The Urban Heat Island Effect in Vancouver

Does Vancouver, a mid-latitude coastal city, have a defined urban heat island? What factors influence temperature patterns in Vancouver?

Geography SL Internal Assessment

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Introduction

Vancouver, BC, is the 8th most populous in Canada, and the most populous city in BC (Government of Canada, 2023; Moreau, 2022). It is a coastal city in southern mainland BC, near the Canadian-American border. It features significant green space, and a prominent urban downtown area to the north of the city.

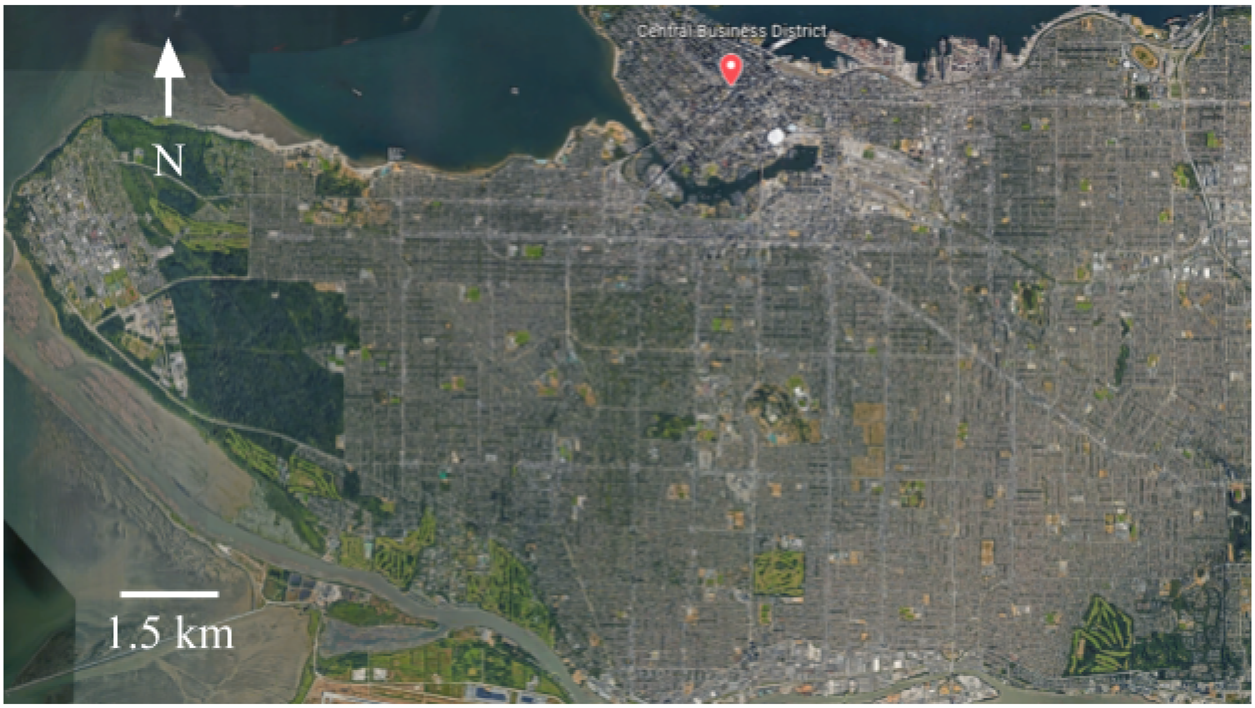

Figure 1. The City of Vancouver, the area under study for this paper. Satellite image taken from Google Earth. (Google, n.d.)

As seen in Figure 2, Vancouver's Central Business District is located in Downtown Vancouver, between Burrard Inlet in the North to False Creek in the South, and from Burrard Street to the West, to Homer Street on the East (*City Center*, 2023). For ease of analysis, as seen in Figure 3, we will approximate the CBD to a single point, at the Vancouver Art Gallery, between Burrard and Homer.

The urban heat island effect is a phenomena in which urbanized areas experience on average warmer temperatures (Environmental Protection Agency, 2022). This tends to be due to an increase in low albedo, concrete coverage, that absorbs sunlight, and heats up the covered area, combined with an increase in traffic and population density (National Geographic Society, n.d.).

Figure 2. Vancouver's central business district, outlined in dotted red. Satellite image taken from Google Earth (Google, n.d.).

Figure 3. Zoomed into the central business district, the Vancouver Art Gallery, used as an approximation for the central business district. Satellite image taken from Google Earth (Google, n.d.).

