Scatter plot for cloudiness and UHI between Betel and Kurala during daytime in September 2021.

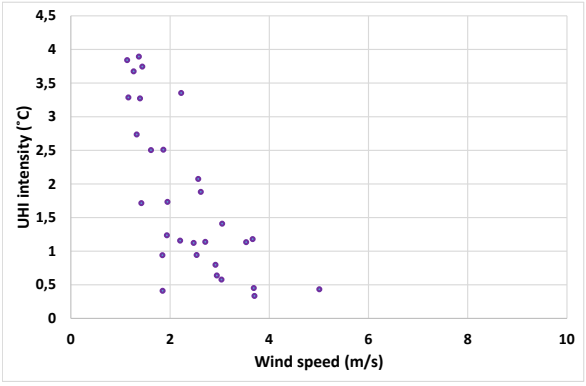

Figure 188. Scatter plot for wind speed and UHI between Betel and Kurala during nighttime in September 2021.

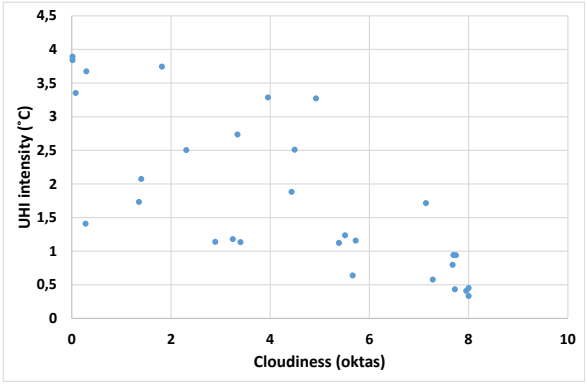

Figure 189. Scatter plot for cloudiness and UHI between Betel and Kurala during nighttime in September 2021.

served between UHI and cloudiness (Table 109). A similar negative correlation was also present at night, although the coefficient was slightly weaker. Additionally, a fairly strong negative correlation between UHI and average wind speed was recorded during nighttime.

During the day, wind speeds mostly ranged from 2 to 5 m/s, with a single outlier reaching 7 m/s (Figure 186). UHI values during the daytime remained between 0 and 1.5 °C. A minor pattern was visible with cloudiness (Figure 187): slightly lower UHI values tended to occur during cloudier conditions. Cloudiness levels varied between 0 and 8. At night, a clearer pattern emerged (Figure 188). Higher wind speeds were associated with lower UHI intensities. Nighttime UHI values ranged from 0 to 4 °C, while wind speeds mostly stayed below 4 m/s. The relationship with cloudiness was less distinct, though generally, higher UHI values were observed during clearer conditions (Figure 189). Nighttime cloudiness levels also ranged from 0 to 8.

The correlation between NAO index and UHI

In September 2021, no statistically significant correlations occurred between the NAO index and the UHI logger pairs (Table 110).

Table 110. Pearson and Spearman correlations between NAO index and different UHI logger pairs in September 2021.

	UHI	NAO index	Significance level
Pearson	Betel & Kurala	-0.021	0.911
	Betel & Niuskala	-0.149	0.432
	Kauppatori & Kurala	-0.001	0.995
	Kauppatori & Niuskala	-0.146	0.442
	Betel & Ryhmäpuutarha	0.062	0.746
	Kauppatori & Ryhmäpuutarha	0.099	0.604
Spearman	Betel & Kurala	-0.174	0.358
	Betel & Niuskala	-0.182	0.335
	Kauppatori & Kurala	-0.169	0.372
	Kauppatori & Niuskala	-0.175	0.356
	Betel & Ryhmäpuutarha	-0.70	0.713
	Kauppatori & Ryhmäpuutarha	-0.028	0.884

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

5.1.10 October

The UHI intensities

For most of October 2021, UHI intensities remained relatively stable (Figures 190–193). Peak values were observed mid-month, with a maximum of around 6 °C recorded on the 22nd between Betel–Kurala and Kauppatori–Kurala, and on the 27th between Betel–Niuskala and Kauppatori–Niuskala. These peaks occurred during the morning hours. At the beginning and end of the month, UHI values were low, remaining under 1 °C. Minor negative values, not exceeding –1 °C, were observed between Betel–Kurala and Kauppatori–Kurala, mostly around midday and concentrated in the middle part of the month.

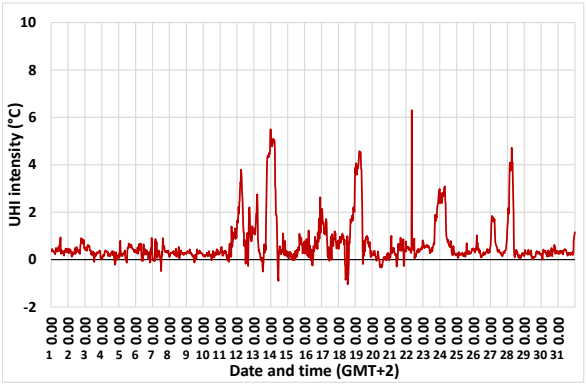

Figure 190. UHI intensity between Betel and Kurala during October 2021.

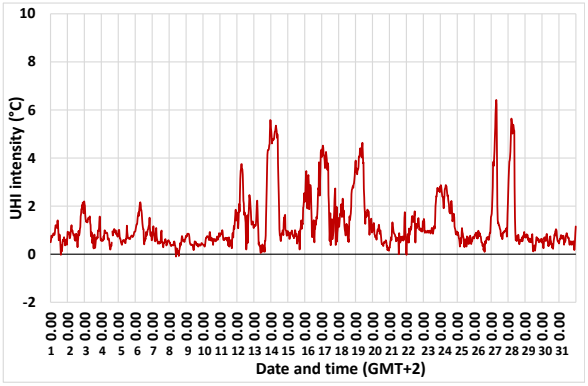

Figure 191. UHI intensity between Betel and Niuskala during October 2021.

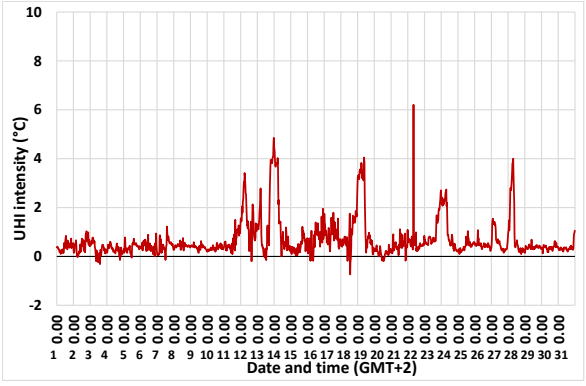

Figure 192. UHI intensity between Kauppatori and Kurala during October 2021.

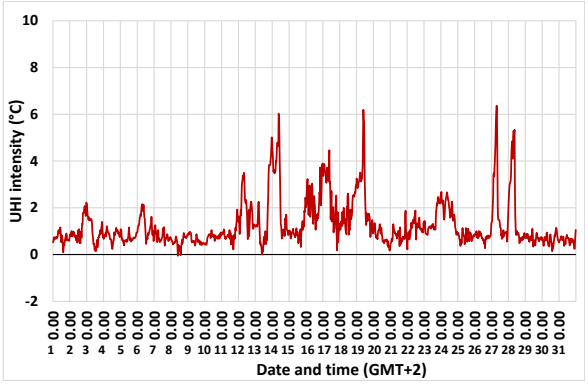

Figure 193. UHI intensity between Kauppatori and Niuskala during October 2021.

In October 2023, UHI intensities generally ranged between 0 °C and 6 °C (Figures 194–197), with occasional minor negative values below –1 °C. The highest intensities occurred between Kauppatori and Niuskala, with some values exceeding 6 °C and a peak of 8 °C recorded on the 6th, near midday. Most maximum intensities were observed in the morning, while the lowest typically occurred in the afternoon. The most stable period was from the 21st to the 28th, during which UHI intensities remained below 2 °C. Distinct peaks were recorded on the 2nd, 6th, 7th, 10th, and 17th across all monitoring sites.

When comparing the two years, 2023 showed a stable period in the latter half of the month, whereas in 2021, stability was mainly observed in the first half and at the very end. Maximum UHI intensity values were comparable between the years.

Monthly summaries

In October 2021, air quality variables mostly remained steady throughout the day. The air quality index consistently stayed below 1.5, generally fluctuating around 1.3 (Figure 198). Higher peaks were observed in the morning around 07.00–08.00, with smaller secondary peaks occurring in the afternoon around 17.00. Nitrogen dioxide recorded the highest peak concentration at approximately 21 µg/m³, while both nitrogen monoxide and respirable particles peaked at around 19 µg/m³. Outside of peak pe-

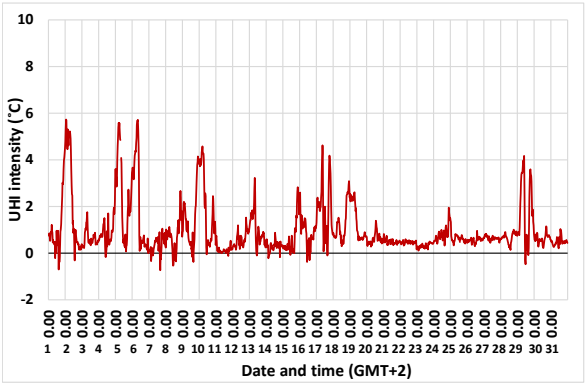

Figure 194. UHI intensity between Betel and Kurala during October 2023.

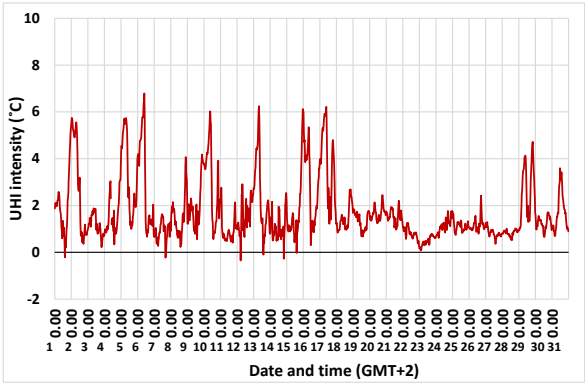

Figure 195. UHI intensity between Betel and Niuskala during October 2023.

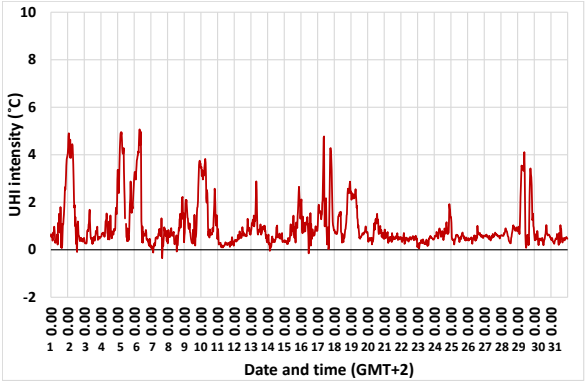

Figure 196. UHI intensity between Kauppatori and Kurala during October 2023.

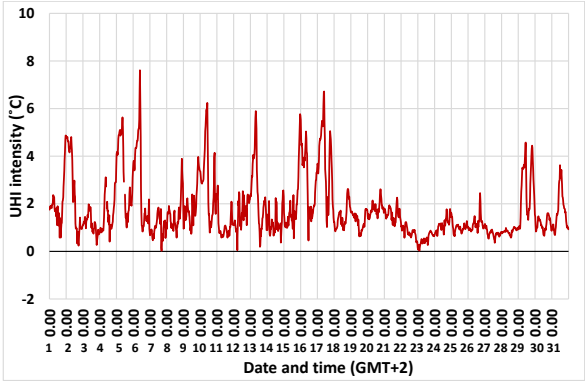

Figure 197. UHI intensity between Kauppatori and Niuskala during October 2023.

riods, nitrogen monoxide levels remained low, staying close to 0 µg/m³ during the night. Fine particle concentrations were relatively stable throughout the day, fluctuating between 6 and 7 µg/m³.

In 2023, the highest air quality variable values were observed in the morning between 06.00–10.00. During this period, the air quality index ranged between 1.00–1.19; nitrogen dioxide between 4.41–22.36 µg/m³; nitrogen monoxide between 0.70–16.47 µg/m³; respirable particles between 4.65–9.29 µg/m³; and fine particles between 2.75–4.46 µg/m³.

The UHI remained relatively stable throughout the day (Figure 199). On average, slightly higher values were recorded in the early morning hours. Overall, UHI intensities ranged between 0.4 °C and 0.8 °C.

The correlations between the UHI and air quality

The UHI between the loggers located in Betel and Kurala in 2021 correlated with all air quality variables except fine particles in the Pearson correlation at 07.00–08.00 (Table 111). Nitrogen dioxide and nitrogen monoxide showed strong positive correlations, which were also significant in the Spearman correlation, though the Spearman coefficients were weaker. During the following hour (08.00–09.00), nitrogen dioxide, nitrogen monoxide, and respirable particles had positive Pearson correlations. Nitrogen monoxide showed a strong co-

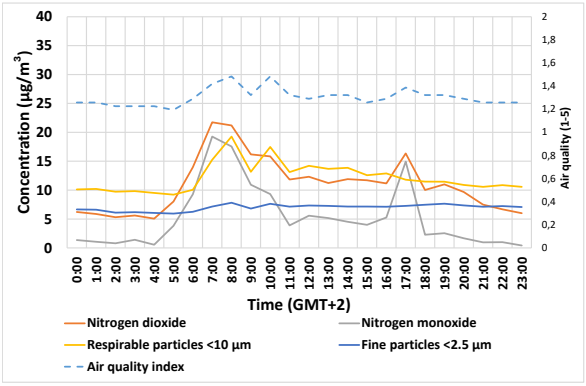

Figure 198. Hourly averages of air quality observations in October 2021.

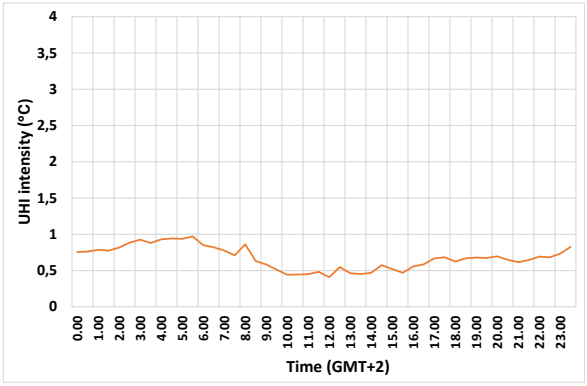

Figure 199. Hourly average UHI intensity between Kauppatori and Kurala in October 2021.

efficient, while the other two were of medium strength. At 15.00–16.00, only the air quality index showed a relatively weak negative Spearman correlation with the UHI. In the following hour (16.00–17.00), this coefficient became stronger, and fine particles also showed a weak negative Spearman correlation.

In 2023, the UHI correlated with nitrogen dioxide during the 07.00–08.00 time frame (Table 112), with a moderate Pearson coefficient but a much weaker Spearman coefficient. In the next hour, all air quality variables correlated except fine particles, which did not show a statistically significant Spearman correlation. Nitrogen dioxide had a strong coefficient in both correlation types, while nitrogen monoxide and respirable particles also had strong Pearson coefficients. The remaining variables had correlations of medium strength. In the afternoon, between 15.00–16.00, only nitrogen dioxide and nitrogen monoxide showed positive Spearman correlations. During 16.00–17.00, only negative Spearman correlations were observed, specifically for the air quality index and fine particles. Of these, the correlation with the air quality index was stronger.

In the case of Betel and Niuskala at 07.00–08.00 in 2021, only nitrogen dioxide and nitrogen monoxide showed a positive Pearson correlation with the UHI (Table 113). During the following hour, the same variables continued to correlate positively, although with weaker coefficients. In the afternoon, respirable particles and fine particles displayed a negative Spearman correlation during both observation time frames, with the correlations being stronger at 15.00–16.00.

In 2023, nitrogen dioxide was the only variable with a statistically significant positive Pearson correlation during the first hour (Table 114). In the following hour, nitrogen monoxide and respirable particles also showed positive Pearson correlations, though not with Spearman. Nitrogen dioxide correlated with both Pearson and Spearman during this time, with a relatively strong coefficient. The coefficients for nitrogen monoxide and respirable particles were of medium strength. In the afternoon, the only statistically significant correlation observed was a weak positive Pearson correlation with nitrogen monoxide at 16.00–17.00.

For Kauppatori and Kurala in 2021, all air quality variables except fine particles showed a statistically significant Pearson correlation with the UHI between 07.00–08.00 (Table 115). In the Spearman correlation, only nitrogen di-

Table 111. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in October 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.484****	0.006	0.303	0.097	-0.286	0.119	-0.316	0.083
	Nitrogen dioxide	**0.729****	<0.001	**0.582****	<0.001	-0.197	0.289	-0.182	0.327
	Nitrogen monoxide	**0.763****	<0.001	**0.708****	<0.001	-0.049	0.793	-0.007	0.971
	Respirable particles	**0.442***	0.013	**0.503****	0.004	-0.166	0.371	-0.146	0.433
	Fine particles	-0.078	0.677	0.048	0.798	-0.137	0.461	-0.182	0.328
Spearman	Air quality index	0.264	0.152	0.129	0.488	**-0.369***	0.041	**-0.538****	0.002
	Nitrogen dioxide	**0.427***	0.017	0.338	0.063	-0.303	0.097	-0.120	0.520
	Nitrogen monoxide	**0.439***	0.014	0.277	0.132	-0.198	0.285	0.089	0.634
	Respirable particles	-0.009	0.962	-0.034	0.855	-0.169	0.363	-0.316	0.084
	Fine particles	-0.167	0.370	-0.218	0.239	-0.306	0.094	**-0.391***	0.030

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 112. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in October 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index			**0.581****	<0.001			-0.199	0.282
	Nitrogen dioxide	**0.593****	<0.001	**0.692****	<0.001	0.216	0.251	**0.662****	<0.001
	Nitrogen monoxide	0.353	0.052	**0.647****	<0.001	0.236	0.209	**0.437***	0.014
	Respirable particles	0.060	0.748	**0.634****	<0.001	-0.002	0.990	**0.436***	0.014
	Fine particles	-0.098	0.598	**0.403***	0.025	0.037	0.847	0.342	0.060
Spearman	Air quality index			**0.438***	0.014			-0.184	0.323
	Nitrogen dioxide	**0.373***	0.039	**0.724****	<0.001	**0.427***	0.018	**0.717****	<0.001
	Nitrogen monoxide	0.033	0.858	**0.531****	0.002	**0.497****	0.005	**0.596****	<0.001
	Respirable particles	0.017	0.928	**0.512****	0.003	0.297	0.111	**0.499****	0.004
	Fine particles	-0.153	0.410	0.270	0.142	0.228	0.226	**0.534****	0.002

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

oxide and nitrogen monoxide were significant, both also showing strong Pearson coefficients. During the following hour (08.00–09.00), Pearson correlations remained relatively strong to moderate for these variables and were of medium strength for Spearman. Additionally, respirable particles displayed a medium-strength Pearson correlation. In the afternoon (15.00–16.00), the air quality index exhibited a negative correlation in both Pearson and Spearman analyses, while fine particles showed a weak negative Spearman correlation. In the final time frame (16.00–17.00), the correlation for fine particles remained nearly unchanged, while the negative coefficients for the air quality index became stronger.

