GLOBE Estonia Learning Expedition

Impact of urban environment features on the microclimates of Tartu

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1. Abstract

As 56% of the global population live in urban areas and thus are being affected by the microclimates of cities, it is important to be aware of their connections, changes and impact on the respective surroundings. That is why we decided to observe the atmospheric aspects of different sites - to see if the greenery that cities are trying to bring in is beneficial to the people residing there. The aim of our study was to find out how the features of an urban environment affect the respective microclimates.

We posed the following research questions: most importantly, how does the abundance of vegetation impact temperature and humidity compare to technological areas? How does the distance to water bodies impact temperature and humidity? Is there a difference of pressure between places at various elevations?

Our hypotheses: the temperature is higher and humidity lower near technological surfaces compared to green areas; there is higher humidity and a slight difference in temperature near water bodies; there is lower pressure at higher elevation.

On 08.08.23 we collected atmospheric protocols from 8 locations across the city of Tartu, Estonia, visiting each spot twice. The sites differed by the amount of vegetation and technological surfaces, distance from water and altitude. Our group gathered data of temperature, humidity, pressure, altitude, coordinates, types of clouds and cloud coverage.

We confirmed that the temperature is lower, and humidity is higher in green spaces compared to technological areas and that there is indeed lower pressure at higher elevations. Our data could not verify whether the distance to water bodies impacts temperature and that the air is more humid near water bodies.

In conclusion the temperature is lower and humidity higher in green areas, which reflects the importance of nature in urban environments. The information we collected can be used to promote enhancing technological areas with more vegetation.

Keywords: atmospheric measurements, Tartu, Estonia, vegetation, technological areas.

Figure 1. Location of Tartu, Estonia shown on Google Maps.

Introduction and review of literature

A city consists of many biologically and atmospherically different areas, also known as microclimates. Greenery is in almost all cities, but typically gathered into separate areas, such as parks. Next to that there are big concrete valleys, ‘plains’ of just buildings and roads with very little nature in them. Those urban environment features may cause a rise in temperature, in severe cases a ‘heat island’. They also reduce air humidity due to higher evaporation caused by temperature, and may have other effects, which are yet unknown. All of these issues make the lives of people living in cities more uncomfortable.

This research topic is important because over 56% of the global population lives in cities and by 2050 the number of city residents is expected to double (World Bank, 2023). With city leaders quickly planning for growth and trying to provide affordable housing for the rapidly expanding population, distributing greenery in the cities may be easily overlooked.

Vegetation does not exactly cool the air, but simply warms the air less than artificial surfaces like concrete (Kurn et al., 1994). Plants create shade, balance solar heat gain through evapotranspiration and convert solar radiation to latent heat. The higher the ratio of green to built area, the greater the air temperature reduction is to be expected. A ground rule would be that a 0.8°C reduction in air temperature can be anticipated for a 10% increase to the ratio of green to built area (Dimoudi, Nikolopoulou, 2003).

Vegetation also increases air humidity. Research analyzing the cooling and humidification effect of vegetation communities in urban parks has found that green areas increase air moisture by 0.5% to 17.33%, on average 6.46% (Y. Zhang, M. Dai, 2022).

Studying and promoting the impact of vegetation on the urban environment helps contribute to making over half of the population’s lives better.

2. Questions and hypotheses

Our main question was: **Is there a noticeable temperature and humidity difference between technological and green areas?**

This is important because urban heat islands and temperature rise are issues in all cities with dense technological spaces. Currently, the top priority has been to expand housing and fit more people in an already tightly populated living space. Creating balance by bringing in broadly spread greenery is a secondary task that often is not valued enough. Showing the change technological surfaces cause would emphasize the importance of nature and prioritize this subject.

We hypothesized that temperature will be higher and humidity lower in technological areas compared to green spaces. But it is important to note that we were not expecting to see any kind of heat island effect in Tartu, as it is a relatively small city.

How does the distance to water bodies impact temperature and humidity?

We hypothesized that the air near a water body would be more humid since the sun and wind cause evaporation. The temperature should also be higher near a water body because there was a heatwave the day before our measurements - water's temperature rises during the heatwave and later it warms the surrounding air.