Between June 25 to July 1, 2021, there were 619 fatalities due to heat related incidents in Vancouver alone (The Government of British Columbia, 2022). Because of this, monitoring the urban heat island effect is important to analyzing communities and areas at risk that are most affected by heat related incidents under extreme conditions.

The aim of this paper will be to determine to what extent the urban heat island effect affects Vancouver, and if there is a defined heat island, to determine potential causes.

Research Question

The research question this paper will answer is:

Does Vancouver, a mid-latitude coastal city, have a defined urban heat island? What factors influence temperature patterns in Vancouver?

Hypothesis

This hypothesis is in two parts:

1) I predict, for the reasons outlined at the end of page 2, that Vancouver will exhibit a significant Urban Heat Island Effect, specifically around the previously outlined Central Business District.
2) I predict that areas with high vegetation, and low building density will experience lower temperatures than areas with low vegetation, and high building density, as areas with higher building density and less vegetation, will have higher concrete coverage, and thus a low albedo, which will absorb more heat.

Methodology

To obtain a heat map of Vancouver, we measured temperatures in evenly distributed intervals. We also measured additional points around the Central Business District to obtain more precision. Each person in the class was assigned three points. Since we had 27 participants, we were able to collect a total of 81 data points. A map of these data points can be found in Figure 5. All coordinates can be found in Table 1.

Each datapoint was labeled with an integer from 1 to 29 (skipping 19 and 28), and a letter from “a” to “c”. Data Points assigned the same number were measured by the same student. The letters, “a” to c”, designate the time at which the temperature was taken. Points labeled “a” were taken at 20:00 pm, points labeled “b” were taken at 20:15, and points labeled “c” were taken at 20:30. These were taken, to maximize the prominence of the urban heat island effect in Vancouver. Prior studies, such as *Characterizing the hourly variation of urban heat islands in a* *snowy climate city during summer*, found that urban heat islands were significantly more prominent at night (Yang et al., 2019). Because of this, temperatures were taken as late as student availability permitted (20:00 to 20:30).

At each site, temperatures were taken one meter away from the ground, using thermometers issued by the school, as seen in Figure 4. Before data collection, all thermometers were compared to one master thermometer, and the deviations were recorded. These deviations were then subtracted or added, such that the final reading matched the master thermometer, so that all data points would be calibrated.

While temperature makes up our quantitative data, we also collected qualitative data on vegetation and building density. With that being said, we did later quantify this data, into two scores between 1 and 5, one indicating vegetation, and the other, building density. This was done in order to track the potential effect of green space and building density on the urban heat island effect. The conversion table can be found in Table 2. It is important to not that these measurements are unreliable, as they are subjective, and dependent on the observer

Figure 4. One thermometer used for data collection.

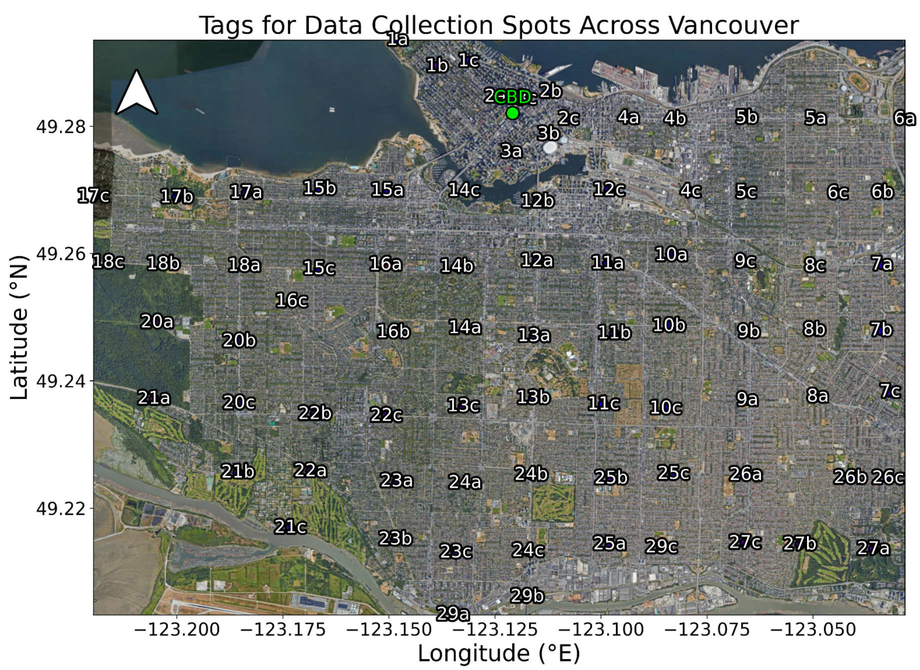

Figure 5. Tags for all data points. Satellite image taken from Google Earth (Google, n.d.).