Table 113. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in October 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.348	0.055	0.148	0.427	-0.328	0.072	-0.330	0.070
	Nitrogen dioxide	**0.598****	<0.001	**0.450***	0.011	-0.126	0.500	-0.120	0.519
	Nitrogen monoxide	**0.510****	0.003	**0.408***	0.023	0.064	0.733	0.012	0.951
	Respirable particles	0.309	0.090	0.274	0.136	-0.329	0.071	-0.237	0.199
	Fine particles	-0.189	0.308	-0.145	0.437	-0.313	0.086	-0.285	0.120
Spearman	Air quality index	0.167	0.369	-0.027	0.887	-0.296	0.105	-0.343	0.059
	Nitrogen dioxide	0.299	0.103	0.245	0.184	-0.116	0.534	-0.119	0.524
	Nitrogen monoxide	0.337	0.064	0.236	0.201	-0.098	0.602	-0.195	0.293
	Respirable particles	-0.144	0.440	-0.065	0.729	**-0.581****	<0.001	**-0.414***	0.021
	Fine particles	-0.332	0.068	-0.311	0.089	**-0.679****	<0.001	**-0.579****	<0.001

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 114. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in October 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index			0.342	0.060			-0.216	0.244
	Nitrogen dioxide	**0.435***	0.015	**0.605****	<0.001	0.095	0.617	0.338	0.063
	Nitrogen monoxide	0.240	0.193	**0.481****	0.006	-0.038	0.841	**0.398***	0.027
	Respirable particles	-0.055	0.768	**0.425***	0.017	-0.102	0.591	-0.029	0.877
	Fine particles	-0.211	0.255	0.142	0.445	-0.106	0.577	-0.112	0.549
Spearman	Air quality index			0.329	0.071			-0.286	0.119
	Nitrogen dioxide	0.190	0.305	**0.558****	0.001	0.034	0.859	0.241	0.191
	Nitrogen monoxide	-0.114	0.543	0.339	0.062	0.009	0.964	0.238	0.197
	Respirable particles	-0.073	0.695	0.226	0.222	0.017	0.929	-0.023	0.904
	Fine particles	-0.211	0.254	-0.049	0.795	-0.082	0.665	-0.095	0.612

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

In 2023, nitrogen dioxide showed a strong Pearson correlation and a weak Spearman correlation at 07.00–08.00 (Table 116). Nitrogen monoxide also had a weak Pearson correlation during this time. At 08.00–09.00, all variables except fine particles showed statistically significant correlations. Nitrogen dioxide had strong coefficients in both Pearson and Spearman correlations, while nitrogen monoxide and respirable particles had strong Pearson coefficients. The remaining variables showed mostly medium-strength correlations. In the afternoon (15.00–16.00), fine particles had a negative correlation, with a stronger Spearman coefficient of medium strength. Dur-

Table 115. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in October 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.451***	0.011	0.253	0.169	**-0.365***	0.044	**-0.440***	0.013
	Nitrogen dioxide	**0.721****	<0.001	**0.559****	0.001	-0.221	0.232	0.009	0.964
	Nitrogen monoxide	**0.722****	<0.001	**0.644****	<0.001	-0.049	0.794	0.213	0.250
	Respirable particles	**0.362***	0.045	**0.427***	0.017	-0.294	0.109	-0.335	0.065
	Fine particles	-0.094	0.614	0.015	0.934	-0.335	0.066	-0.399*	0.026
Spearman	Air quality index	0.259	0.160	0.042	0.821	**-0.450***	0.011	**-0.542****	0.002
	Nitrogen dioxide	**0.501****	0.004	**0.456****	0.010	-0.258	0.160	-0.091	0.626
	Nitrogen monoxide	**0.444***	0.012	**0.417***	0.020	-0.025	0.893	0.128	0.494
	Respirable particles	-0.002	0.991	-0.005	0.979	-0.244	0.185	-0.289	0.115
	Fine particles	-0.129	0.488	-0.182	0.327	**-0.369***	0.041	**-0.367***	0.043

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 116. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in October 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index			**0.579****	<0.001			**-0.357***	0.049
	Nitrogen dioxide	**0.601****	<0.001	**0.683****	<0.001	-0.111	0.559	0.153	0.413
	Nitrogen monoxide	**0.378***	0.036	**0.611****	<0.001	-0.063	0.741	0.029	0.876
	Respirable particles	0.078	0.678	**0.603****	<0.001	-0.258	0.169	0.055	0.768
	Fine particles	-0.075	0.690	**0.384***	0.033	**-0.394***	0.031	-0.102	0.584
Spearman	Air quality index			**0.411***	0.022			-0.306	0.094
	Nitrogen dioxide	**0.366***	0.043	**0.662****	<0.001	-0.153	0.419	0.217	0.241
	Nitrogen monoxide	0.021	0.912	**0.469****	0.008	-0.160	0.397	0.125	0.504
	Respirable particles	-0.005	0.979	**0.440***	0.013	-0.312	0.093	0.087	0.640
	Fine particles	-0.150	0.419	0.201	0.279	**-0.427***	0.019	0.008	0.964

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

ing the final hour (16.00–17.00), the air quality index showed a weak negative Pearson correlation.

For Kauppatori and Niuskala in 2021, nitrogen dioxide and nitrogen monoxide had medium-strength Pearson correlations with the UHI at 07.00–08.00 (Table 117). At the same time, fine particles showed a weak negative Spearman correlation. During the following hour, the Pearson coefficient for nitrogen dioxide decreased, and the Spearman coefficient for fine particles also weakened. In the afternoon (15.00–16.00), the air quality index, respirable particles, and fine particles all had negative correlations. The coefficients for respira-

Table 117. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in October 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.297	0.105	0.101	0.588	**-0.367***	0.042	-0.311	0.088
	Nitrogen dioxide	**0.561****	0.001	**0.424***	0.017	-0.041	0.827	0.104	0.579
	Nitrogen monoxide	**0.430***	0.016	0.339	0.062	0.177	0.339	0.157	0.398
	Respirable particles	0.226	0.222	0.204	0.272	**-0.531****	0.002	**-0.379***	0.036
	Fine particles	-0.216	0.243	-0.185	0.319	**-0.578****	<0.001	**-0.443***	0.013
Spearman	Air quality index	0.166	0.372	-0.072	0.702	**-0.391***	0.030	-0.291	0.113
	Nitrogen dioxide	0.313	0.086	0.285	0.121	-0.089	0.632	-0.042	0.821
	Nitrogen monoxide	0.325	0.075	0.275	0.134	0.074	0.692	-0.039	0.835
	Respirable particles	-0.203	0.274	-0.097	0.603	**-0.627****	<0.001	**-0.380***	0.035
	Fine particles	**-0.392***	0.029	**-0.368***	0.042	**-0.754****	<0.001	**-0.551****	0.001

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 118. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in October 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index			0.312	0.088			-0.215	0.245
	Nitrogen dioxide	**0.425***	0.017	**0.585****	<0.001	-0.069	0.718	-0.022	0.905
	Nitrogen monoxide	0.249	0.177	**0.430***	0.016	-0.216	0.253	0.126	0.499
	Respirable particles	-0.056	0.764	**0.373***	0.039	-0.219	0.246	-0.271	0.140
	Fine particles	-0.208	0.262	0.096	0.608	-0.302	0.105	-0.351	0.053
Spearman	Air quality index			0.283	0.123			-0.245	0.184
	Nitrogen dioxide	0.180	0.331	**0.528****	0.002	-0.287	0.125	-0.137	0.464
	Nitrogen monoxide	-0.162	0.385	0.312	0.087	-0.340	0.066	-0.126	0.500
	Respirable particles	-0.089	0.639	0.180	0.332	-0.271	0.148	-0.306	0.094
	Fine particles	-0.216	0.244	-0.106	0.572	**-0.397***	0.030	**-0.413***	0.021

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

ble and fine particles ranged from medium to strong, while the air quality index showed a weak correlation. In the final observation hour (16.00–17.00), only respirable and fine particles maintained statistically significant correlations, though the coefficients were weaker than in the previous hour.

In 2023, only nitrogen dioxide showed a statistically significant positive Pearson correlation during the first observation hour (7.00–8.00), with a coefficient of medium strength (Table 118). In the following hour, this correlation strengthened and was also significant in Spearman. Additionally, nitrogen monox-

Table 119. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in October 2021. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index	**0.601****	<0.001
	Nitrogen dioxide	**0.654****	<0.001
	Nitrogen monoxide	**0.593****	<0.001
	Respirable particles	**0.476****	0.007
	Fine particles	-0.029	0.876
Spearman	Air quality index	0.233	0.207
	Nitrogen dioxide	**0.433***	0.015
	Nitrogen monoxide	**0.403***	0.025
	Respirable particles	0.076	0.684
	Fine particles	-0.058	0.755

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 120. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in October 2023. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index	0.348	0.055
	Nitrogen dioxide	**0.712****	<0.001
	Nitrogen monoxide	**0.562****	<0.001
	Respirable particles	**0.496****	0.005
	Fine particles	0.279	0.128
Spearman	Air quality index	0.245	0.184
	Nitrogen dioxide	**0.745****	<0.001
	Nitrogen monoxide	**0.423***	0.018
	Respirable particles	**0.547****	0.001
	Fine particles	0.333	0.067

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

ide and respirable particles had statistically significant correlations, with coefficients ranging from weak to medium strength. In the afternoon, fine particles were the only variable to correlate with the UHI in Spearman. This negative correlation was observed during both time frames and was stronger during the later hour.

The correlation between the 05.00 UHI and the 08.00 air quality

In October 2021, all air quality variables except for fine particles at 08.00 showed statistically significant Pearson correlations with the UHI measured at 05.00 (Table 119). These correlations ranged from medium to quite strong, with the weakest correlation observed with respirable particles and the strongest with nitrogen dioxide. For Spearman correlations, only nitrogen dioxide and nitrogen monoxide were statistically significant, both showing medium-strength coefficients that were weaker than their corresponding Pearson values.

In 2023, nitrogen dioxide, nitrogen monoxide, and respirable particles all had statistically significant correlations with both Pearson and Spearman methods (Table 120). All of these correlations were positive, ranging from medium to strong. Nitrogen dioxide had the strongest correlation in both analyses, while the weakest correlation was with respirable particles in Pearson and with nitrogen monoxide in Spearman.

Overall, the results from 2021 and 2023 were quite similar for the 05.00 UHI and 08.00 air quality variable correlations, although the correlation coefficients in 2023 were stronger.

The correlation between the UHI, average wind speed and cloudiness

In October, daytime lasted from 07.00 to 17.30. During this period, a weak to moderate negative correlation was observed between UHI intensity and cloudiness (Table 121), while average wind speed showed some moderate statistically significant correlations. In contrast, nighttime conditions revealed a strong negative correlation with cloudiness and a generally weaker negative correlation with average wind speed.

Table 121. Pearson and Spearman correlation coefficients between the wind speed and UHI and between the cloudiness and UHI during daytime and nighttime in October 2021. Four different UHI intensities are calculated based on the Betel, Kurala, Kauppatori and Niuskala observation sites.

			Betel & Kurala Average UHI	Betel & Niuskala Average UHI	Kauppatori & Kurala Average UHI	Kauppatori & Niuskala Average UHI
Day	Pearson	Average wind speed	**-0.412***	-0.154	**-0.417***	-0.146
		Average cloudiness	-0.231	**-0.460****	**-0.367***	**-0.497****
	Spearman	Average wind speed	-0.135	0.087	-0.290	0.013
		Average cloudiness	-0.274	**-0.479****	**-0.371***	**-0.418***
Night	Pearson	Average wind speed	**-0.631****	**-0.390***	**-0.651****	**-0.366***
		Average cloudiness	**-0.539****	**-0.739****	**-0.479****	**-0.749****
	Spearman	Average wind speed	**-0.521****	-0.188	**-0.565****	-0.188
		Average cloudiness	**-0.723****	**-0.796****	**-0.682****	**-0.773****

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

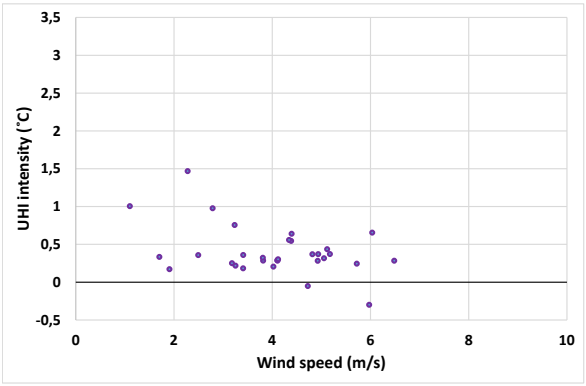

Figure 200. Scatter plot for wind speed and UHI between Betel and Kurala during daytime in October 2021.

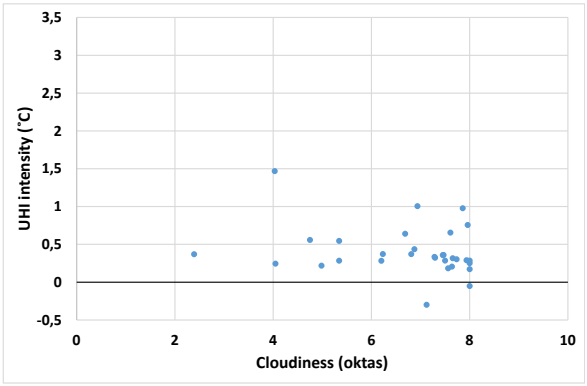

Figure 201. Scatter plot for cloudiness and UHI between Betel and Kurala during nighttime in October 2021.

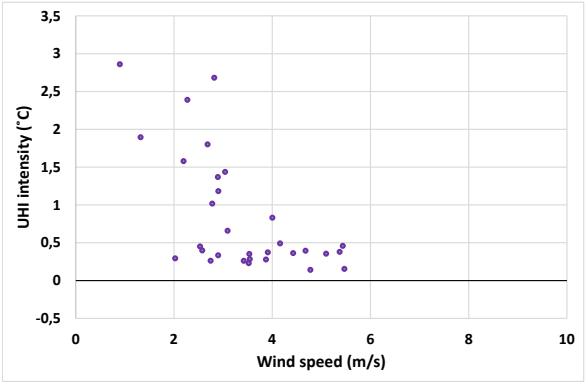

Figure 202. Scatter plot for wind speed and UHI between Betel and Kurala during nighttime in October 2021.

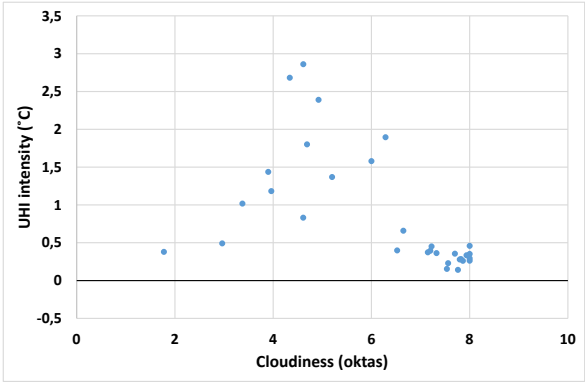

Figure 203. Scatter plot for cloudiness and UHI between Betel and Kurala during daytime in October 2021.

Table 122. Pearson and Spearman correlations between NAO index and different UHI logger pairs in October 2021.

	UHI	NAO index	Significance level
Pearson	Betel & Kurala	-0.177	0.342
	Betel & Niuskala	-0.291	0.112
	Kauppatori & Kurala	-0.144	0.440
	Kauppatori & Niuskala	-0.295	0.107
	Betel & Ryhmäpuutarha	-0.143	0.442
	Kauppatori & Ryhmäpuutarha	-0.087	0.641
Spearman	Betel & Kurala	**-0.417***	0.020
	Betel & Niuskala	**-0.419***	0.019
	Kauppatori & Kurala	-0.273	0.138
	Kauppatori & Niuskala	**-0.394***	0.028
	Betel & Ryhmäpuutarha	-0.309	0.091
	Kauppatori & Ryhmäpuutarha	-0.005	0.979

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

During the day, wind speeds fluctuated between 1 and 6.5 m/s (Figure 200). The intensity of the UHI effect remained below 1.5 °C, with occasional negative values. Cloud cover was generally high, with most values exceeding 5, although some lower values were also observed (Figure 201). At night, wind speeds typically ranged between 2 and 5.5 m/s, while UHI intensity showed greater variability, reaching up to nearly 3 °C (Figure 202). Cloudiness fluctuated during the night as well; however, in most cases when cloud cover reached its maximum value of 8, UHI intensity remained at or below 0.5 °C (Figure 203). Notably, no negative UHI values were recorded during nighttime hours.

The correlation between NAO index and UHI

In October 2021, no statistically significant correlations were found between the UHI intensity and the NAO index using Pearson correlation analysis (Table 122). However, Spearman correlation revealed statistically significant negative associations between the NAO index and the UHI intensities for the Betel–Kurala, Betel–Niuskala, and Kauppatori–Niuskala logger pairs. The Spearman coefficients were all approximately –0.4, indicating moderate negative correlations. Among these, the strongest correlation was observed for Betel–Niuskala, while the weakest occurred between Kauppatori and Niuskala.