Is there a difference of pressure between places at different elevations?

We hypothesized that at lower elevation there is higher pressure compared to places at higher elevations.

3. Research methods and materials

To see how the urban environment affects microclimates, we took atmospheric measurements using GLOBE atmosphere protocols: the air temperature, humidity and pressure. Coordinates, altitude, cloud types and cloud coverage were also noted down. We used a digital thermometer, a psychrometer, a hygrometer, a barometer, a phone compass and a GLOBE Cloud Chart.

At first, we attempted to measure temperature with the digital thermometer, but since we stopped at each measuring location for only around 5 minutes, the thermometer could not show the right result. We noticed that the temperature data from the psychrometer's dry bulb was much more accurate and changed according to location faster. This is why we ended up using temperature taken from the psychrometer.

The hygrometer also proved to be inefficient, because the humidity percentage it showed was always in the same range - around 60% to 70%, which means that it also did not react fast enough to record accurate measurements within the short time spent at each location. However, numbers from the psychrometer changed faster according to location and the current conditions. After about four measurements in different locations, we decided not to use the hygrometer data in analysis, since the psychrometer seemed much more accurate.

Air pressure was measured using two barometers at the same time, which occasionally showed very different results from each other, so we wrote down both numbers. When organizing this information, we calculated the average between the two readings for each location and used that in the conclusions.

To determine our coordinates and elevation, we used the Estonian Land Board X-GIS map. The phone compass app was necessary to find the cardinal directions, so we could take pictures of them in each location.

Finally, we also took note of the cloud type and coverage in each location. This did not align with our research topic, but it is still useful for drawing connections between some of the measurements later on.

All of the atmospheric protocols were uploaded to the GLOBE Observer app. After the expedition we transferred the data to Google Sheets in order to catalogue and analyze the numbers, make conclusions and create graphs.

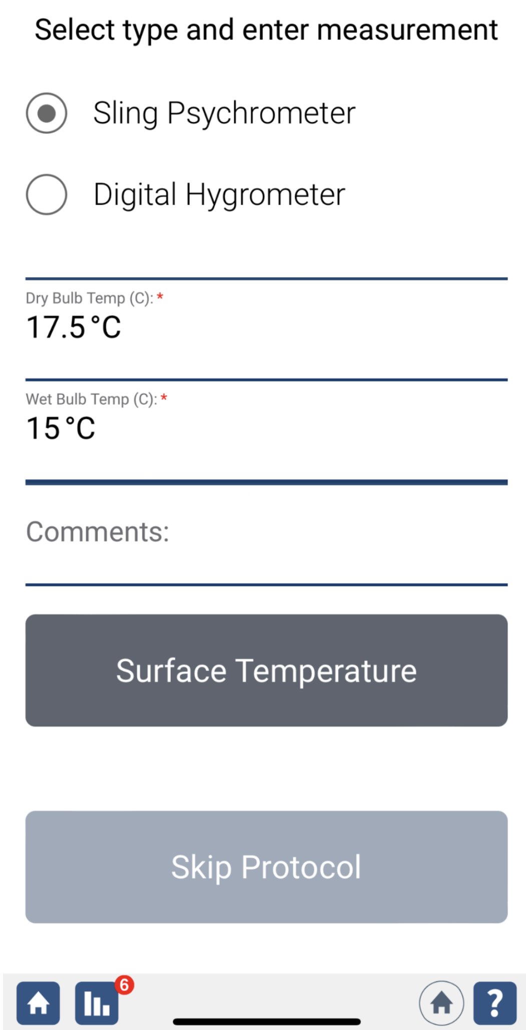

Figure 2. Data entry to the GLOBE Observer app.

4. Research locations

For analyzing the impact of the urban environment on microclimates, we chose 8 locations around Tartu to take atmospheric measurements. The spots varied by amount of vegetation and technological surfaces, elevation and distance from water bodies.