Data and Observations

Table 1 - Coordinates and Tags for Temperature Collection

Tag	Latitude (°N)	Longitude (°E)	Tag	Latitude (°N)	Longitude (°E)	Tag	Latitude (°N)	Longitude (°E)
1a	49.29350336	-123.1479372	11a	49.25837416	-123.0983864	22a	49.22576942	-123.1684303
1b	49.28934953	-123.1386159	11b	49.24740917	-123.0968311	22b	49.23474926	-123.1673863
1c	49.29015536	-123.1312263	11c	49.23628836	-123.0993905	22c	49.23446694	-123.150588
2a	49.28459498	-123.1248715	12a	49.25874316	-123.1150446	23a	49.22417196	-123.148093
2b	49.28532736	-123.111852	12b	49.26810635	-123.1149498	23b	49.21506223	-123.1484201
2c	49.28109036	-123.1075976	12c	49.26990094	-123.0981019	23c	49.21302459	-123.13419
3a	49.27591196	-123.1210579	13a	49.24699674	-123.1157341	24a	49.22393399	-123.1319867
3b	49.27869046	-123.1123187	13b	49.23724606	-123.1159283	24b	49.22520745	-123.116418
3c	49.28424186	-123.1175059	13c	49.23596436	-123.1324583	24c	49.21322498	-123.1171635
4a	49.28123136	-123.0934485	14a	49.24823236	-123.1320317	25a	49.21429398	-123.0978984
4b	49.28102188	-123.0824625	14b	49.25786716	-123.1339601	25b	49.22463758	-123.0975571
4c	49.26969178	-123.0788299	14c	49.26980774	-123.1322741	25c	49.22536214	-123.0828569
5a	49.28113756	-123.0493142	15a	49.26982852	-123.1503089	26a	49.22518956	-123.0657886
5b	49.28126266	-123.0655975	15b	49.27008726	-123.1663104	26b	49.22471416	-123.0411448
5c	49.26955563	-123.0657543	15c	49.25752935	-123.1664823	26c	49.22466135	-123.0322836
6a	49.28107617	-123.0283381	16a	49.25819196	-123.1507389	27a	49.21353243	-123.0356983
6b	49.26951726	-123.0336059	16b	49.24757466	-123.1489304	27b	49.21425931	-123.0530779
6c	49.26941946	-123.0441467	16c	49.25243576	-123.1729321	27c	49.21450993	-123.0660106
7a	49.25821756	-123.0337062	17a	49.26946693	-123.1836121	29a	49.20323713	-123.1348224
7b	49.24788116	-123.0338872	17b	49.26876679	-123.1999887	29b	49.20605112	-123.117329
7c	49.23822896	-123.031848	17c	49.26890022	-123.2196262	29c	49.21382417	-123.0857056
8a	49.237488	-123.0488344	18a	49.25801636	-123.1840459			
8b	49.24795657	-123.0496321	18b	49.25827976	-123.2031788			
8c	49.25798866	-123.0495538	18c	49.25853952	-123.2161789			
9a	49.23694916	-123.0654383	20a	49.24913095	-123.2045855			
9b	49.24762355	-123.0650826	20b	49.24615996	-123.1852437			
9c	49.25865467	-123.0659644	20c	49.23642895	-123.185314			
10a	49.25967926	-123.0833847	21a	49.23715138	-123.2053286			
10b	49.2485732	-123.0839275	21b	49.22557626	-123.1855617			
10c	49.23563173	-123.0847622	21c	49.21689797	-123.1732052			

Table 2 - Quantification Criteria for Qualitative Data

Score	Building Density	Vegetation
1	Extensive Green Space, Low Density Single Detached	Central Business District, Paved, Commercial, or Industry
2	Residential, Primarily Single Detached, Some Apartment or Condos	Business, Comercial, Industrial, or High Density Residential
3	Higher Density Residential or Commercial	Residential
4	Three to Five Story Buildings, or Commercial	Low Density Residential, Parks, or Green Space
5	Central Business District, most Buildings Above Five Stories	Extensive Green Space, Golf Course, Parks