5.1.11 November

The UHI intensities

In November 2021 UHI intensities ranged between 0 °C and 6 °C (Figures 204–207). The highest values, reaching 6 °C, were observed between the Betel–Niuskala and Kauppatori–Niuskala logger pairs, while peak intensities between Betel–Kurala and Kauppatori–Kurala remained slightly lower at approximately 5 °C and 4 °C, respectively. Distinct peaks occurred on the 7th, 13th–15th, and 22nd, most commonly during the early morning hours. However, on certain days, such as the 22nd, the maximum values were recorded during the daytime. Minor negative UHI values appeared, with the most intense cold island conditions observed

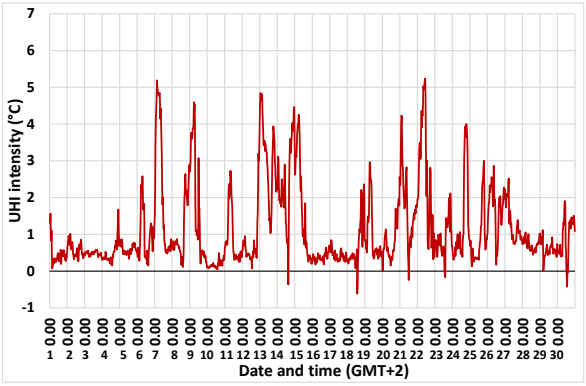

Figure 204. UHI intensity between Betel and Kurala during November 2021.

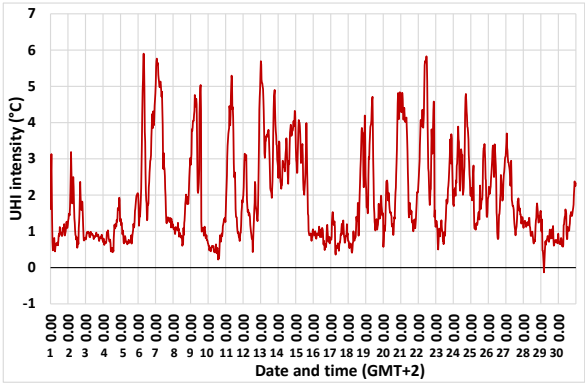

Figure 205. UHI intensity between Betel and Niuskala during November 2021.

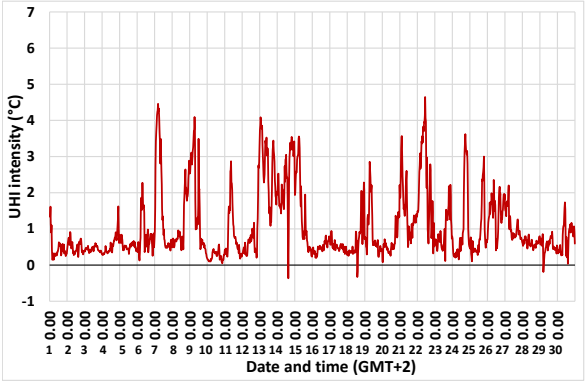

Figure 206. UHI intensity between Kauppatori and Kurala during November 2021.

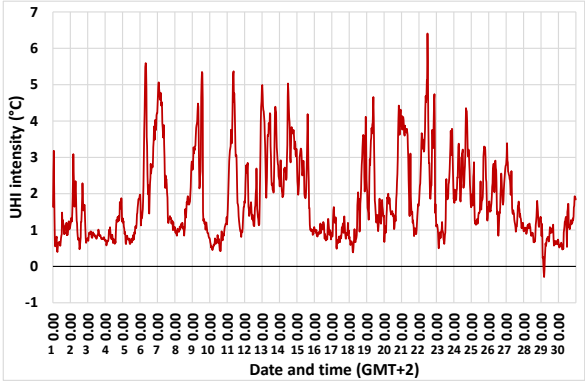

Figure 207. UHI intensity between Kauppatori and Niuskala during November 2021.

between the Betel–Kurala and Kauppatori–Kurala logger pairs, typically in the afternoon, and not exceeding –1 °C. During more stable periods, UHI intensities generally remained below 1 °C.

In November 2023, UHI intensities also ranged between 0 °C and 6 °C (Figures 208–211). The lowest maximum values were recorded between Kauppatori and Kurala, with peaks up to 5 °C, while the highest UHI intensity exceeded 7 °C on the 6th between Kauppatori and Niuskala. A period of stable and relatively low UHI intensities was observed from the 20th to the 28th. Additional notable peaks occurred on the 2nd and 18th. Minor negative UHI values were again present. Most peak values occurred around midnight or during the early morning hours. Compared to 2021, the year 2023 exhibited a more pronounced stable period in the middle of the month, while in 2021, stable periods were shorter and occurred between more frequent peaks. The frequency and magnitude of negative UHI values remained similar in both years. Although peak UHI intensities were comparable, high values were recorded more frequently in 2021 than in 2023.

Monthly summaries

In November 2021, air quality variables showed two distinct daily concentration peaks. One in

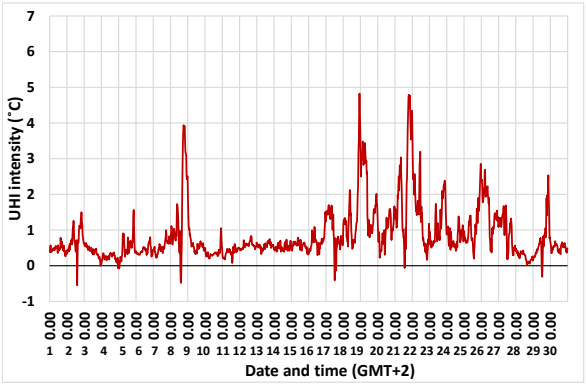

Figure 208. UHI intensity between Betel and Kurala during November 2023.

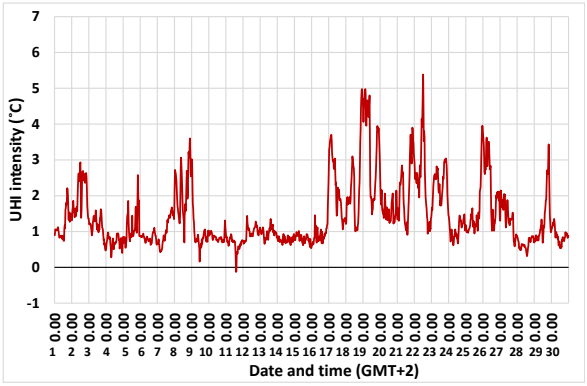

Figure 209. UHI intensity between Betel and Niuskala during November 2023.

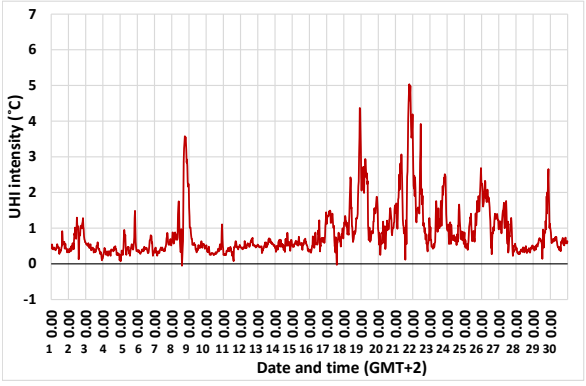

Figure 210. UHI intensity between Kauppatori and Kurala during November 2023.

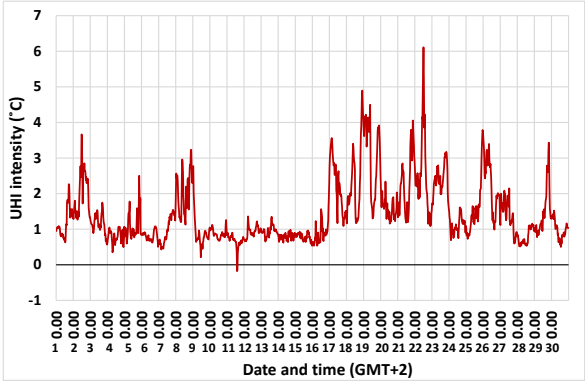

Figure 211. UHI intensity between Kauppatori and Niuskala during November 2023.

the morning between 07.00–09.00 and another in the afternoon between 15.00–17.00 (Figure 212). During these periods, the air quality index rose to approximately 1.3–1.4, while at other times it remained lower, around 1.1–1.2. Nitrogen dioxide peaked at 26 µg/m³, with typical values between 7–15 µg/m³ outside peak hours. Nitrogen monoxide reached a maximum of 21 µg/m³, and respirable particles peaked at 15 µg/m³, otherwise staying below 5 µg/m³ and 10 µg/m³, respectively. Fine particles did not display clear peaks and remained steady at around 5 µg/m³ throughout the day.

In contrast, 2023 showed a more consistent elevation in air quality variable concentrations, with values remaining relatively high from 07.00 to 21.00. The air quality index ranged between 1.03–1.30, nitrogen dioxide between 5.97–22.69 µg/m³, nitrogen monoxide between 0.71–9.93 µg/m³, respirable particles between 6.03–14.65 µg/m³, and fine particles between 3.84–6.48 µg/m³.

The UHI intensity in November 2021 remained fairly stable across the day (Figure 213), with no major fluctuations. A slight dip occurred around 15.00, when UHI dropped to approximately 0.6 °C, while during other hours, the average intensity stayed between 0.9–1.2 °C.

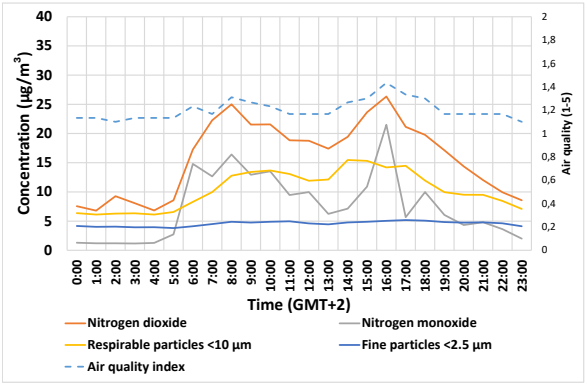

Figure 212. Hourly averages of air quality observations in November 2021.

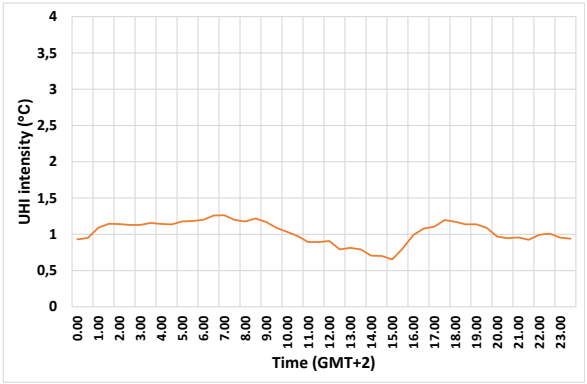

Figure 213. Hourly average UHI intensity between Kauppatori and Kurala in November 2021.

The correlations between the UHI and air quality

During the morning hours observed in this report, the UHI between Betel and Kurala in 2021 showed positive Pearson correlations with all air quality variables except fine particles (Table 123). Among these, the strongest correlation occurred with nitrogen monoxide, while the weakest was with the air quality index. The Pearson coefficients for nitrogen dioxide and nitrogen monoxide increased towards the 08.00–09.00 period, whereas the coefficients for the air quality index and respirable particles decreased. No statistically significant Spearman correlations were observed during this time. At 15.00–16.00, only nitrogen dioxide had a statistically significant positive Pearson correlation with UHI. However, during the 16.00–17.00 period, all air quality variables showed statistically significant correlations in both Pearson and Spearman analyses, except for fine particles, which only correlated in Spearman. Spearman coefficients were generally weaker than the corresponding Pearson coefficients, with the exception of respirable particles, whose Spearman coefficient increased. Nitrogen dioxide continued to exhibit the strongest correlation, followed by nitrogen monoxide with a moderately strong coefficient.

In 2023, no statistically significant correlations between UHI and air quality variables were observed during the morning hours (Table 124). However, a weak positive Spearman correlation with respirable particles was identified between 07.00 and 09.00. At 15.00–16.00, weak to moderate positive Pearson correlations were observed with nitrogen dioxide and nitrogen monoxide. During the 16.00–17.00 period, all variables except respirable particles showed statistically significant Pearson correlations. Nitrogen dioxide had a strong positive Pearson correlation, while the remaining variables showed moderate to weak positive correlations. In the Spearman analysis, only the air quality index and nitrogen dioxide correlated significantly, with nitrogen dioxide exhibiting a stronger coefficient than the air quality index, though still weaker than its corresponding Pearson coefficient.

For the UHI between Betel and Niuskala in 2021, statistically significant correlations were observed only during the time periods of 08.00–09.00 and 16.00–17.00 (Table 125). At 08.00–09.00, both nitrogen dioxide and nitrogen monoxide exhibited positive, medium-strength Pearson correlations with the UHI. In the afternoon period, from 16.00 to 17.00, statistically significant Pearson correlations were observed for air quality index, ni-

Table 123. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in November 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.455***	0.013	**0.361***	0.050	0.206	0.274	**0.515****	0.004
	Nitrogen dioxide	**0.432***	0.019	**0.545****	0.002	**0.421***	0.021	**0.823***'	<0.001
	Nitrogen monoxide	**0.559****	0.002	**0.639****	<0.001	-0.239	0.203	**0.663****	<0.001
	Respirable particles	**0.480****	0.008	**0.446***	0.013	0.255	0.174	**0.361***	0.050
	Fine particles	0.051	0.795	0.069	0.718	-0.056	0.767	0.176	0.351
Spearman	Air quality index	0.283	0.136	0.088	0.645	0.078	0.681	**0.383***	0.037
	Nitrogen dioxide	0.192	0.319	0.292	0.118	0.325	0.080	**0.708****	<0.001
	Nitrogen monoxide	0.118	0.544	0.241	0.199	-0.160	0.398	**0.578****	<0.001
	Respirable particles	0.158	0.412	-0.019	0.919	0.323	0.081	**0.529****	0.003
	Fine particles	0.129	0.504	-0.044	0.819	0.198	0.295	**0.412***	0.024

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 124. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in November 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.198	0.294	0.324	0.081	0.117	0.537	**0.480****	0.007
	Nitrogen dioxide	0.224	0.235	0.266	0.155	**0.442***	0.014	**0.702****	<0.001
	Nitrogen monoxide	-0.015	0.935	0.153	0.421	**0.377***	0.040	**0.412***	0.024
	Respirable particles	0.327	0.078	0.293	0.116	0.080	0.675	0.343	0.064
	Fine particles	0.302	0.105	0.234	0.212	0.191	0.312	**0.389***	0.034
Spearman	Air quality index	0.278	0.137	0.302	0.105	0.059	0.756	**0.382***	0.037
	Nitrogen dioxide	0.305	0.102	0.312	0.093	0.287	0.124	**0.546****	0.002
	Nitrogen monoxide	0.115	0.547	0.045	0.814	0.050	0.792	0.147	0.437
	Respirable particles	**0.417***	0.022	**0.369***	0.045	0.017	0.927	0.226	0.230
	Fine particles	0.238	0.205	0.154	0.416	0.114	0.549	0.264	0.158

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

trogen dioxide, and nitrogen monoxide. Of these, nitrogen dioxide and nitrogen monoxide also had statistically significant Spearman correlations. The Pearson coefficients for nitrogen dioxide and nitrogen monoxide were strong, while the corresponding Spearman coefficients were weaker.

In 2023, the only statistically significant correlation involving the UHI occurred during the 16.00–17.00 time frame (Table 126). During this period, the UHI correlated positively with nitrogen dioxide, although the strength of this Pearson correlation was moderate.

Table 125. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in November 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.263	0.169	0.178	0.346	0.103	0.588	**0.474****	0.008
	Nitrogen dioxide	0.243	0.203	**0.481****	0.007	0.125	0.512	**0.725****	<0.001
	Nitrogen monoxide	0.261	0.172	**0.487****	0.006	-0.305	0.102	**0.652****	<0.001
	Respirable particles	0.213	0.268	0.243	0.195	0.189	0.318	0.227	0.229
	Fine particles	-0.047	0.809	-0.032	0.866	-0.037	0.846	0.176	0.351
Spearman	Air quality index	0.220	0.251	0.053	0.783	0.108	0.568	**0.384***	0.036
	Nitrogen dioxide	0.055	0.777	0.274	0.144	0.150	0.430	**0.528****	0.003
	Nitrogen monoxide	-0.050	0.795	0.212	0.261	-0.162	0.392	0.311	0.094
	Respirable particles	0.049	0.802	-0.056	0.769	0.239	0.203	0.322	0.083
	Fine particles	0.001	0.995	-0.105	0.580	0.055	0.774	0.185	0.327

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 126. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in November 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.186	0.325	0.216	0.251	-0.134	0.479	0.113	0.553
	Nitrogen dioxide	0.238	0.205	0.201	0.286	0.212	0.260	**0.454***	0.012
	Nitrogen monoxide	-0.001	0.994	-0.018	0.924	0.105	0.580	0.253	0.177
	Respirable particles	0.245	0.193	0.249	0.184	-0.124	0.514	0.051	0.790
	Fine particles	0.213	0.257	0.186	0.324	-0.094	0.622	0.118	0.533
Spearman	Air quality index	0.247	0.188	0.302	0.105	-0.168	0.374	0.122	0.521
	Nitrogen dioxide	0.186	0.324	0.269	0.151	0.161	0.396	**0.421***	0.021
	Nitrogen monoxide	0.004	0.981	-0.066	0.729	0.015	0.938	0.170	0.369
	Respirable particles	0.199	0.291	0.140	0.461	-0.117	0.539	0.026	0.890
	Fine particles	0.135	0.475	0.025	0.894	-0.055	0.771	0.114	0.550

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

During the morning hours in 2021, the UHI between Kauppatori and Kurala exhibited positive Pearson correlations with all air quality variables except fine particles (Table 127). At 07.00–08.00, the correlations were of medium strength. By 08.00–09.00, the Pearson coefficient for nitrogen monoxide strengthened, while the coefficient for respirable particles weakened. Nitrogen dioxide's correlation also increased in strength, whereas the air quality index no longer showed a statistically significant correlation. In the afternoon, only nitrogen dioxide correlated at 15.00–16.00, with both Pearson and Spearman correlations being posi-

Table 127. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in November 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.452***	0.014	0.341	0.065	0.240	0.202	**0.484****	0.007
	Nitrogen dioxide	**0.440***	0.017	**0.514****	0.004	**0.451***	0.012	**0.799****	<0.001
	Nitrogen monoxide	**0.583****	<0.001	**0.617****	<0.001	-0.161	0.396	**0.604****	<0.001
	Respirable particles	**0.509****	0.005	**0.441***	0.015	0.232	0.218	**0.376***	0.040
	Fine particles	0.057	0.768	0.047	0.804	-0.125	0.511	0.162	0.393
Spearman	Air quality index	0.239	0.212	0.070	0.713	0.199	0.291	0.353	0.055
	Nitrogen dioxide	0.237	0.216	0.295	0.113	**0.482****	0.007	**0.667****	<0.001
	Nitrogen monoxide	0.205	0.286	0.290	0.120	0.148	0.435	**0.586****	<0.001
	Respirable particles	0.088	0.650	-0.061	0.750	0.295	0.113	**0.491****	0.006
	Fine particles	0.023	0.905	-0.101	0.596	0.169	0.372	**0.375***	0.041

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 128. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in November 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.196	0.299	0.337	0.069	-0.011	0.955	**0.424***	0.020
	Nitrogen dioxide	0.253	0.177	0.286	0.125	**0.413***	0.023	**0.669****	<0.001
	Nitrogen monoxide	0.016	0.935	0.189	0.316	0.321	0.084	**0.379***	0.039
	Respirable particles	0.333	0.072	0.275	0.141	-0.028	0.883	0.285	0.127
	Fine particles	0.313	0.092	0.224	0.233	0.042	0.825	0.318	0.087
Spearman	Air quality index	0.278	0.137	0.302	0.105	0.014	0.943	0.340	0.066
	Nitrogen dioxide	0.338	0.068	0.354	0.055	0.330	0.075	**0.541****	0.002
	Nitrogen monoxide	0.166	0.380	0.055	0.774	0.102	0.594	0.146	0.443
	Respirable particles	**0.416***	0.022	0.319	0.086	0.010	0.959	0.175	0.356
	Fine particles	0.243	0.196	0.118	0.536	0.050	0.794	0.173	0.360

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

tive. During the subsequent hour (16.00–17.00), nearly all air quality variables correlated with the UHI. Fine particles lacked a statistically significant Pearson correlation, and air quality index did not correlate with Spearman. Nitrogen dioxide and nitrogen monoxide showed strong correlations, while the remaining variables ranged from medium to quite weak in strength.