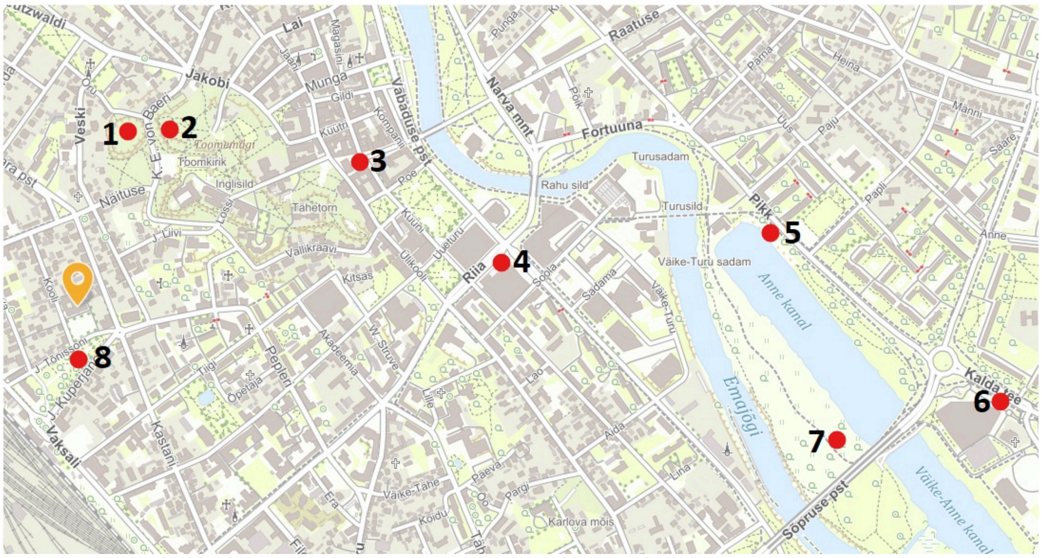

Figure 3. Measuring locations at the city of Tartu, numbered by the order of the journey.

Table 1. Measured locations.

Nr	Name	Coordinates	Elevation	Description
1	Kassitoome org	58°22'51"N 26°42'42"E	46.5m	An open valley with short grass and trees only at the edges.
2	Toomemägi	58°22'52"N 26°42'48"E	70m	A hill with gravel paths and many trees.
3	Raekoja plats	58°22'49"N 26°43'22"E	38m	The town square, surrounded by many stone buildings. The whole ground was covered with cobblestone. Not much greenery in sight.

4	Riia-Turu intersection	56°22'41"N 26°43'43"E	36m	Big crossroads, tall buildings, lots of people and cars - one of Tartu's busiest spots. Not much greenery in sight.
5	Anne canal	58°22'35"N 26°44'45"E	33m	A field with some trees near a water body.
6	Eeden	58°22'26"N 26°45'4"E	34m	A shopping centre next to a big road. There were some trees, but in the distance.
7	Sõpruse sild	58°23'6"N 26°43'22"E	33m	A green area next to a water body and a bridge with traffic.
8	Karupark	58°22'20"N 26°44'39"E	64.5m	A park with gravel paths, trees and lots of greenery.

We visited each spot twice, with around 2.5 hours between measurements taken at the same location.

5. Results

6.1 Temperature in technological and green areas

How does the abundance of vegetation in green areas impact temperature compared to lack of greenery in technological areas? For this research question, our 8 measuring locations were roughly divided into two categories: technological and green areas.

There were 3 technological areas - Raekoja plats, Riia-Turu intersection and Eeden. The average temperature of the 6 measurements taken in those locations was 19.7°C.

There were 5 green areas - Kassitoome org, Toomemägi, Anne canal, Sõpruse sild and Karupark.

The first temperature measurement in Anne canal was not taken into account, because it was raining heavily during that time. The average temperature of the 9 measurements taken in those locations was 18.3°C.

The average temperature difference in technological and green areas was 1.4°C.