In 2023, no statistically significant Pearson correlations between the UHI and air quality variables were observed during the morning hours (Table 128). However, a moderate positive Spearman correlation with respir-

Table 129. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in November 2021.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.221	0.250	0.130	0.495	0.112	0.555	**0.452***	0.012
	Nitrogen dioxide	0.210	0.274	**0.433***	0.017	0.121	0.525	**0.710****	<0.001
	Nitrogen monoxide	0.221	0.250	**0.433***	0.017	-0.255	0.173	**0.612****	<0.001
	Respirable particles	0.182	0.345	0.201	0.287	0.166	0.380	0.234	0.213
	Fine particles	-0.057	0.769	-0.062	0.743	-0.072	0.703	0.167	0.377
Spearman	Air quality index	0.191	0.321	0.046	0.808	0.154	0.418	**0.379***	0.039
	Nitrogen dioxide	0.044	0.821	0.301	0.106	0.182	0.335	**0.522****	0.003
	Nitrogen monoxide	-0.063	0.746	0.234	0.214	-0.061	0.748	0.313	0.093
	Respirable particles	0.003	0.989	-0.050	0.793	0.211	0.263	0.265	0.157
	Fine particles	-0.034	0.861	-0.121	0.524	0.026	0.892	0.150	0.428

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 130. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in November 2023.

		07.00–08.00		08.00–09.00		15.00–16.00		16.00–17.00	
	Kauppatori & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.186	0.324	0.229	0.223	-0.197	0.296	0.051	0.789
	Nitrogen dioxide	0.263	0.160	0.219	0.244	0.180	0.342	**0.412***	0.024
	Nitrogen monoxide	0.021	0.911	0.004	0.985	0.065	0.733	0.214	0.256
	Respirable particles	0.246	0.190	0.242	0.197	-0.176	0.352	-0.011	0.953
	Fine particles	0.218	0.247	0.183	0.332	-0.172	0.365	0.043	0.821
Spearman	Air quality index	0.247	0.188	0.315	0.091	-0.232	0.217	0.046	0.808
	Nitrogen dioxide	0.218	0.247	0.297	0.110	0.172	0.365	**0.366***	0.047
	Nitrogen monoxide	0.037	0.846	-0.012	0.949	0.021	0.911	0.148	0.435
	Respirable particles	0.189	0.318	0.102	0.592	-0.145	0.444	0.006	0.973
	Fine particles	0.151	0.425	0.042	0.824	-0.107	0.572	0.035	0.855

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

able particles was detected at 07.00–08.00. At 15.00–16.00, nitrogen dioxide displayed a moderate positive Pearson correlation. During 16.00–17.00, weak to moderate positive Pearson correlations emerged with air quality index and nitrogen monoxide, while nitrogen dioxide again demonstrated a stronger positive Pearson correlation. For Spearman, only nitrogen dioxide showed a statistically significant correlation, with a medium-strength positive coefficient.

In the case of the Kauppatori–Niuskala pair in 2021, no statistically significant correlations between UHI and air quality variables were

Table 131. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in November 2021. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index	**0.483****	0.008
	Nitrogen dioxide	**0.385***	0.039
	Nitrogen monoxide	**0.579****	0.001
	Respirable particles	**0.450***	0.014
	Fine particles	0.091	0.640
Spearman	Air quality index	0.335	0.076
	Nitrogen dioxide	0.180	0.349
	Nitrogen monoxide	0.177	0.360
	Respirable particles	0.217	0.258
	Fine particles	0.198	0.303

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 132. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in November 2023. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index	0.303	0.104
	Nitrogen dioxide	0.042	0.826
	Nitrogen monoxide	-0.155	0.413
	Respirable particles	**0.441***	0.015
	Fine particles	0.315	0.090
Spearman	Air quality index	0.340	0.066
	Nitrogen dioxide	0.125	0.511
	Nitrogen monoxide	0.051	0.789
	Respirable particles	**0.516****	0.004
	Fine particles	0.257	0.170

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

observed during the 07.00–08.00 and 15.00–16.00 time periods (Table 129). At 08.00–09.00, both nitrogen dioxide and nitrogen monoxide exhibited positive Pearson correlations with the UHI, with identical coefficients. During the 16.00–17.00 period, the air quality index, nitrogen dioxide, and nitrogen monoxide all showed statistically significant correlations. Of these, nitrogen dioxide did not correlate significantly with Spearman. Pearson correlations for both nitrogen dioxide and nitrogen monoxide were strong, while the air quality index showed a weaker correlation. The Spearman correlation for nitrogen dioxide, while statistically significant, was weaker than the Pearson coefficient and fell within the medium strength range.

In 2023, the UHI did not exhibit any statistically significant correlations with air quality variables during the morning hours or the 15.00–16.00 period (Table 130). At 16.00–17.00, only nitrogen dioxide displayed a moderate positive Pearson correlation and weak Spearman correlation with the UHI.

The correlation between the 05.00 UHI and the 08.00 air quality

In November 2021, all air quality variables except fine particles exhibited statistically significant Pearson correlations with the UHI at 05.00 (Table 131). These correlations were of moderate strength, with the exception of nitrogen dioxide, which displayed a relatively weaker coefficient. No air quality variables showed statistically significant Spearman correlations during this period.

In contrast, in 2023, only respirable particles demonstrated a statistically significant correlation with the 05.00 UHI (Table 132). This association was evident in both Pearson and Spearman analyses, with positive, moderate-strength coefficients; the Spearman coefficient was slightly stronger than the Pearson.

While neither year yielded significant Spearman correlations for most variables, 2021 featured multiple significant Pearson correlations, whereas in 2023 only respirable particles retained a significant Pearson association.

Table 133. Pearson and Spearman correlation coefficients between the wind speed and UHI and between the cloudiness and UHI during daytime and nighttime in November 2021. Four different UHI intensities are calculated based on the Betel, Kurala, Kauppatori and Niuskala observation sites.

			Betel & Kurala Average UHI	Betel & Niuskala Average UHI	Kauppatori & Kurala Average UHI	Kauppatori & Niuskala Average UHI
Day	Pearson	Average wind speed	-0.609**	-0.530**	-0.609**	-0.511**
		Average cloudiness	-0.383*	-0.387*	-0.471**	-0.428*
	Spearman	Average wind speed	-0.613**	-0.509**	-0.560**	-0.462*
		Average cloudiness	-0.423*	-0.473**	-0.409*	-0.456*
Night	Pearson	Average wind speed	-0.672**	-0.568**	-0.678**	-0.554**
		Average cloudiness	-0.550**	-0.578**	-0.510**	-0.549**
	Spearman	Average wind speed	-0.557**	-0.548**	-0.601**	-0.552**
		Average cloudiness	-0.617**	-0.556**	-0.536**	-0.520**

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

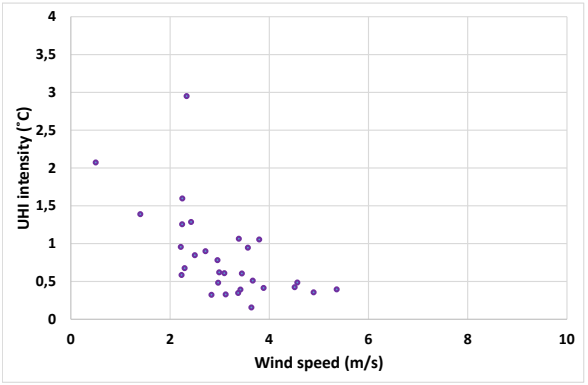

Figure 214. Scatter plot for wind speed and UHI between Betel and Kurala during daytime in November 2021.

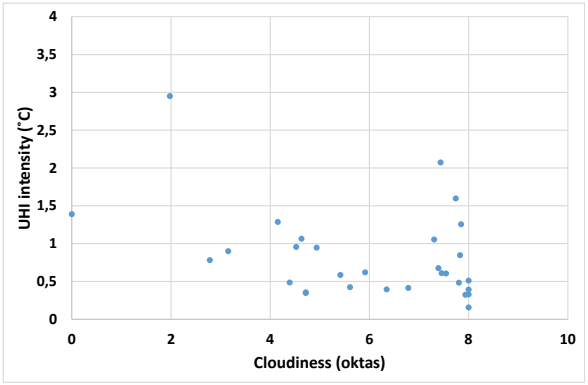

Figure 215. Scatter plot for cloudiness and UHI between Betel and Kurala during daytime in November 2021.

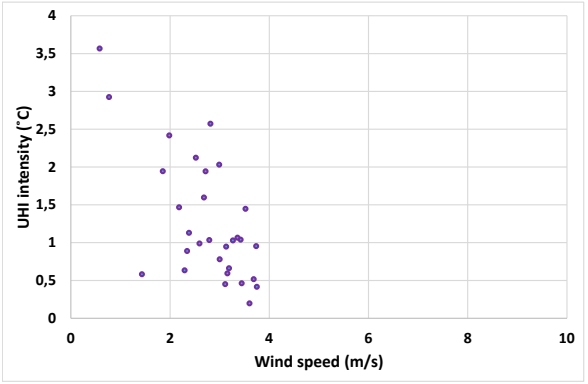

Figure 216. Scatter plot for wind speed and UHI between Betel and Kurala during nighttime in November 2021.

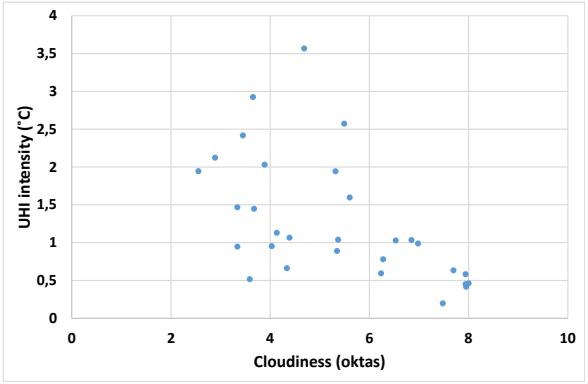

Figure 217. Scatter plot for cloudiness and UHI between Betel and Kurala during nighttime in November 2021.

The correlation between the UHI, average wind speed and cloudiness

In November, daytime lasted from 08.30 to 16.00. During this period, the UHI intensity showed a quite strong negative correlation with average wind speed and a quite weak negative correlation with cloudiness (Table 133). At night, both variables demonstrated stronger negative correlations with UHI, indicating that as wind speed or cloudiness increased, UHI intensity decreased.

In the daytime scatter plots for November, most wind speeds ranged between 2 and 5 m/s (Figure 214). UHI intensities generally stayed below 1.5 °C, though some outliers with higher intensities were recorded. These higher UHI values typically occurred during periods of low wind speeds, reflecting the observed weak negative correlation between UHI and wind speed. Cloud cover during the day was predominantly above 4 oktas, frequently nearing 8 oktas (Figure 215). Despite this, the correlation with UHI remained weakly negative, suggesting that cloudier conditions only slightly reduced UHI intensity during daylight hours. At night, wind speeds mostly fell between 2 and 4 m/s, with some instances dropping below 1 m/s (Figure 216). The highest UHI intensities, approaching 3 °C, occurred during these calmer wind conditions, reinforcing the negative relationship between wind speed and UHI. Cloud cover at night was more variable, ranging mostly from 3 to 8 oktas (Figure 217). While no clear visual pattern emerged in the scatter plot, the data still indicated a strong negative correlation between cloudiness and UHI, meaning clearer nights were more conducive to higher UHI intensities. Overall, wind speed had a more pronounced effect on UHI than cloud cover, particularly during nighttime.

The correlation between NAO index and UHI

No statistically significant correlations occurred between the NAO index and the observed UHI logger pairs in November 2021 (Table 134).

Table 134. Pearson and Spearman correlations between NAO index and different UHI logger pairs in November 2021.

	UHI	NAO index	Significance level
Pearson	Betel & Kurala	0.210	0.265
	Betel & Niuskala	0.131	0.490
	Kauppatori & Kurala	0.221	0.240
	Kauppatori & Niuskala	0.124	0.514
	Betel & Ryhmäpuutarha	0.122	0.521
	Kauppatori & Ryhmäpuutarha	0.108	0.571
Spearman	Betel & Kurala	-0.030	0.873
	Betel & Niuskala	0.077	0.685
	Kauppatori & Kurala	0.027	0.886
	Kauppatori & Niuskala	0.108	0.570
	Betel & Ryhmäpuutarha	-0.088	0.643
	Kauppatori & Ryhmäpuutarha	-0.059	0.757

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

5.1.12 December

The UHI intensities

In December 2021, UHI peak values occurred during the period from the 22nd to the 28th, with intensities reaching up to 8.5 °C (Figures 218–221). These peaks were more pronounced between Betel–Kurala and Betel–Niuskala. The peaks appeared at random times throughout the day, with the highest recorded during the late afternoon, and others occurring during the day and even in the morning. The rest of the month was calmer, with a minor peak period between the 6th and 9th, during which values reached only up to 5 °C. Negative values were rare and negligible.

In December 2023, UHI intensities ranged from below 1 °C to a maximum of 6 °C (Figures 222–225). For most of the month, UHI remained relatively stable at approximately 1 °C, with a few distinct peak values. The most prominent peaks were observed on the 6th, 7th, 18th, and 26th, with the highest occurring on the 6th. In the days leading up to this peak, UHI values fluctuated frequently. Most of the maximum intensities were recorded in the late evening, with some occurring after midnight. The only negative UHI value of the month was observed on the 6th, although it was minimal and did not exceed –0.5 °C. Unlike other instances of UCIs, this negative value occurred after midnight.

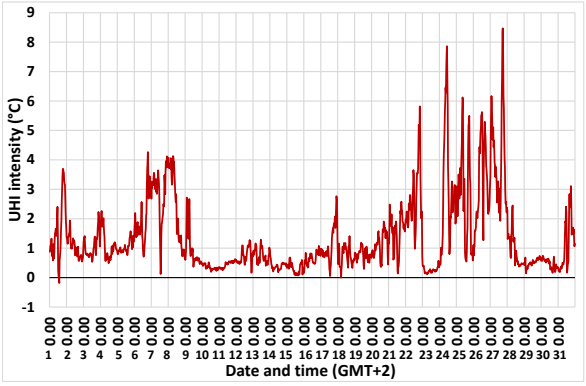

Figure 218. UHI intensity between Betel and Kurala during December 2021.

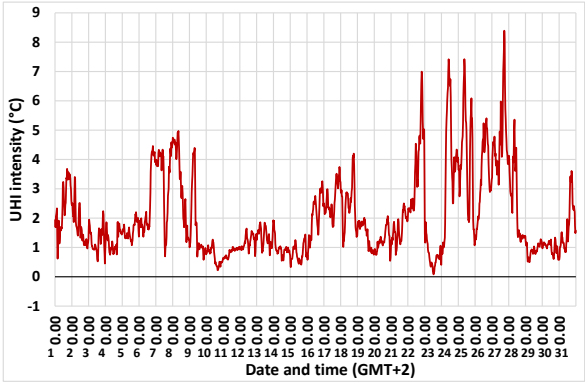

Figure 219. UHI intensity between Betel and Niuskala during December 2021.

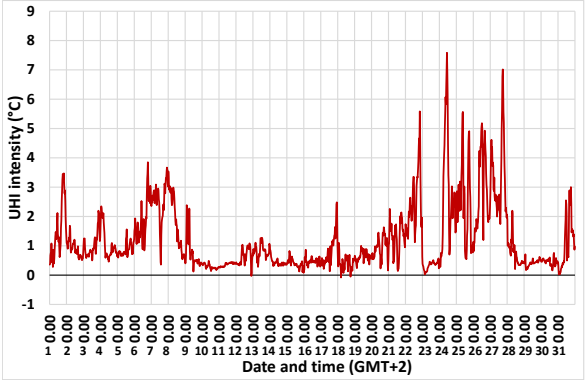

Figure 220. UHI intensity between Kauppatori and Kurala during December 2021.

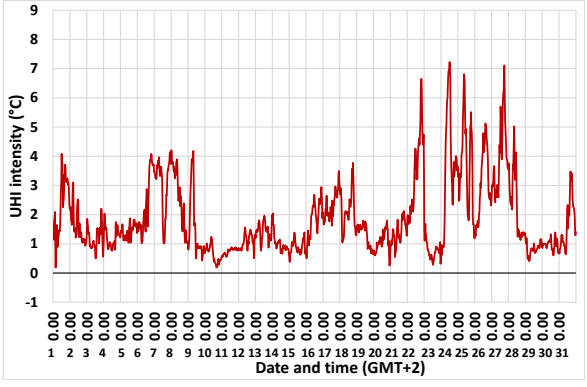

Figure 221. UHI intensity between Kauppatori and Niuskala during December 2021.

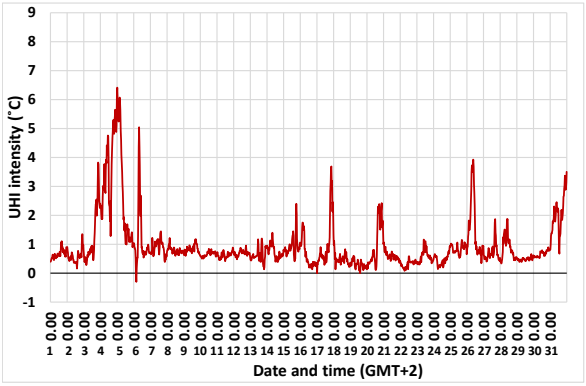

Figure 222. UHI intensity between Betel and Kurala during December 2023.

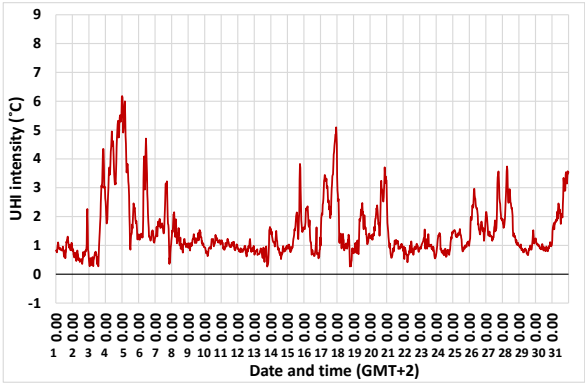

Figure 223. UHI intensity between Betel and Niuskala during December 2023.

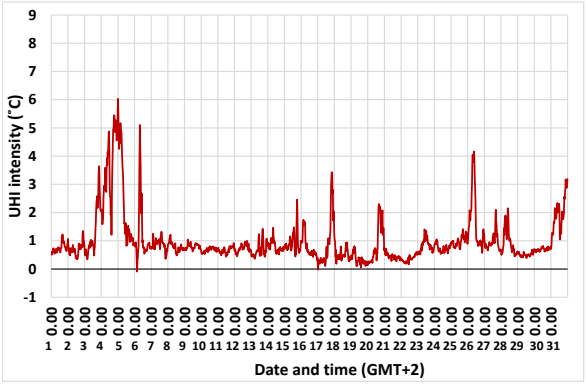

Figure 224. UHI intensity between Kauppatori and Kurala during December 2023.

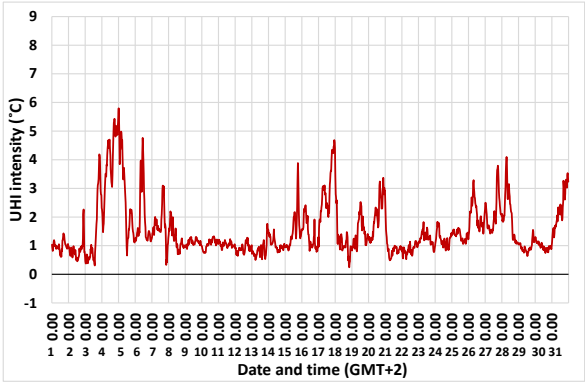

Figure 225. UHI intensity between Kauppatori and Niuskala during December 2023.

Compared to 2021, the year 2023 exhibited considerably calmer UHI conditions, with lower peak intensities and more stable periods.

Monthly summaries

In December 2021, the air quality index reached peak values of approximately 1.5 during the day, with smaller peaks occurring around midday and shortly after 17.00 (Figure 226). During the night, values ranged between 1.1 and 1.3. Nitrogen monoxide and respirable particles exhibited peak concentrations in the morning and around midday, with nitrogen monoxide reaching approximately 27 µg/m³ and respirable particles about 23 µg/m³. Smaller peaks were observed in the afternoon between 14.00 and 16.00. Nitrogen dioxide peaked similarly to the air quality index just after 17.00, reaching 30 µg/m³, with a smaller peak in the morning slightly exceeding 25 µg/m³. Fine particle concentrations remained relatively stable throughout the day, with a modest peak around midday reaching approximately 6 µg/m³.

In 2023, the highest air quality values were recorded between 09.00 and 18.00. During this period, the air quality index ranged from 1.10 to 1.26, nitrogen dioxide from 8.27 to 21.64 µg/m³, nitrogen monoxide from 1.01 to 9.36 µg/m³, respirable particles from 6.42 to 9.61 µg/m³, and fine particles from 5.27 to 6.91 µg/m³.

In 2021, peaks in UHI were observed during the morning and late afternoon (Fig-

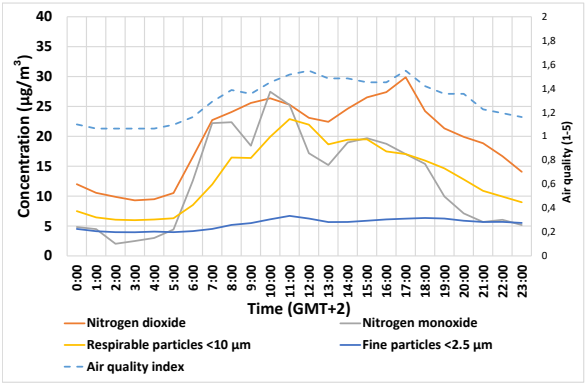

Figure 226. Hourly averages of air quality observations in December 2021.

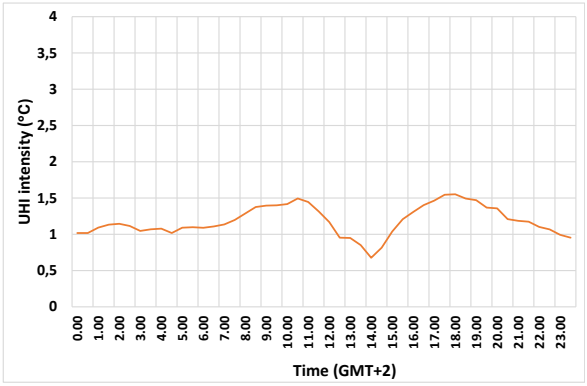

Figure 227. Hourly average UHI intensity between Kauppatori and Kurala in December 2021.

ure 227), specifically between 07.30–11.30 and 15.00–20.30. During these periods, UHI intensities ranged from approximately 1.2 to 1.5 °C, while during other hours, values were generally around 0.8 to 1.0 °C.

The correlations between the UHI and air quality

In 2021, the UHI between the Betel and Kurala loggers showed statistically significant Pearson correlations with all air quality variables except respirable particles during the 07.00–08.00 time frame (Table 135). Most of the coefficients ranged from weak to medium strength. For Spearman, the air quality index exhibited a medium-strength correlation. During the subsequent hour, nitrogen dioxide and nitrogen monoxide had weak Pearson correlations, while the air quality index and nitrogen dioxide showed medium-strength Spearman correlations. In the afternoon, at 15.00–16.00, all variables correlated with UHI except respirable particles, which correlated only in the Spearman analysis. Nitrogen dioxide and nitrogen monoxide had strong Pearson coefficients, whereas in the Spearman correlation, air quality index, nitrogen dioxide, and fine particles all had strong coefficients. During the following hour, the same variables remained correlated, except nitrogen monoxide, which correlated only in the Pearson analysis. Pearson coefficients were generally weaker than in the previous hour, except for nitrogen monoxide, whose coefficient strengthened. For Spearman, all coefficients were weaker than in the preceding hour.

In 2023, the UHI had a weak positive Pearson correlation with nitrogen monoxide during 07.00–08.00 (Table 136). Additionally, fine particles exhibited a positive Spearman correlation. In the following hour, nitrogen dioxide and nitrogen monoxide showed strong to medium-strength Pearson correlations. For Spearman, nitrogen dioxide's coefficient was stronger, while that of nitrogen monoxide was weaker. Respirable and fine particles also had medium-strength Spearman correlations. In the afternoon at 15.00–16.00, the UHI had a quite strong positive Pearson correlation with nitrogen dioxide and moderate correlations with nitrogen monoxide and respirable particles. For Spearman, nitrogen dioxide, respirable particles, and fine particles exhibited positive medium-strength correlations. During the following hour, all coefficients increased in strength. Respirable particles remained at approximately the same level, but the correlation with nitrogen monoxide grew significantly stronger. Additionally, nitrogen monoxide showed a weak positive Spearman correlation.

Table 135. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in December 2021.

		07.00-08.00		08.00-09.00		15.00-16.00		16.00-17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	**0.396***	0.027	0.316	0.083	**0.498****	0.004	**0.401***	0.025
	Nitrogen dioxide	**0.317**	0.082	**0.370***	0.040	**0.808****	<0.001	**0.611****	<0.001
	Nitrogen monoxide	**0.442***	0.013	**0.360***	0.047	**0.708****	<0.001	**0.783****	<0.001
	Respirable particles	0.354	0.057	0.265	0.150	0.226	0.222	0.206	0.265
	Fine particles	**0.359***	0.047	0.264	0.151	**0.585****	<0.001	**0.580****	<0.001
Spearman	Air quality index	**0.426***	0.017	**0.521****	0.003	**0.664***	<0.001	**0.543****	0.002
	Nitrogen dioxide	0.248	0.178	**0.454***	0.010	**0.699****	<0.001	**0.674****	<0.001
	Nitrogen monoxide	0.047	0.802	0.208	0.261	**0.425***	0.017	0.328	0.072
	Respirable particles	0.232	0.210	0.342	0.060	**0.540****	0.002	**0.501****	0.004
	Fine particles	0.173	0.352	0.286	0.119	**0.608****	<0.001	**0.595****	<0.001

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 136. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in December 2023.

		07.00-08.00		08.00-09.00		15.00-16.00		16.00-17.00	
	Betel & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	-0.123	0.508	0.007	0.969	0.293	0.110	0.348	0.055
	Nitrogen dioxide	0.276	0.133	**0.426***	0.017	**0.610****	<0.001	**0.656****	<0.001
	Nitrogen monoxide	**0.380***	0.035	**0.530****	0.002	**0.588****	<0.001	**0.721****	<0.001
	Respirable particles	0.048	0.797	0.043	0.819	**0.558****	0.001	**0.559****	0.001
	Fine particles	0.053	0.776	0.093	0.617	0.294	0.108	0.344	0.058
Spearman	Air quality index	0.065	0.730	0.229	0.216	0.204	0.270	0.245	0.184
	Nitrogen dioxide	0.351	0.053	**0.621****	<0.001	**0.467****	0.008	**0.578****	<0.001
	Nitrogen monoxide	0.133	0.476	**0.361***	0.046	0.265	0.150	**0.363***	0.044
	Respirable particles	**0.365***	0.043	**0.490****	0.005	**0.448***	0.011	**0.552****	0.001
	Fine particles	**0.436***	0.014	**0.488****	0.005	**0.437***	0.014	**0.515****	0.003

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

For the Betel and Niuskala logger pair in 2021, nitrogen monoxide exhibited a weak positive Pearson correlation with UHI at 07.00–08.00 (Table 137). During the following hour, this correlation strengthened slightly. In addition, nitrogen dioxide showed both weak Pearson and Spearman correlations. At 15.00–16.00, all variables except respirable particles correlated with UHI in the Pearson analysis. Nitrogen dioxide and nitrogen monoxide had strong Pearson coefficients. In the Spearman analysis, air quality index, nitrogen dioxide, and fine particles were correlated, with nitrogen dioxide showing a strong correlation. During the subsequent

Table 137. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in December 2021.

		07.00-08.00		08.00-09.00		15.00-16.00		16.00-17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.240	0.194	0.268	0.144	**0.399***	0.026	**0.414***	0.021
	Nitrogen dioxide	0.298	0.103	**0.369***	0.041	**0.804****	<0.001	**0.643****	<0.001
	Nitrogen monoxide	**0.358***	0.048	**0.367***	0.042	**0.686****	<0.001	**0.748****	<0.001
	Respirable particles	0.252	0.171	0.259	0.159	0.090	0.628	0.151	0.417
	Fine particles	0.308	0.092	0.269	0.144	**0.449***	0.011	**0.493****	0.005
Spearman	Air quality index	0.165	0.375	0.303	0.097	**0.522***	0.003	**0.466****	0.008
	Nitrogen dioxide	0.197	0.288	**0.387***	0.032	**0.689***	<0.001	**0.612****	<0.001
	Nitrogen monoxide	0.066	0.726	0.201	0.279	0.354	0.051	0.259	0.159
	Respirable particles	0.017	0.929	0.109	0.559	0.327	0.072	0.355	0.050
	Fine particles	0.024	0.897	0.135	0.468	**0.408***	0.023	**0.471****	0.007

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 138. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in December 2023.

		07.00-08.00		08.00-09.00		15.00-16.00		16.00-17.00	
	Betel & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	-0.193	0.297	-0.013	0.943	0.228	0.218	0.246	0.182
	Nitrogen dioxide	0.257	0.163	**0.361***	0.046	**0.544****	0.002	**0.579****	<0.001
	Nitrogen monoxide	**0.403***	0.024	**0.566****	<0.001	**0.448***	0.011	**0.528****	0.002
	Respirable particles	-0.065	0.730	-0.045	0.808	**0.372***	0.039	**0.410***	0.022
	Fine particles	-0.114	0.541	-0.093	0.620	0.085	0.650	0.128	0.494
Spearman	Air quality index	-0.108	0.565	0.044	0.813	0.172	0.354	0.245	0.184
	Nitrogen dioxide	0.202	0.275	0.277	0.131	0.331	0.069	0.346	0.056
	Nitrogen monoxide	0.078	0.678	0.104	0.579	0.121	0.517	0.139	0.456
	Respirable particles	-0.035	0.850	-0.052	0.782	0.164	0.378	**0.379***	0.036
	Fine particles	-0.085	0.650	-0.126	0.498	0.027	0.887	0.156	0.401

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

hour, the same variables remained correlated. For Pearson, all coefficients strengthened except that of nitrogen dioxide, which weakened slightly in relative terms. In the Spearman analysis, the correlation for fine particles increased in strength, while the coefficients for air quality index and nitrogen dioxide weakened.

In 2023, nitrogen monoxide exhibited a medium-strength positive correlation at 07.00–08.00 (Table 138). This variable continued to correlate during the next hour, with an even stronger coefficient. Nitrogen dioxide also showed a quite weak positive correlation during this time. At 15.00–16.00, nitrogen dioxide and nitrogen mon-

Table 139. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in December 2021.

		07.00-08.00		08.00-09.00		15.00-16.00		16.00-17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.354	0.051	0.244	0.186	0.480**	0.006	**0.423***	0.018
	Nitrogen dioxide	0.265	0.150	0.314	0.085	**0.798****	<0.001	**0.645****	<0.001
	Nitrogen monoxide	**0.359***	0.047	0.266	0.149	**0.692****	<0.001	**0.775****	<0.001
	Respirable particles	0.303	0.097	0.197	0.287	0.214	0.247	0.220	0.234
	Fine particles	0.304	0.097	0.196	0.292	**0.579****	<0.001	**0.601****	<0.001
Spearman	Air quality index	**0.460****	0.009	**0.538****	0.002	**0.661****	<0.001	**0.554****	0.001
	Nitrogen dioxide	0.280	0.127	**0.489****	0.005	**0.690****	<0.001	**0.706****	<0.001
	Nitrogen monoxide	0.078	0.676	0.274	0.137	**0.428***	0.016	**0.372***	0.039
	Respirable particles	0.327	0.072	**0.460****	0.009	**0.563****	<0.001	**0.545****	0.002
	Fine particles	0.280	0.127	**0.394***	0.028	**0.616****	<0.001	**0.643****	<0.001

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 140. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in December 2023.

		07.00-08.00		08.00-09.00		15.00-16.00		16.00-17.00	
	Kauppatori & Kurala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	-0.122	0.513	-0.016	0.932	0.266	0.147	0.311	0.089
	Nitrogen dioxide	0.234	0.205	**0.369***	0.041	**0.552****	0.001	**0.605****	<0.001
	Nitrogen monoxide	**0.357***	0.048	**0.502****	0.004	**0.557****	0.001	**0.710****	<0.001
	Respirable particles	0.035	0.852	0.029	0.879	**0.561****	0.001	**0.550****	0.001
	Fine particles	0.050	0.788	0.083	0.655	0.284	0.122	0.317	0.083
Spearman	Air quality index	-0.011	0.954	0.174	0.350	0.118	0.526	0.186	0.316
	Nitrogen dioxide	0.234	0.205	**0.405***	0.024	**0.361***	0.046	**0.484****	0.006
	Nitrogen monoxide	0.059	0.751	0.226	0.221	0.198	0.285	0.321	0.078
	Respirable particles	0.236	0.201	0.325	0.074	**0.475****	0.007	**0.510****	0.003
	Fine particles	0.346	0.057	**0.439***	0.013	**0.459****	0.009	**0.482****	0.006

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

oxide exhibited a medium-strength positive correlation with UHI, and respirable particles a quite weak one. All correlations were positive. During the following hour, the same three variables remained correlated with medium-strength coefficients. Additionally, respirable particles also had a positive Spearman correlation.

In 2021, the UHI between Kauppatori and Kurala showed a weak Pearson correlation with nitrogen monoxide at 07.00–08.00 (Table 139). A medium-strength Spearman correlation was also observed with the air quality index during this time. Between 08.00–09.00, all variables except nitrogen monoxide exhibited positive

Table 141. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in December 2021.

		07.00-08.00		08.00-09.00		15.00-16.00		16.00-17.00	
	Kauppatori & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	0.181	0.330	0.199	0.282	**0.381***	0.034	**0.440***	0.013
	Nitrogen dioxide	0.252	0.171	0.324	0.076	**0.807****	<0.001	**0.684****	<0.001
	Nitrogen monoxide	0.276	0.133	0.285	0.120	**0.681****	<0.001	**0.741****	<0.001
	Respirable particles	0.204	0.272	0.200	0.281	0.072	0.701	0.158	0.397
	Fine particles	0.254	0.168	0.209	0.258	**0.440***	0.013	**0.505****	0.004
Spearman	Air quality index	0.172	0.354	0.270	0.141	**0.498****	0.004	**0.473****	0.007
	Nitrogen dioxide	0.195	0.293	**0.373***	0.039	**0.711****	<0.001	**0.610****	<0.001
	Nitrogen monoxide	0.064	0.731	0.206	0.266	**0.391***	0.029	0.271	0.140
	Respirable particles	-0.017	0.930	0.075	0.689	0.307	0.093	0.353	0.052
	Fine particles	-0.002	0.992	0.125	0.502	**0.395***	0.028	**0.466****	0.008

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 142. Pearson and Spearman correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in December 2023.