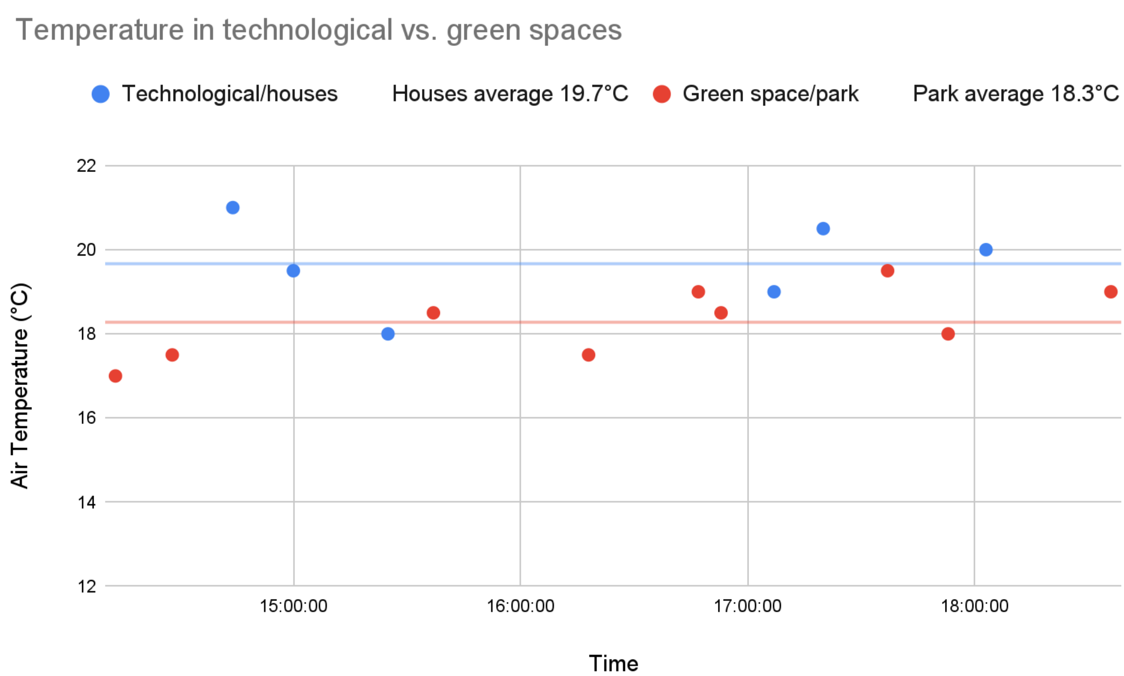

Figure 4. Temperature difference in technological and green spaces.

6.2 Humidity in technological and green areas

How does the abundance of vegetation in green areas impact humidity, compared to technological areas? For this research question we used the same technological and green area categories for our measurement locations, as in the previous subsection.

The average humidity of the 6 measurements taken in technological areas was 62.5%.
The average humidity of the 10 measurements taken in green areas was 71.6%.
The average humidity difference in technological and green areas was 9.1%.