		07.00-08.00		08.00-09.00		15.00-16.00		16.00-17.00	
	Kauppatori & Niuskala	UHI	Significance level	UHI	Significance level	UHI	Significance level	UHI	Significance level
Pearson	Air quality index	-0.198	0.285	-0.039	0.834	0.214	0.248	0.220	0.235
	Nitrogen dioxide	0.219	0.237	0.315	0.085	**0.515****	0.003	**0.546****	0.002
	Nitrogen monoxide	**0.391***	0.030	**0.562****	<0.001	**0.437***	0.014	**0.528****	0.002
	Respirable particles	-0.082	0.661	-0.066	0.726	**0.383***	0.033	**0.410***	0.022
	Fine particles	-0.122	0.512	-0.114	0.542	0.078	0.675	0.109	0.561
Spearman	Air quality index	-0.151	0.419	-0.009	0.960	0.172	0.354	0.186	0.316
	Nitrogen dioxide	0.092	0.624	0.164	0.378	0.324	0.075	0.311	0.089
	Nitrogen monoxide	-0.039	0.836	0.018	0.925	0.103	0.583	0.098	0.601
	Respirable particles	-0.109	0.559	-0.114	0.542	0.250	0.175	**0.360***	0.047
	Fine particles	-0.148	0.427	-0.180	0.333	0.103	0.580	0.135	0.470

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Spearman correlations, with the strongest correlation observed for the air quality index and the weakest for fine particles. In the afternoon, all air quality variables except respirable particles were positively correlated in the Pearson analysis; respirable particles correlated only in the Spearman analysis. Nitrogen dioxide, nitrogen monoxide, and fine particles had strong Pearson coefficients, while the remaining variables exhibited weak to medium-strength correlations.

In 2023, the UHI showed a weak positive Pearson correlation with nitrogen monoxide at 07.00–08.00 (Table 140). During the follow-

ing hour, nitrogen monoxide exhibited a medium-strength positive correlation, and nitrogen dioxide a weak positive correlation. In the Spearman analysis, nitrogen dioxide and fine particles had medium-strength coefficients. At 15.00–16.00, the UHI exhibited a moderate positive Pearson correlation with nitrogen dioxide, nitrogen monoxide, and respirable particles. In the Spearman analysis, nitrogen dioxide, respirable particles, and fine particles correlated with coefficients ranging from weak to medium strength. During 16.00–17.00, the same variables remained correlated, with most coefficients strengthening compared to the previous hour, except for respirable particles in the Pearson analysis, which showed a weaker correlation. Nitrogen dioxide and monoxide had a strong Pearson correlation, and all correlations were positive.

In the case of Kauppatori and Niuskala in 2021, the UHI did not exhibit any statistically significant correlations during the first time frame (Table 141). At 08.00–09.00, only nitrogen dioxide showed a weak positive Spearman correlation. In the afternoon, all air quality variables except respirable particles were correlated with the UHI. However, during the final observation hour, nitrogen monoxide correlated only in the Pearson analysis. Nitrogen dioxide had a strong correlation coefficient for both Pearson and Spearman, though its strength decreased in the latter hour. Nitrogen monoxide also showed a strong Pearson correlation, with the coefficient increasing during the last hour. The remaining variables had coefficients ranging from weak to medium strength. Overall, most coefficients increased in the latter hour, except for nitrogen dioxide and the air quality index in the Spearman analysis, which showed a decrease.

In 2023, the UHI had a quite weak positive Pearson correlation with nitrogen monoxide at 07.00–08.00 (Table 142). At 08.00–09.00, this correlation increased to medium strength. In the afternoon, a medium-strength positive Pearson correlation was observed with nitrogen dioxide and nitrogen monoxide, while respirable particles showed a weaker correlation. By 16.00–17.00, the correlation coefficients had strengthened relative to the previous hour. Additionally, respirable particles exhibited a weak positive Spearman correlation.

The correlation between the 05.00 UHI and the 08.00 air quality

In December 2021, all air quality variables exhibited statistically significant Pearson correlations with the UHI (Table 143). All coefficients were strong, with nitrogen monoxide showing the strongest correlation and respirable particles the weakest. In the Spearman analysis, all variables except nitrogen monoxide correlated with the UHI. These correlations were weaker than the Pearson coefficients but remained of medium strength.

In 2023, nitrogen dioxide and nitrogen monoxide showed positive, statistically significant Pearson correlations with the 05.00 UHI (Table 144). These correlations were of medium strength, with nitrogen monoxide being slightly stronger. In contrast, the Spearman analysis revealed only a weak positive correlation between fine particles and the UHI. No other statistically significant correlations were observed. Compared to 2021, the number of statistically significant correlations in 2023 was lower, and the correlation coefficients were notably weaker.

Table 143. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in December 2021. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index	**0.730****	<0.001
	Nitrogen dioxide	**0.794****	<0.001
	Nitrogen monoxide	**0.837****	<0.001
	Respirable particles	**0.600****	<0.001
	Fine particles	**0.732****	<0.001
Spearman	Air quality index	**0.588****	<0.001
	Nitrogen dioxide	**0.524****	0.003
	Nitrogen monoxide	0.344	0.058
	Respirable particles	**0.554****	0.001
	Fine particles	**0.605****	<0.001

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 144. Pearson and Spearman correlation coefficients between the UHI intensity at 05.00 and air quality parameters at 08.00 in December 2023. The UHI intensity is calculated based on the Betel and Huhkola observation sites.

		UHI	Significance level
Pearson	Air quality index	-0.113	0.545
	Nitrogen dioxide	**0.414***	0.021
	Nitrogen monoxide	**0.463****	0.009
	Respirable particles	0.101	0.589
	Fine particles	0.075	0.689
Spearman	Air quality index	-0.022	0.909
	Nitrogen dioxide	0.277	0.131
	Nitrogen monoxide	0.109	0.560
	Respirable particles	0.299	0.102
	Fine particles	**0.379***	0.036

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

The correlation between the UHI, average wind speed and cloudiness

In December, daytime lasted from 09.30 in the morning until 15.30 in the afternoon. During this period, the UHI exhibited a moderately strong negative correlation with average wind speed (Table 145). A weak negative correlation was also observed with cloudiness. At night, both variables correlated more strongly with UHI, with the correlation between UHI and cloudiness increasing more notably than that with average wind speed.

The daytime scatter plot depicting wind speed shows a negative relationship between wind speed and UHI intensity, although a few outliers are present (Figure 228). General-

Table 145. Pearson and Spearman correlation coefficients between the wind speed and UHI and between the cloudiness and UHI during daytime and nighttime in December 2021. Four different UHI intensities are calculated based on the Betel, Kurala, Kauppatori and Niuskala observation sites.

			Betel & Kurala Average UHI	Betel & Niuskala Average UHI	Kauppatori & Kurala Average UHI	Kauppatori & Niuskala Average UHI
Day	Pearson	Average wind speed	**-0.618****	**-0.598****	**-0.631****	**-0.610****
		Average cloudiness	**-0.355***	-0.336	**-0.379***	**-0.355***
	Spearman	Average wind speed	**-0.706****	**-0.602****	**-0.723****	**-0.615****
		Average cloudiness	**-0.629****	**-0.559****	**-0.578****	**-0.553****
Night	Pearson	Average wind speed	**-0.680****	**-0.619****	**-0.691****	**-0.623****
		Average cloudiness	**-0.493****	**-0.492****	**-0.489****	**-0.491****
	Spearman	Average wind speed	**-0.703****	**-0.597****	**-0.740****	**-0.638****
		Average cloudiness	**-0.711****	**-0.653****	**-0.644****	**-0.617****

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

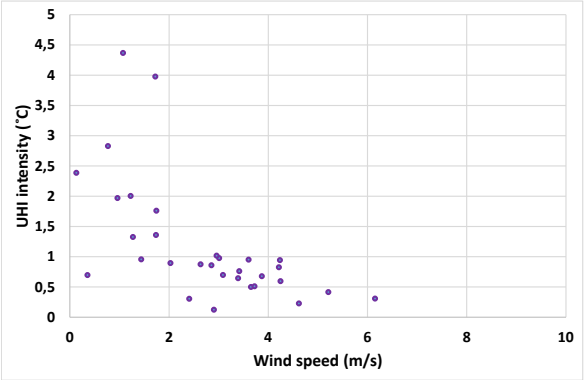

Figure 228. Scatter plot for wind speed and UHI between Betel and Kurala during daytime in December 2021.

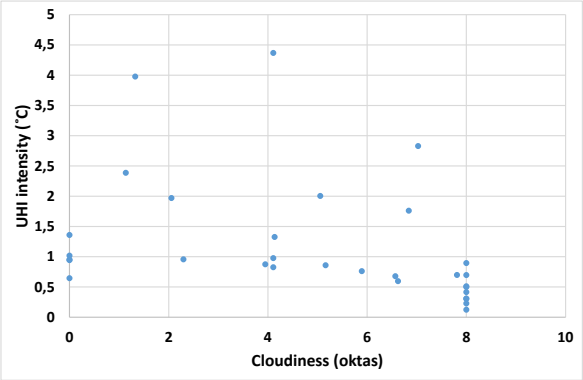

Figure 229. Scatter plot for cloudiness and UHI between Betel and Kurala during daytime in December 2021.

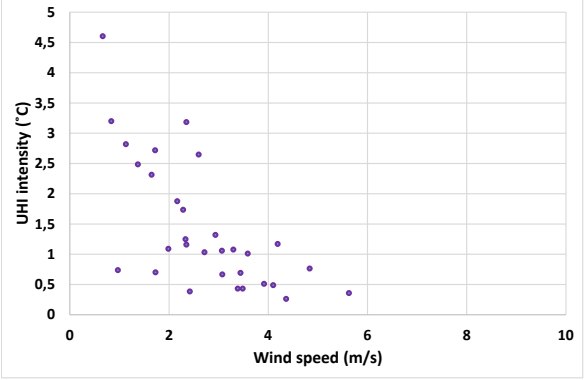

Figure 230. Scatter plot for wind speed and UHI between Betel and Kurala during nighttime in December 2021.

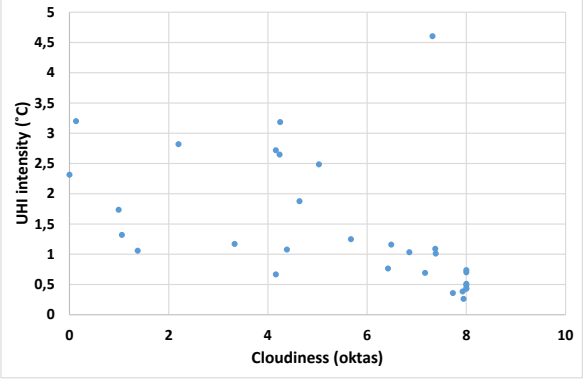

Figure 231. Scatter plot for cloudiness and UHI between Betel and Kurala during nighttime in December 2021.

ly, UHI intensity decreases as wind speed increases. Most UHI values remain below 3°C, although a few isolated values approach 4°C. Wind speeds reach a maximum of 6 m/s. In contrast, cloudiness during the day appears more randomly distributed (Figure 229), with some clustering around a value of 8, where UHI intensities tend to be lower. At night, a similar inverse relationship between UHI intensity and wind speed is evident (Figure 230). Wind speeds remain below 6 m/s, and UHI values are comparable to those observed during the day. Additionally, cloudiness at night shows a clearer correlation with UHI intensity, with UHI values tending to decrease under cloudier conditions (Figure 231).

The correlation between NAO index and UHI

In December 2021, no statistically significant correlations occurred between the NAO index and the observed UHI logger site pairs (Table 146).

Frost period review

In December 2021, one frost period was recorded, occurring between the 5th and 8th of the month. During this period, UHI intensi-

Table 146. Pearson and Spearman correlations between NAO index and different UHI logger pairs in December 2021.

	UHI	NAO index	Significance level
Pearson	Betel & Kurala	-0.019	0.918
	Betel & Niuskala	-0.101	0.589
	Kauppatori & Kurala	0.031	0.867
	Kauppatori & Niuskala	-0.066	0.726
	Betel & Ryhmäpuutarha	0.065	0.729
	Kauppatori & Ryhmäpuutarha	0.150	0.420
Spearman	Betel & Kurala	-0.122	0.514
	Betel & Niuskala	-0.215	0.246
	Kauppatori & Kurala	0.025	0.896
	Kauppatori & Niuskala	-0.181	0.331
	Betel & Ryhmäpuutarha	-0.023	0.901
	Kauppatori & Ryhmäpuutarha	0.175	0.345

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

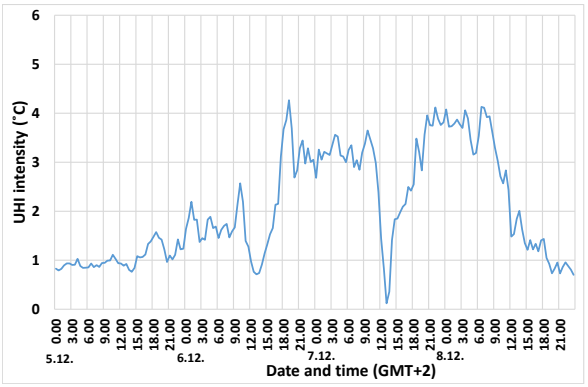

Figure 232. UHI intensity between Betel and Kurala during the frost period on the 5th-8th of December in 2021.

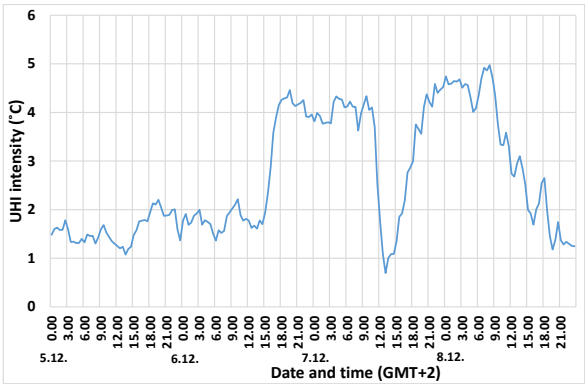

Figure 233. UHI intensity between Betel and Niuskala during the frost period on the 5th-8th of December in 2021.

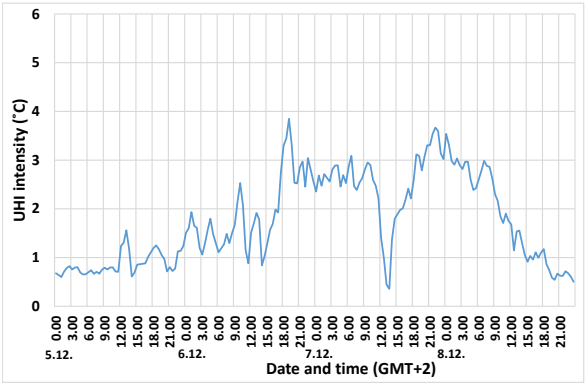

Figure 234. UHI intensity between Kauppatori and Kurala during the frost period on the 5th-8th of December in 2021.

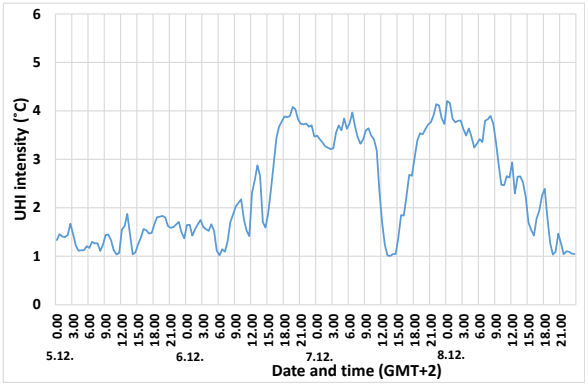

Figure 235. UHI intensity between Kauppatori and Niuskala during the frost period on the 5th-8th of December in 2021.

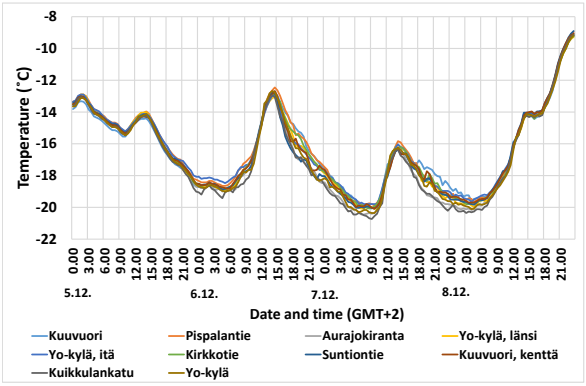

Figure 236. Turku Student Village temperatures during the frost period on the 5th–8th of December in 2021.

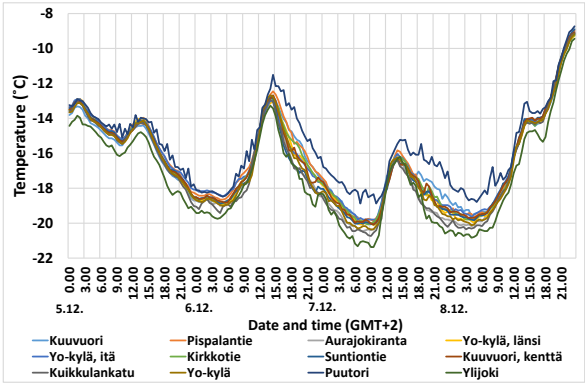

Figure 237. Turku Student Village, Puutori and Ylijoki temperatures during the frost period on the 5th–8th of December in 2021.

ty varied without displaying a consistent diurnal rhythm (Figure 232–235). Prolonged peaks were observed from the late afternoon to midday on the 7th and 8th, with UHI values ranging between 3–4 °C. A sudden drop in UHI intensity occurred at midday on the 7th, falling close to 0 °C. Outside of peak times, UHI intensity generally remained between 1–2 °C. No negative UHI values were recorded, indicating that no UCIs were present in December.