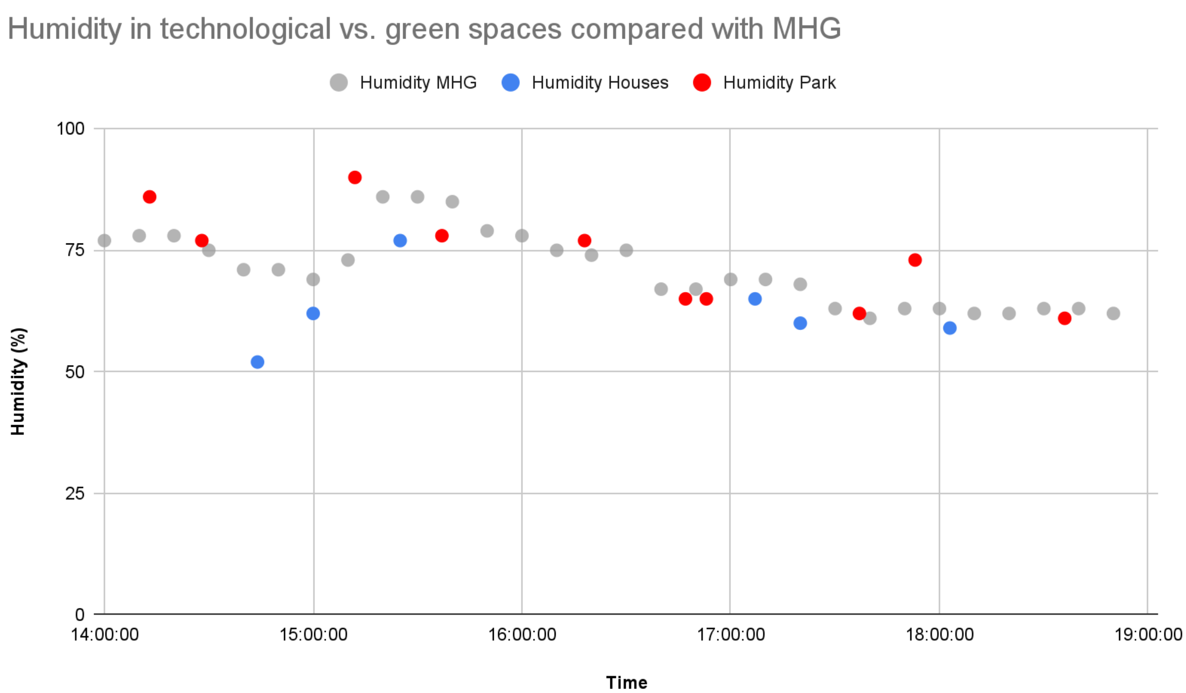

Figure 5. Humidity difference in technological and green spaces compared to Miina Härma Gymnasium's weather station.

To show the difference between technological and green spaces, data from Miina Härma Gymnasium's automatic Davies Vantage Pro 2 weather station was added. This was suitable because MHG could be described as being in between the two categories - there's greenery and also many houses around.

There is a visible rise in humidity between 15.00-16.00, which was caused by rain.

6.3 Temperature near and far from water

How does the distance to water bodies impact temperature? For this research question the measuring locations were again divided into two categories - 4 are near water and 4 are away from water. 3 measurements were removed from the data analysis, due to rain drastically affecting the numbers.

Raekoja plats, Anne canal, Eeden and Sõpruse sild were up to 200m from a water body. The average temperature of the 7 measurements there was 19.14°C.

Kassitoome org, Toomemägi, Riia turu rist and Karupark were more than 200m in distance from a water body. The average temperature of the 6 measurements there was 19.08°C.

The average temperature difference between locations near and far from water was only 0.06°C. Answering our research question, the distance to water bodies has a very minimal impact on air temperature.

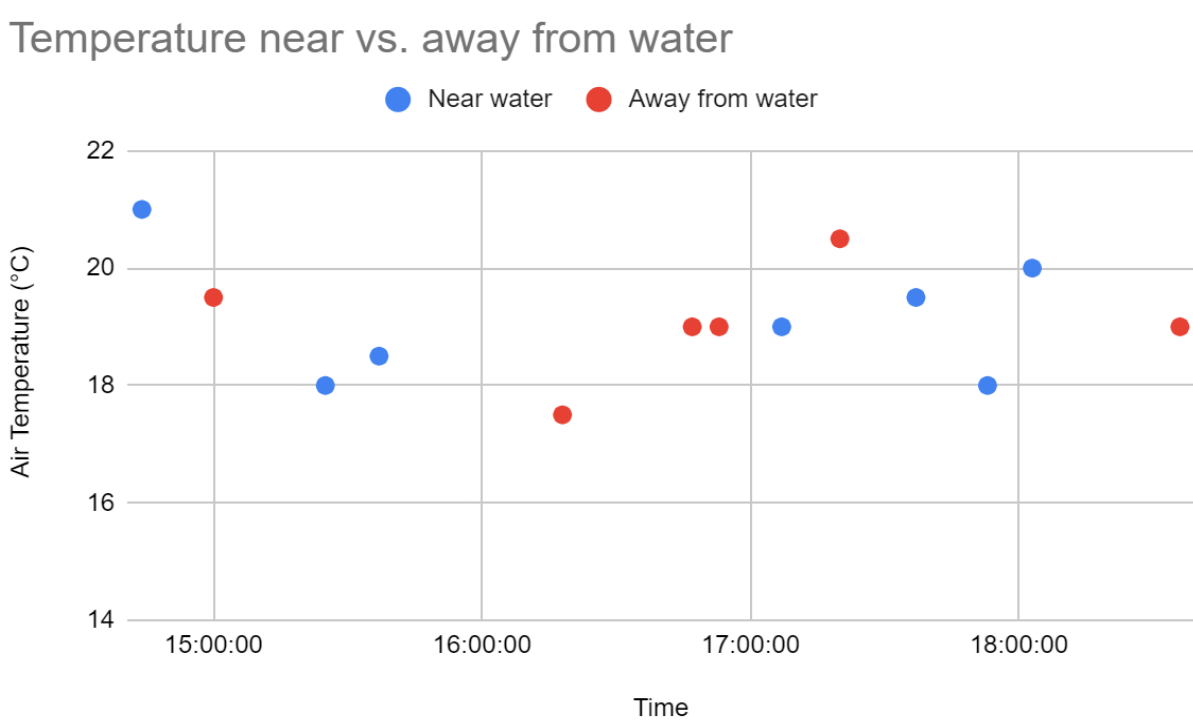

Figure 6. Temperatures measured near and far from water.

6.4 Humidity near and far from water

How does the distance to water bodies impact humidity? For this research question we used the same categories of locations near and far from water, as in the previous subsection.

3 measurements were removed from the data analysis here too, due to rain drastically affecting the numbers.

The average humidity of 7 measurements taken in locations near water was 66.57%.
The average humidity of 6 measurements taken in locations far from water was 65%.
The average humidity difference between locations near and far from water was only 1.57%. Answering our research question, the distance to water bodies has a very minimal impact on air humidity.