Temperature observations from the Turku Student Village during the frost period show that the logger measurements were mostly consistent (Figure 236). Temperatures gradually rose toward the end of the period, with the lowest values reaching approximately –20 °C. Contrary to typical patterns, Kuikkulankatu emerged as the coldest site instead of Aurajokiranta. The warmest site varied over time, being Kuuvuori on some occasions and Pispalantie on others. Observations from Puutori and Ylijoki diverged notably from those at the Student Village (Figure 237). Puutori remained significantly warmer than the Student Village sites for most of the frost period. In contrast, Ylijoki recorded the coldest temperatures overall, although towards the end of the frost period its temperature readings began to converge with those from the Student Village, making the distinction less pronounced.

5.2 Annual overview

The monthly average UHI intensity values ranged from 0.6 to 3.0 °C in 2021 and from 0.8 to 3.0 °C in 2023 (Table 147). Among the four observation site pairs, Betel–Niuskala and Kauppatori–Niuskala consistently exhibited the highest UHI intensities. Peak UHI intensity values were predominantly observed during the summer months, particularly in June and July, across all site pairs, whereas weaker intensities were generally concentrated in autumn and winter. The monthly standard deviation of UHI intensity followed a similar seasonal pattern, being highest in summer and lowest in autumn and winter. The standard deviation ranged from 0.8 to 1.8 in 2021 and from 0.7 to 2.4 in 2023 (Table 148). The highest momentary maximum UHI intensities in 2021 were recorded in February between Betel–Kurala (9.1 °C) and Kauppatori–Kurala (8.0 °C), and in June between Betel–Niuskala (8.7 °C) and Kauppatori–Niuskala (9.3 °C) (Table 149). In 2023, the maximum values again occurred in February between Betel–Kurala (8.8 °C) and Kauppatori–Kurala (8.3 °C), while for Betel–Niuskala (8.8 °C) and Kauppatori–Niuskala (8.4 °C), the highest values were reached in March. Regarding momentary UCI intensities, the maximum values in 2021 were observed in June between Betel–Kurala (1.8 °C) and Kauppatori–Kurala (1.2 °C), and in March between Betel–Niuskala (2.4 °C) and Kauppatori–Niuskala (2.9 °C) (Table 150). In 2023, the highest momentary UCI intensities were consistently recorded in April across all site pairs. Among these, the maximum value of 3.2 °C was observed between Betel–Niuskala, while the minimum value of 2.3 °C was measured between Kauppatori–Kurala. Intermediate values were recorded at Betel–Kurala (2.5 °C) and Kauppatori–Niuskala (3.0 °C).

Table 147. Monthly average UHI intensities in 2021 and 2023 between the four observed logger site pairs; Betel–Kurala, Betel–Niuskala, Kauppatori–Kurala and Kauppatori–Niuskala.

	Average UHI intensity (°C)							
	2021				2023			
Month	Betel & Kurala	Betel & Niuskala	Kauppa-tori & Kurala	Kauppa-tori & Niuskala	Betel & Kurala	Betel & Niuskala	Kauppa-tori & Kurala	Kauppa-tori & Niuskala
January	0.9	1.3	0.9	1.2	0.8	1.4	1.0	1.6
February	1.7	2.2	1.6	2.1	1.0	1.7	1.2	1.9
March	0.9	1.4	0.9	1.5	1.3	1.8	1.4	1.9
April	1.0	1.6	1.1	1.7	1.7	2.1	1.6	2.1
May	1.0	1.4	1.1	1.6	1.5	2.0	1.7	2.1
June	1.4	2.3	1.6	2.5	1.5	2.8	1.8	3.0
July	1.2	2.8	1.4	3.0	1.3	2.5	1.4	2.6
August	1.0	2.1	1.2	2.3	0.9	1.9	1.0	2.0
September	1.2	2.0	1.2	2.1	1.0	1.8	1.1	1.9
October	0.6	1.2	0.7	1.3	1.0	1.7	1.0	1.7
November	1.1	1.9	1.0	1.8	0.8	1.4	0.9	1.4
December	1.4	2.0	1.2	1.9	0.9	1.5	1.0	1.5

Table 148. Monthly standard deviations of UHI intensities in 2021 and 2023 between the four observed logger site pairs; Betel–Kurala, Betel–Niuskala, Kauppatori–Kurala and Kauppatori–Niuskala.

	Standard deviation of the UHI intensity (°C)							
	2021				2023			
Month	Betel & Kurala	Betel & Niuskala	Kauppa-tori & Kurala	Kauppa-tori & Niuskala	Betel & Kurala	Betel & Niuskala	Kauppa-tori & Kurala	Kauppa-tori& Niuskala
January	1.0	1.0	0.9	0.9	0.9	1.0	0.9	1.0
February	1.8	1.7	1.6	1.5	1.2	1.3	1.2	1.4
March	0.9	1.3	0.8	1.2	1.8	1.9	1.7	1.8
April	1.3	1.8	1.2	1.7	1.7	2.0	1.7	2.0
May	1.2	1.7	1.1	1.7	1.8	2.4	1.7	2.4
June	1.6	1.7	1.5	1.7	2.0	2.2	1.9	2.1
July	1.6	1.8	1.4	1.7	1.5	1.7	1.5	1.7
August	1.3	1.4	1.1	1.3	0.9	1.1	0.9	1.1
September	1.3	1.3	1.1	1.2	1.2	1.3	1.1	1.3
October	1.0	1.1	0.8	1.0	1.1	1.3	1.0	1.2
November	1.1	1.3	0.9	1.1	0.7	0.9	0.7	0.9
December	1.3	1.4	1.1	1.3	0.9	1.0	0.9	0.9

Table 149. Monthly momentary maximum UHI intensities in 2021 and 2023 between the four observed logger site pairs; Betel–Kurala, Betel–Niuskala, Kauppatori–Kurala and Kauppatori–Niuskala.

	Momentary maximum UHI intensity (°C)							
	2021				2023			
Month	Betel & Kurala	Betel & Niuskala	Kauppa-tori & Kurala	Kauppa-tori & Niuskala	Betel & Kurala	Betel & Niuskala	Kauppa-tori & Kurala	Kauppa-tori & Niuskala
January	8.2	7.4	7.1	6.2	5.3	5.4	5.5	5.9
February	9.1	8.3	8.0	7.1	8.8	7.3	8.3	7.7
March	6.0	5.8	5.8	5.7	8.6	8.8	7.9	8.4
April	6.3	7.2	6.1	6.9	6.5	7.9	6.4	7.5
May	6.0	7.8	6.0	7.8	7.3	7.8	7.1	7.8
June	6.2	8.7	6.0	9.3	7.6	8.1	7.7	8.1
July	6.7	8.2	6.6	7.7	6.5	7.7	6.4	7.5
August	6.6	7.5	6.2	7.2	4.3	5.2	4.5	5.4
September	5.7	6.1	5.2	5.9	5.5	6.4	5.2	6.7
October	5.5	6.4	4.9	6.4	5.7	6.8	5.1	7.6
November	5.2	5.9	4.6	6.4	4.8	5.4	5.0	6.1
December	8.5	8.4	7.6	7.2	6.4	6.2	6.0	5.8

Table 150. Monthly momentary maximum UCI intensities in 2021 and 2023 between the four observed logger site pairs; Betel–Kurala, Betel–Niuskala, Kauppatori–Kurala and Kauppatori–Niuskala.

	Momentary maximum UCI intensity (°C)							
	2021				2023			
Month	Betel & Kurala	Betel & Niuskala	Kauppa-tori & Kurala	Kauppa-tori & Niuskala	Betel & Kurala	Betel & Niuskala	Kauppa-tori & Kurala	Kauppa-tori & Niuskala
January	1.3	0.8	0.8	0.9	1.1	0.2	0.5	-
February	0.9	-	0.6	-	1.2	0.1	1.2	-
March	1.0	2.4	0.9	2.9	2.0	2.1	1.4	1.8
April	1.2	1.4	0.9	1.5	2.5	3.2	2.3	3.0
May	1.5	2.3	0.9	2.6	1.6	1.4	0.7	2.1
June	1.8	1.7	1.2	2.0	1.7	1.5	1.9	1.0
July	1.7	0.1	0.9	0.1	1.7	0.8	0.9	1.2
August	1.3	1.1	0.6	0.6	1.2	1.5	1.2	1.2
September	1.3	0.2	0.8	0.5	1.4	0.8	0.9	1.0
October	1.0	0.1	0.7	-	0.7	0.3	0.4	-
November	0.6	0.1	0.4	0.3	0.5	0.1	0.1	0.2
December	0.2	-	0.1	0.2	0.3	0.3	0.1	-

In 2021, the highest monthly average air quality values were observed in December for both the air quality index and nitrogen monoxide (Table 151). Nitrogen dioxide and respirable particles reached their peak averages in February–March, while fine particles recorded their highest value in October. It should be noted, however, that fine particle concentration data were not available until September 2021. In 2023, the highest air quality values occurred in April, when the air quality index, respirable particles, and fine particles all reached their maximum levels, whereas nitrogen dioxide and nitrogen monoxide exhibited peak

Table 151. Monthly average air quality parameter values in 2021 and 2023 between the four observed logger site pairs; Betel–Kurala, Betel–Niuskala, Kauppatori–Kurala and Kauppatori–Niuskala.

	Average air quality values (µg/m³)									
	2021					2023				
Month	Air quality index	Nitrogen dioxide	Nitrogen monoxide	Respirable particles	Fine particles	Air quality index	Nitrogen dioxide	Nitrogen monoxide	Respirable particles	Fine particles
January	1.09	16.64	6.38	7.82	-	1.07	12.59	4.30	6.39	4.35
February	1.17	22.83	7.40	8.45	-	1.21	13.57	3.39	9.31	5.25
March	1.25	12.29	2.67	13.89	-	1.19	13.28	3.16	10.38	4.18
April	1.17	10.70	3.10	12.94	-	1.75	11.61	2.30	30.38	7.41
May	1.08	10.59	2.62	8.60	-	1.23	8.80	1.46	13.45	5.32
June	1.16	10.42	2.46	13.02	-	1.23	8.20	1.69	12.49	5.90
July	1.08	9.87	1.60	10.83	-	1.00	7.17	1.61	7.53	3.91
August	1.02	10.47	2.88	7.61	-	1.05	7.69	2.08	8.86	4.53
September	1.07	12.55	4.99	9.70	4.18	1.14	7.51	2.35	9.94	5.65
October	1.30	10.94	5.32	12.16	6.99	1.04	10.31	4.55	7.27	3.52
November	1.20	15.91	7.52	10.37	4.55	1.13	15.32	5.41	9.27	4.88
December	1.31	19.65	12.74	13.43	5.36	1.17	15.45	4.91	8.10	6.04

concentrations during the winter months of November–December. Overall, air quality concentrations in 2023 were generally higher than in 2021, although nitrogen monoxide reached higher values in 2021.

Statistically significant correlations between air quality and UHI across the four logger pairs were observed throughout the study period (Tables 152–155). In general, these monthly correlations were weak, with moderate coefficients most commonly occurring during the winter months. The correlations were predominantly positive, although negative correlations were recorded during the summer of 2021 for all variables and during the summer of 2023 for nitrogen monoxide. Overall, the relationships between UHI and air quality variables remained weak across most site pairs, with the exception of Betel–Niuskala and Kauppatori–Niuskala, where strong correlations with the air quality index and nitrogen dioxide were identified in January. Correlations involving fine particles between January and August 2021 could not be assessed due to missing concentration data for that period.

Table 152. Monthly correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Kurala observation sites in 2021 and 2023.

	UHI intensity and air quality correlation coefficients Betel & Kurala									
	2021					2023				
Month	Air quality index	Nitrogen dioxide	Nitrogen monoxide	Respirable particles	Fine particles	Air quality index	Nitrogen dioxide	Nitrogen monoxide	Respirable particles	Fine particles
January	**0.562****	**0.548****	**0.509****	**0.390****	-	**0.471****	**0.504****	**0.586****	**0.410****	**0.255****
February	**0.392****	**0.445****	**0.257****	**0.190****	-	**0.099***	**0.302****	**0.138****	**0.135****	0.049
March	**-0.093***	0.054	**-0.232****	-0.055	-	**0.240****	**0.519****	**0.236****	**0.215****	**0.265****
April	-0.028	**0.118****	**-0.153****	-0.023	-	**0.243****	**0.232****	-0.062	**0.224****	**0.282****
May	**-0.093***	**-0.169****	**-0.216****	**-0.081***	-	**0.173****	**0.258****	**-0.152****	**0.188****	**0.237****
June	**-0.160****	**0.091***	**-0.188****	**-0.108****	-	0.008	**0.201****	**-0.268****	0.029	**0.076***
July	**-0.076***	**0.154****	**-0.243****	-0.043	-	-0.008	**0.325****	**-0.150****	0.035	**0.107****
August	-0.004	**0.211****	**-0.124****	**0.109****	-	**-0.114****	**0.135****	**-0.103****	-0.031	-0.045
September	0.003	**0.207****	**0.085***	-0.062	0.096	**-0.166****	**0.286****	**0.214****	**-0.152****	**-0.232****
October	-0.108**	**0.284****	**0.268****	**-0.094***	**-0.200****	**0.190****	**0.411****	**0.280****	**0.210****	0.057
November	0.247**	0.443**	0.355**	0.313**	0.101**	0.338**	0.487**	0.373**	0.389**	0.490**
December	0.351**	0.531**	0.405**	0.250**	0.430**	0.275**	0.502**	0.540**	0.353**	0.320**

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 153. Monthly correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Betel and Niuskala observation sites in 2021 and 2023.

	UHI intensity and air quality correlation coefficients Betel & Niuskala									
	2021					2023				
Month	Air quality index	Nitrogen dioxide	Nitrogen monoxide	Respirable particles	Fine particles	Air quality index	Nitrogen dioxide	Nitrogen monoxide	Respirable particles	Fine particles
January	**0.601****	**0.622****	**0.509****	**0.427****	-	**0.372****	**0.461****	**0.503****	**0.341****	**0.119****
February	**0.330****	**0.388****	**0.205****	**0.098****	-	0.072	**0.316****	**0.180****	**0.135****	-0.005
March	**-0.144****	**0.192****	**-0.140****	**-0.126****	-	**0.271****	**0.546****	**0.257****	**0.259****	0.262**
April	-0.013	**0.230****	-0.046	0.032	-	**0.243****	**0.261****	-0.015	**0.244****	**0.334****
May	**-0.121****	-0.031	**-0.207****	-0.054	-	**0.169****	**0.284****	-0.118**	0.162**	0.211**
June	**-0.222****	**0.202****	-0.041	**-0.177****	-	**0.123****	**0.362****	**-0.110****	**0.148****	**0.202****
July	-0.040	**0.248****	**-0.107****	0.043	-	-0.020	**0.395****	0.002	**0.081***	**0.087***
August	**0.131****	**0.355****	**0.097****	**0.209****	-	0.001	0.064	**-0.122****	**0.093***	**0.082***
September	0.072	**0.271****	**0.210****	-0.033	0.076	**-0.252****	**0.300****	**0.346****	**-0.240****	**-0.371****
October	**-0.117****	**0.327****	**0.300****	**-0.121****	**-0.284****	**0.187****	**0.406****	**0.269****	**0.128****	-0.065
November	0.152**	**0.350****	**0.263****	**0.186****	0.003	**0.240****	**0.381****	**0.196****	**0.202****	**0.309****
December	0.281**	0.494**	0.382**	0.198**	0.354**	0.169**	0.418**	0.445**	0.208**	0.116**

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 154. Monthly correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Kurala observation sites in 2021 and 2023.

	UHI intensity and air quality correlation coefficients Kauppatori & Kurala									
	2021					2023				
Month	Air quality index	Nitrogen dioxide	Nitrogen monoxide	Respirable particles	Fine particles	Air quality index	Nitrogen dioxide	Nitrogen monoxide	Respirable particles	Fine particles
January	0.587**	0.579**	**0.528****	**0.404****	-	**0.454****	**0.538****	**0.575****	**0.375****	**0.193****
February	**0.393****	**0.457****	**0.252****	**0.198****	-	**0.117****	**0.355****	**0.184****	**0.165****	0.062
March	-0.023	**0.142****	**-0.142****	0.007	-	**0.224****	**0.515****	**0.237****	**0.201****	**0.245****
April	-0.039	**0.149****	**-0.140****	-0.030	-	**0.249****	**0.276****	-0.026	**0.238****	0.296**
May	**-0.090***	**-0.177****	**-0.209****	**-0.078***	-	**0.155****	**0.248****	**-0.159****	**0.173****	**0.206****
June	**-0.157****	**0.142****	**-0.120****	**-0.105****	-	0.021	**0.232****	**-0.247****	0.045	**0.075***
July	**-0.087***	**0.176****	**-0.223****	-0.029	-	-0.011	**0.333****	**-0.139****	0.046	**0.110****
August	0.055	**0.265****	-0.061	**0.195****	-	**-0.115****	**0.171****	-0.068	-0.017	-0.035
September	-0.004	**0.229****	**0.091***	-0.070	0.066	**-0.197****	**0.306****	**0.253****	**-0.172****	**-0.276****
October	-0.100**	0.343**	0.325**	**-0.073***	**-0.208****	**0.212****	**0.423****	**0.269****	**0.219****	0.040
November	0.250**	0.492**	0.368**	0.339**	0.097**	0.315**	0.511**	0.370**	0.368**	0.458**
December	0.339**	0.533**	0.381**	0.248**	0.415**	0.247**	0.474**	0.541**	0.334**	0.296**

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Table 155. Monthly correlation coefficients between the air quality parameters measured at the Turku Market Square and the UHI intensity calculated based on the Kauppatori and Niuskala observation sites in 2021 and 2023.