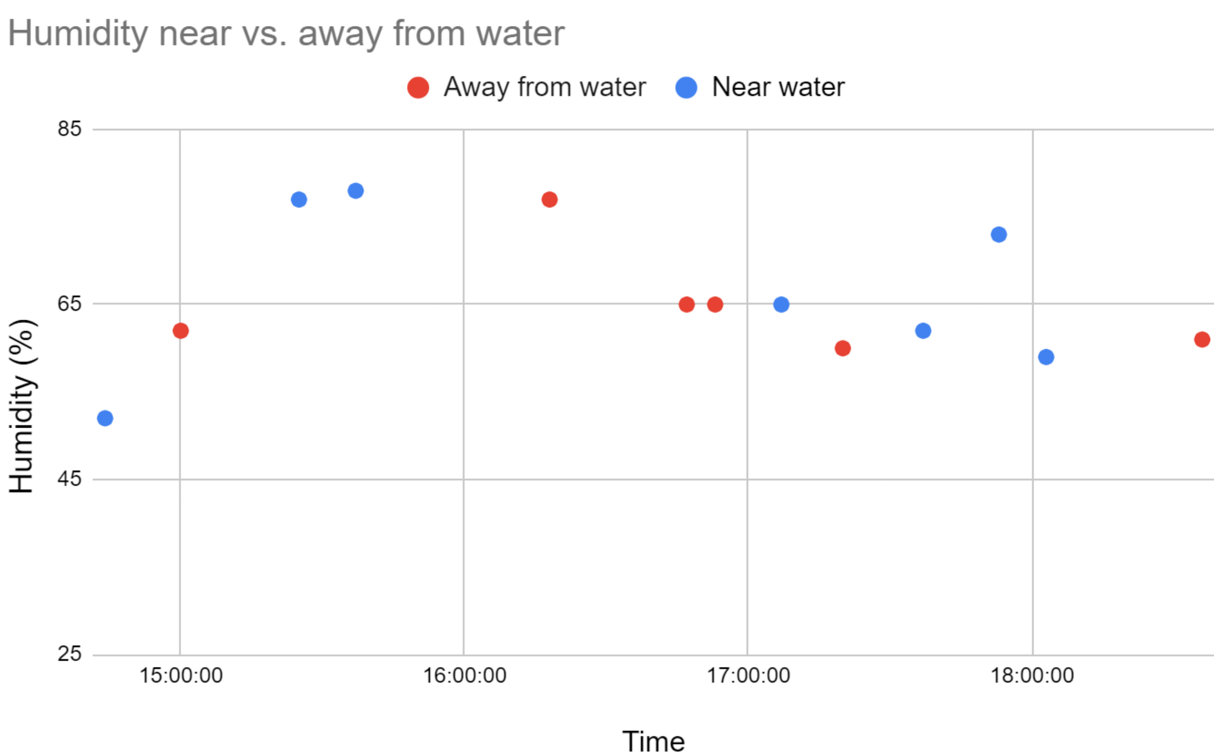

Figure 7. Humidity measured near and far from water.

6.5 Pressure change between elevation

Is there a difference of pressure between places at various elevations? In order to get more accurate results for this research question, data from only two locations was used: Kassitoome org, elevation 46.5m and Toomemägi, elevation 70m.

These locations were chosen because they are quite close together, as seen on the expedition map (location 1 & 2 on figure 2). Since air pressure changes over time, it was very important to take measurements with as little time in between as possible. We measured pressure in both locations twice, with around 2.5 hours in between.

Table 2. Two pressure measurements in two locations at different elevations.

Time	Kassitoome org (46.5m)	Toomemägi (70m)	Difference
14.13-14.28	1007.5 mbar	1006.5 mbar	1 mbar
16.47-16.53	1010 mbar	1007.5 mbar	2.5 mbar
Average	difference		1.75 mbar

On average, the pressure was 1.75 mbar lower at higher altitude.

With the air pressure data, elevation difference can actually be calculated using the formula of pressure: $p = Pgh$

p - pressure (pascals)

P - air density (1.14 kg/m^3 according to Miina Härma Gymnasium's weather station)

g - gravitational acceleration (9.81 m/s^2)

h - height (m)

The height can be extracted from the formula of pressure: h = p / (Pg)

After converting the average pressure difference from mbar to pascals, all the values can be added to the equation.

$h = 175\ Pa / (1.14\ kg/m^3 \times 9.81\ m/s^2)$

h = 15.7m

Calculated height difference is 15.7m. Actual height difference is 70m - 46.5m = 23.5m. Considering the crude nature of the instruments and methods used, this result has an acceptable accuracy.

6. Discussion

Changes in the weather, time difference between measurements in each location and the inaccuracy of our measuring equipment - all of these factors certainly affected our data and due to this, the information provided may not be entirely correct.

When organizing the data, we tried our best to eliminate measurements that were disturbed by suddenly changed weather, e.g. abrupt rain. To slightly decrease the inaccuracy of our air pressure measurements we used two barometers and found the average of the two different values. If possible, the same technique should be applied to other measuring equipment too.

Temperature in technological and green areas

On average, the temperature was 1.4°C lower in green areas compared to technological areas. The average temperature in technological areas was 19.7°C ± 1.08°C. The average temperature in green areas was 18.3°C ± 0.83°C. With these numbers barely overlapping, it can be said for certain that the average temperature was slightly lower in green areas compared to technological areas.

We hypothesized that the temperature will be higher in technological areas. This data supports our hypothesis.

The temperature is lower in green areas, because plants reflect a bit of sunlight and use up some of the energy surrounding them in the process of evapotranspiration, water moving from the land surface to the atmosphere as water vapor. It should also be noted that asphalt tends to absorb a lot of sunlight and therefore it tends to be hotter near the roads.

This result is very similar to other studies. Research done by others also found that vegetation aids in warming the air less than technological surfaces. (Kurn et al., 1994; Dimoudi & Nikolopoulou, 2003).

Humidity in technological and green areas

On average, the humidity was 9.1% higher in green areas compared to technological areas.

We hypothesized that the humidity will be lower in technological areas. This supports our hypothesis.

Humidity is higher in green areas due to a process called transpiration, which is the natural release of water vapour from plants. Actively transpiring plants add moisture to the air, raising the humidity level in green spaces.

Similarly, research of cooling and humidification effects of vegetation communities in urban parks found that the moisture is increased in a green area by 6.46% on average (Y. Zhang, M. Dai, 2022).

Temperature near and far from water

On average, the temperature was only 0.06°C higher near water bodies.

We hypothesized that the temperature will be higher near water and this conclusion supports our hypothesis. However, the data measured lacks clear connections and is more of an anomaly (see Figure 5). Based on our data, our hypothesis could not be confirmed, and it seems as though there is no relationship between the air temperature and the distance from a body of water.

Considering the heatwave that was the day before our expedition, we thought that the water body, which was warmer than usual, would warm up the air around it for a while. This result was not present in our measurements, which might be because too much time had already passed. If the measurements were taken on the night right after the heatwave, a clearer temperature difference may have been visible.

Humidity near and far from water

On average, the air was only 1.57% more humid near water bodies.

We hypothesized that humidity would be higher near water and this conclusion supports our hypothesis. Again however, because the data measured lacks clear connections and is more of an anomaly (see figure 6), it must be said that our hypothesis is not exactly true.

We assumed that wind and sun would cause the water body to start evaporating, which in turn would increase nearby air humidity. This result was not present in our measurements. If the measurements were taken on a hot sunny day, maybe a more certain humidity rise near water bodies might be seen.

Pressure change between elevation

On average, the pressure decreased 1.75 mbar going from altitudes of 46.5m to 70m. We hypothesized that the pressure would be lower at higher altitude. This supports our hypothesis.

With this research question, the main source of error was that the pressure measurements were not taken at the same time. While moving from one spot to the other, the moving winds might have altered the air pressure. Also, since we did not stay for more than 10 minutes in each spot, there is a chance the barometer could not fully adapt to the new location, showing inadequate numbers.

Still, the results acquired are fairly accurate. This is proven by using the collected pressure data to calculate the elevation difference between the two measuring locations. The calculated elevation difference was only 33% off the actual difference, which is quite close.

7. Conclusions

We took atmospheric measurements in 8 locations around Tartu, Estonia and gathered data for 3 research questions.

Categorizing our measurement locations by environmental properties into technological and green areas, we confirmed that the temperature is lower and humidity higher in green spaces compared to technological areas. This outcome supports bringing more greenery to urban areas with a lot of technological surfaces, which would create more balance and reduce the severity of a possible heat-island effect. Research highlighting the importance of nature in an urban environment will get increasingly more people to acknowledge the value plants and balance have.

Categorizing our measurement locations by geographical properties into 'near water' and 'far from water' areas, we saw that the humidity and temperature were slightly higher near water bodies. However, since most of the data appeared as an anomaly and had no clear connections, the statement 'temperature and humidity levels are higher near water bodies' cannot be confirmed as a fact, based on our research.

Categorizing our measurement locations by elevation, we confirmed that air pressure decreases as the altitude gets higher. To prove that our conclusion is correct, the elevation difference between our two measuring locations was mathematically calculated using the air pressure data and then compared to the actual difference - the result was not off by much.

Comparing atmospheric measurements from two different locations would be much more precise if the measuring was done in both places at the same time. Doing this will decrease the inaccuracy caused by weather conditions changing between measurements. Staying in one measuring location and letting the instruments (e.g., the barometer and thermometer) adapt to the current settings for a longer time might also help make the results more accurate.

An idea developed after analysing the data from this expedition: the same research comparing the atmospheric properties of green and technological areas should be done in winter. It would be interesting to see if the effect of nature (decreasing temperature and raising humidity levels) still remains apparent with snow present. Snow has an albedo of 0.8-0.9, which means it reflects most of the sun and does not absorb much. In winter, deciduous trees have also lost all leaves, which means transpiration would not help cool the air. Hypothetically, considering the aforementioned winter conditions, there would be a difference in results between technological and green areas compared to the results from measurements taken in summer.

Doing this project with mentors helped us feel more comfortable and confident doing the research. We were directly guided on how to correctly use the atmospheric measurement instruments and we never had to doubt anything, because we could always ask questions from the mentors. They also helped keep up the pace and made sure everybody was working as a team. We are all very thankful to Uku and Liisa.

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