	UHI intensity and air quality correlation coefficients Kauppatori & Niuskala									
	2021					2023				
Month	Air quality index	Nitrogen dioxide	Nitrogen monoxide	Respirable particles	Fine particles	Air quality index	Nitrogen dioxide	Nitrogen monoxide	Respirable particles	Fine particles
January	**0.623****	**0.653****	**0.519****	**0.439****	-	**0.339****	**0.467****	**0.468****	**0.295****	0.059
February	0.323**	0.393**	0.193**	**0.096***	-	**0.084***	**0.351****	**0.215****	**0.156****	0.006
March	**-0.100****	**0.259****	**-0.074***	**-0.089***	-	**0.255****	**0.537****	**0.256****	**0.245****	**0.239****
April	-0.019	**0.260****	-0.027	0.032	-	**0.245****	**0.295****	0.015	**0.253****	**0.342****
May	**-0.117***	-0.031	**-0.197****	-0.051	-	**0.153****	**0.273****	**-0.119****	**0.148****	**0.185****
June	**-0.207****	**0.241****	0.037	**-0.167****	-	**0.139****	**0.393****	**-0.080***	**0.167****	**0.205****
July	-0.046	**0.270****	**-0.073***	0.062	-	-0.022	**0.390****	0.017	0.090*	0.087*
August	**0.187****	**0.398****	**0.168****	**0.281****	-	0.002	**0.090***	**-0.089***	**0.105****	**0.091***
September	0.072	**0.290****	**0.226****	-0.035	0.043	**-0.272****	0.303**	0.374**	-0.251**	-0.399**
October	-0.108**	0.368**	0.339**	-0.104**	-0.294**	0.200**	0.404**	0.252**	0.121**	-0.090*
November	0.134**	0.362**	0.250**	0.181**	-0.016	**0.212****	**0.390****	**0.181****	**0.172****	**0.269****
December	0.260**	0.488**	0.355**	0.189**	0.328**	0.137**	0.388**	0.440**	0.182**	0.082*

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

6
SYNTHESIS

In 2021, the most stable UHI intensity conditions occurred in January and October, when only a few higher peak values were observed, whereas during the rest of the months the variation in UHI intensity was small. Greater and regular diurnal variability of UHI intensity was observed in the summer months, particularly in July. The largest UHI intensity range of approximately 11 °C was recorded in June between Kauppatori and Niuskala, while the smallest range, around 5 °C, was observed in November between Kauppatori and Kurala. The highest momentary UHI intensity of slightly over 9 °C occurred twice: once in February between Betel and Kurala, and again in June between Kauppatori and Niuskala. The highest momentary UCI intensity, 3 °C, was recorded in March between Kauppatori and Niuskala. In the majority of cases, the Betel–Niuskala and Kauppatori–Niuskala logger pairs exhibited greater variability and wider UHI intensity ranges than the Betel–Kurala and Kauppatori–Kurala pairs, which generally showed more stable behaviour. Principally the UHI intensity reached the strongest values between the urban and rural observation site pairs Betel–Niuskala and Kauppatori–Niuskala while the weakest UHI intensity values often were reached between Kauppatori–Kurala. The timing of UHI intensity peaks varied by month, while UCIs occurred more frequently during the summer months. This seasonal pattern aligns with general expectations, as UCIs tend to be more common in summer. However, minor UCIs were detected almost every month. These cold islands typically occurred during daytime, particularly around midday or in the afternoon. In contrast, UHI intensity peaks most often occurred at night, usually after midnight or in the early morning.

In 2023, the most stable UHI intensity conditions occurred in January, when the average intensity range of the four observation site pairs was the smallest, approximately 6 °C. A range of same magnitude was observed in August, although diurnal variability within individual days was greater than in January. The most pronounced UHI intensity variability occurred in April, with a maximum range of 11 °C between Betel and Niuskala. Other months with large intensity ranges were March and June, when ranges were almost 10 °C. Overall, the months from February to July exhibited the greatest intensity variability. Similar to 2021, the Betel–Niuskala and Kauppatori–Niuskala logger pairs had larger intensity ranges, while the Betel–Kurala and Kauppatori–Kurala pairs demonstrated more stable conditions. The highest individual UHI intensity in 2023 was approximately 9 °C, recorded in February between Betel and Kurala during the night. The highest UCI intensity, 3 °C, occurred in April between Betel and Niuskala during midday. As in 2021, UCIs were most common during summer daytime hours, while UHI intensity peaks primarily occurred during the night or early morning. The timing of these peaks did not follow a consistent monthly pattern.

A comparison of 2021 and 2023 from a monthly perspective reveals that April, July, September, and October were characterized by relatively similar UHI behaviour in both years in terms of peak intensities and diurnal varia-

bility. January also showed a similar pattern, although peak values were clearly higher in 2021 than in 2023. This trend of higher UHI peaks in 2021 was also evident in February, August, and December, while 2023 exhibited higher peak values in March, June, and November. In May 2021, UHI conditions were rather stable, whereas in 2023, more pronounced diurnal variability was observed. Nonetheless, the overall UHI intensity ranges for May did not differ much between the years.

In both 2021 and 2023, air quality averages typically showed peak concentrations during the morning and afternoon rush hours. In many cases, only a morning peak was observed, while air quality remained relatively stable throughout the rest of the day. This was evident, for example, in January, February, and September 2021, when only morning peaks were recorded. Clear afternoon peaks were observed in March, April, June, and October 2021. In some instances, only certain air quality variables peaked during a given time, with nitrogen dioxide and nitrogen monoxide often following similar diurnal patterns. Likewise, the air quality index and respirable particles frequently exhibited comparable trends. In 2023, afternoon peaks were also recorded in January and February. In November and December, elevated concentrations persisted over a longer portion of the day. The highest air pollution levels were observed in February and December, while the lowest concentrations occurred in August across all variables. Among the pollutants, nitrogen dioxide typically recorded the highest concentrations, whereas fine particles and respirable particles tended to show the lowest values.

Regarding the hour-basis monthly summaries, the UHI intensity between Kauppatori and Kurala generally peaked during the nighttime and late evening hours. In February and September, UHI values were also elevated during the morning. UHI intensity got typically weaker in the morning after 06.00. In January, October, and November, no clear peak period was observed. In contrast, December featured distinct UHI peaks during both the morning and late afternoon, coinciding with rush hour periods. UHI values during peak periods generally ranged between 1.2 and 3.0 °C. The most intense UHI events were recorded in the summer months. In June and July, the UHI peak values reached approximately 3.0 °C and 3.5 °C, respectively. Outside of these peak periods, UHI values tended to remain within the range of 0.3–1.1 °C.

In both 2021 and 2023, the UHIs and air quality variables tended to show stronger and more frequent correlations during the winter months. In contrast, correlations were less common in the summer, with many instances of no statistically significant relationships between the variables. The correlation was mostly positive indicating that air quality is often poorer during the strong UHI intensity situations. The seasonal variability in the strength of correlation may be partly explained by inversions that are often more common in winter. During inversions, air quality is often poorer than on average. The road maintenance measures, such as gritting of the roads during slippery conditions in winter, as well as use of studded tyres, may also explain the seasonal differences in the correlation between the UHI and air quality. Differences in radiative conditions may also explain the seasonal differences, as in summer, solar radiation effectively breaks inversions already before the morning rush hours and also promotes small-scale turbulence and local winds that in turn weaken the UHI intensity. Among the air quality variables, nitrogen diox-

ide and nitrogen monoxide were most strongly correlated with UHI intensity. In contrast, the air quality index and fine particles correlated less frequently with the UHI intensity and, in some cases, not at all. Correlations were more commonly observed during the morning rush hours between 07.00 and 09.00 than in the afternoon. In many months, correlation was not statistically significant in the afternoon hours, especially when all four observation site pairs used in determining the UHI were considered. Exceptions to this pattern occurred in May and November, when the statistically most significant correlations occurred during the afternoon. In May 2021, only one air quality variable showed a statistically significant correlation with UHI intensity, and it happened in the afternoon. Even if the correlations between the UHI and air quality parameters were mostly positive, also statistically significant negative correlations were observed in both years, and they occurred most often in the afternoon hours, but occasionally also in the morning. Afternoon negative correlations occurred, for example, in May, June, September, and October.

When comparing the two study years 2021 and 2023, the overall number of variables showing statistically significant correlations was generally similar. However, there were instances, when a specific variable correlated at certain rush hour in 2023, but not in 2021, and vice versa. No consistent or overarching month-related pattern was identified between the two observation years. While some months, such as April and December, showed similar correlation patterns across both years, others, like May and September, differed noticeably.

In 2021, the strongest correlations between the 05.00 UHI intensity and 08.00 air quality values occurred in February, April, August, October, and December. These months not only had the strongest coefficients but also saw most air quality variables exhibiting statistically significant correlations. The correlations were positive indicating that strong UHI intensity at 05.00 is often followed by poor air quality at 08.00. In contrast, the fewest correlations were observed in March, July, and especially in May, when none of the variables correlated significantly. The rest of the months fell between these extremes, typically showing a few statistically significant positive correlations with medium-strength coefficients. In 2023, the strongest correlations appeared in January, April, and June. However, even in these months, the coefficients were weaker compared to the strongest months of 2021. The weakest and fewest correlations occurred in February, March, August, September, November, and December. The other months displayed intermediate behaviour, with a few variables correlating at medium strength. All of the statistically significant correlations in 2023 were positive.

Across both years, most monthly correlation tables between the 05.00 UHI and 08.00 air quality data featured a few variables with statistically significant medium-strength coefficients. This pattern was observed in months like January and November. Occasionally, stronger correlations were recorded in 2021 for example, in February, April, August, and December often accompanied by a greater number of variables correlating than in 2023. In such cases, the 2021 coefficients were typically clearly stronger than those in 2023. Notably, in September, none of the air quality variables correlated significantly with UHI in 2023, while nearly all variables did in 2021, with medium-strength coefficients. October, however, showed similar correlation tables for both years, with a comparable number of statistically significant variables and quite strong co-

efficients. March was also similar across both years, with only one variable showing a significant correlation of medium strength. In only three months did 2023 exhibit stronger correlations than 2021. In June, just two variables correlated in 2021 with medium-strength coefficients, while nearly all variables correlated in 2023, including some with stronger coefficients. In July, only one variable correlated weakly in 2021, while three variables correlated in 2023, all with medium-strength coefficients. May presented a marked contrast between the years: no statistically significant correlations were observed in 2021, while nearly all air quality variables correlated statistically significantly in 2023, with weak to medium-strength coefficients. In summary, in 2021 correlation was more apparent than in 2023 both in terms of the number of air quality parameters, number of clearly correlating months and the strengths of correlations.

The correlations, calculated on a monthly basis between the UHI intensity and wind speed, and between the UHI intensity and cloudiness, were throughout the year negative during both daytime and nighttime. Generally, the correlations were stronger during the night, suggesting a greater influence of these weather parameters on the UHI intensity during nocturnal hours. June exhibited the fewest correlations, with only a weak daytime correlation observed with average wind speed. In July, no statistically significant correlations were found during the night; however, both cloudiness and wind speed correlated during the day. Overall, the correlations were predominantly of moderate to strong magnitude, indicating that average wind speed and cloudiness exert a measurable influence on UHI behaviour. Scatter plots provided a useful visual aid in illustrating these relationships. In all instances where a visible trend was observed, the scatter plots demonstrated that UHI intensity decreased as wind speed or cloudiness increased, confirming the direction and nature of the correlations.

Regarding the correlations between the UHI and the North Atlantic Oscillation (NAO) index in 2021, statistically significant positive association were found in January and April. In January, statistically significant correlations were observed primarily with the Pearson method, while in April, both Pearson and Spearman correlations were statistically significant. Conversely, statistically significant negative correlations occurred in February and October, but in October only with Spearman correlation. Across all months with statistically significant results, correlation strengths were moderate. Statistically significant correlations were not observed during the other months.

The studied frost periods were recorded in January, February, and December, while heatwave periods occurred in June and July. During the frost periods in January and February, the maximum UHI intensity values approached 8 °C, occasionally exceeding this threshold. However, such peak values were rare, and UHI intensity was mostly less than 5 °C. One of the two-day periods in February formed an exception, as then the UHI intensity was over 5 °C approximately 50 % of the time. Notably, negative UHI values, i.e. UCIs, were practically absent during these winter frost periods. In December, the maximum UHI intensity was slightly below 5 °C, whereas for most of the time, the intensity fluctuated around 2 °C, being thus weaker than during the frost periods of January and February.

During the heatwave periods in June and July, maximum UHI intensities varied between 4 °C and 6 °C. A clear diurnal pattern emerged:

UHI intensity peaked during the night and early morning hours and decreased significantly to less than 2 °C during the day. UCIs were clearly more frequent during these heatwave periods than in winter-time frost periods, and in some cases, UCI occurred almost daily. The appearance of cold islands was more common with some logger pairs, and it occurred most often in the afternoon. A few cold islands also emerged during the morning hours, typically following a steep drop in UHI intensity from the nighttime peak. Observed UCI intensities were with one exception less than 2 °C.

Spatial temperature variation among the Turku Student Village loggers during the frost and heatwave periods was small. Two sites, however, often stood out during the coldest or warmest moments of the periods: Kuuvuori, which consistently recorded the highest temperatures, and Aurajokiranta, which registered the lowest. The differences between these two and the other loggers were usually modest, typically only a few degrees Celsius. Aurajokiranta is situated in a low-lying riverbank area adjacent to the River Aura, while Kuuvuori is located at the highest elevation among the Student Village loggers. When comparing these Student Village observation sites to the Puutori and Ylijoki sites, much larger temperature difference was observed. Puutori, located in the Turku city centre, often recorded the highest temperatures during both frost and heatwave periods, while Ylijoki, a rural site approximately 10 km to the NNE of the city centre, consistently recorded the lowest. The temperature differences between Puutori and Ylijoki frequently exceeded those observed among the Student Village loggers, particularly during coldest or warmest moments of the heatwave and frost periods.

7
CONCLUSIONS

This study analysed spatiotemporal variability of UHI intensity and its relations with air quality and weather during the years 2021 and 2023.

Temporally, UHI intensity had clear seasonal and diurnal variability. Temporal variability of UHI intensity was smallest in January and October in both of the years studied, including only few strong UHI situations. In contrast, summer months, particularly June and July, exhibited pronounced diurnal variability and greater intensity ranges. The highest recorded UHI intensities were approximately 9 °C, and the strongest intensities occurred typically during nighttime or early morning hours, while the strongest UCI intensities were almost 3 °C, and once in April even slightly over 3 °C. The strongest UCIs occurred mainly in March and April, although UCIs were more frequent in summer occurring mostly during midday or afternoon.

Spatially, observation site pairs that included rural Niuskala as a reference site (e.g., Betel–Niuskala, Kauppatori–Niuskala) showed consistently higher UHI intensity, UHI intensity ranges and variability compared to those involving Kurala. UCIs were clearly connected to season, being most common in summer.

Air quality parameters peaked during the morning and afternoon rush hours in both 2021 and 2023 (denoting that the air quality was poorer than at other times). However, in many cases only a morning maximum was evident, as in January, February, and September 2021. Clear afternoon peaks occurred in several months, such as March, April, June, and October 2021, with nitrogen dioxide and nitrogen monoxide often showing similar diurnal patterns, and the air quality index and particle concentrations frequently aligning with these trends. In 2023, afternoon peaks also appeared in January and February, while in November and December elevated levels persisted over longer periods of the day. Across both years, the highest pollution levels were recorded in February and December, and the lowest in August. Among the measured pollutants, nitrogen dioxide consistently showed the highest concentrations, whereas fine and respirable particles were the lowest.

The hourly UHI intensity (averaged on a monthly basis based on each day's observations) between Kauppatori and Kurala generally peaked during nighttime and late evening. In February and September, also occasional morning peaks occurred. In most months, the intensity weakened after 06.00, while December stood out with distinct morning and late-afternoon peaks coinciding with rush hour periods. Peak UHI values typically ranged from 1.2 to 3.0 °C, with the strongest events occurring in summer when intensities reached about 3.0 °C in June and 3.5 °C in July. Outside these peaks, UHI remained modest, usually between 0.3 and 1.1 °C.

The UHI intensities and air quality parameters showed statistically significant correlations especially during the winter months, particularly in the early morning hours. The correlations were more common and stronger in 2021 than in 2023, especially in February, April, August, and December. Conversely, in 2023, statistically significant correlations oc-

curred more sporadically and were generally weaker, with only June and July as exceptions; during those months, the correlations between the UHI intensity and air quality were stronger than in 2021.

Of the air quality parameters, nitrogen dioxide and nitrogen monoxide correlated most clearly and consistently with UHI, while fine particles and the air quality index showed weak or no correlation with UHI. When comparing the two study years 2021 and 2023, no month-specific consistency was detected, suggesting the notable role of weather conditions and other factors behind the short-term variability in UHI and air quality.

Regarding the connections between UHI and weather, UHI intensity was inversely correlated with wind speed and cloudiness, especially during nighttime. Wind intensifies mixing of air and thus reduces spatial temperature differences, such as UHI. Cloud cover in turn reduces urban-rural differences in outgoing longwave radiation, which is one factor behind the UHI phenomenon. During cloudy weather, when direct solar radiation is minimal, less heat is stored to the urban construction material than during clear sky conditions. This weakens the possibility of a strong UHI especially in summer.

The NAO index that reflects the status of large-scale weather systems in the Northern Atlantic region, exhibited variable correlations with UHI intensity without consistent seasonal patterns. Statistically significant and moderate positive correlations occurred in January and April 2021, while in February and October 2021, the correlations were negative. The analyses were conducted using the daily three-hour average of UHI intensity alongside the daily NAO index value. It is possible that usage of full-day average of UHI intensity might have resulted in a stronger correlation between the NAO index and UHI intensity.

Heatwave and frost period analyses completed the information gained from the monthly analyses and emphasized the central role of weather conditions behind the spatial temperature differences. In January, the UHI intensities reached their maxima of the month during the frost events, occasionally exceeding 8 °C in the late evening. UCIs, on the other hand, were rare. The frost events in February were similar although the maximum UHI of the month, exceeding 9 °C, was not reached during these cold spells. During summer, high UHI intensities occurred during heatwaves in June and July, particularly during nighttime, when the UHI intensity was often between 5 °C and 7 °C, and peaked at slightly over 9 °C. Compared to the frost periods, heatwaves were characterized by more frequent UCIs, occurring mostly in the afternoon.

The spatial distribution of temperatures in the Student Village area during the heatwave and frost periods was often characterised by the hill-top site Kuuvuori as the warmest site and the relatively low-lying Aurajokiranta as the coldest This reflects the impact of topography on temperature during extreme weather periods.

To relate the Student Village temperatures to the temperatures of Turku city centre and rural areas inland, the city centre site Puutori consistently exhibited the highest temperatures during the warmest and coldest moments of the period, while the inland rural site Ylijoki appeared as the coldest, demonstrating larger urban–rural thermal gradient compared to the urban-suburban or suburban-rural thermal gradients.

In summary, while both the years 2021 and 2023 shared several similar seasonal and spa-

tial patterns, the year 2021, which was characterized by a clear cold anomaly in winter and warm anomaly in summer, demonstrated more consistent and stronger relationships between the UHI intensity and air quality. The results underscore the complex interplay between urban morphology, meteorological conditions and atmospheric pollutants, and highlight the need for spatially and temporally extensive data when assessing the various aspects of urban climate dynamics.

8
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9
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