Table 3 - Temperatures for Each Datapoint

Tag	Temp (°C)	Tag	Temp (°C)	Tag	Temp (°C)	Tag	Temp (°C)	Tag	Temp (°C)	Tag	Temp (°C)
1a	11.5	15a	13.0	1b	16.0	15b	14.0	1c	14.0	15c	13.0
2a	17.0	16a	19.5	2b	14.0	16b	19.0	2c	16.0	16c	18.5
3a	23.5	17a	14.0	3b	25.0	17b	13.0	3c	14.0	17c	12.0
4a	15.0	18a	16.5	4b	14.5	18b	14.5	4c	13.0	18c	14.0
5a	18.0	20a	16.5	5b	17.0	20b	15.5	5c	16.0	20c	15.5
6a	14.0	21a	18.0	6b	14.0	21b	16.0	6c	13.5	21c	15.0
7a	14.5	22a	17.0	7b	13.0	22b	16.5	7c	15.0	22c	16.0
8a	16.5	23a	15.5	8b	16.5	23b	16.0	8c	20.0	23c	16.0
9a	16.0	24a	14.0	9b	15.0	24b	14.5	9c	15.2	24c	15.0
10a	12.0	25a	15.5	10b	12.0	25b	15.5	10c	13.0	25c	15.0
11a	13.0	26a	15.0	11b	13.0	26b	14.5	11c	12.0	26c	14.5
12a	16.0	27a	16.0	12b	17.5	27b	16.0	12c	14.5	27c	16.5
13a	16.0	29a	12.5	13b	16.0	29b	13.0	13c	15.5	29c	13.5
14a	14.5			14b	13.5			14c	12.5		

Table 4 - Vegetation for Each Datapoint

Tag	Vegetation	Tag	Vegetation	Tag	Vegetation	Tag	Vegetation	Tag	Vegetation	Tag	Vegetation
1a	5	15a	2.5	1b	1.5	15b	3	1c	2	15c	3
2a	1	16a	3	2b	2	16b	4	2c	3	16c	3
3a	1	17a	3	3b	2	17b	4	3c	1	17c	5
4a	2	18a	2	4b	2.5	18b	4.5	4c	1.5	18c	5
5a	2	20a	5	5b	2	20b	4	5c	1	20c	4
6a	2	21a	5	6b	3	21b	4	6c	2	21c	4
7a	1	22a	4	7b	3	22b	3	7c	1	22c	3
8a	4	23a	4	8b	3	23b	3	8c	3	23c	3
9a	2	24a	3	9b	4	24b	3	9c	2	24c	2
10a	3	25a	3	10b	3.5	25b	3	10c	3	25c	3
11a	3	26a	2.5	11b	3	26b	2.5	11c	3	26c	2.5
12a	3	27a	4	12b	2	27b	4	12c	2	27c	3
13a	4	29a	2	13b	4	29b	2	13c	3.5	29c	4
14a	5			14b	4			14c	3		

Table 5 - Building Density for Each Datapoint

Tag	Building Density	Tag	Building Density	Tag	Building Density	Tag	Building Density	Tag	Building Density	Tag	Building Density
1a	1	15a	2.5	1b	4	15b	2	1c	5	15c	2
2a	5	16a	2	2b	5	16b	1	2c	5	16c	2
3a	4	17a	2	3b	5	17b	1	3c	5	17c	1
4a	3.5	18a	4	4b	3	18b	1	4c	2	18c	1
5a	3	20a	1	5b	2	20b	1	5c	4	20c	1
6a	4	21a	1	6b	2	21b	1	6c	3	21c	1
7a	3	22a	2	7b	3	22b	2	7c	4	22c	3
8a	2	23a	1	8b	1	23b	2	8c	2	23c	2
9a	3	24a	2	9b	1	24b	2	9c	3	24c	3
10a	2	25a	2	10b	2	25b	2	10c	2	25c	2
11a	2	26a	2.5	11b	2	26b	3	11c	2	26c	2.5
12a	2	27a	2	12b	2	27b	2	12c	3	27c	2
13a	2	29a	4	13b	2	29b	5	13c	1.5	29c	1
14a	1			14b	3			14c	4		

Analysis

Generation of the following isotherm, contour, 3d surface, and 3d contour maps were generated via custom made software, written by the author of this paper. All source code can be found on Github, at: https://github.com/liam-ilan/geography-ia. The Python package, Matplotlib, was used to render the graphs. Christoph Heindl's implementation of the Thin Plate Spline algorithm was used to interpolate between data points, providing a reliable and deterministic method for interpreting the contour lines (2018). The satellite images used are sourced from Google Earth.

The first step in analyzing our data is to create an isotherm of the collected data, to see visually, if there is a heat island around the Central Business District. This can be seen in Figure 6.

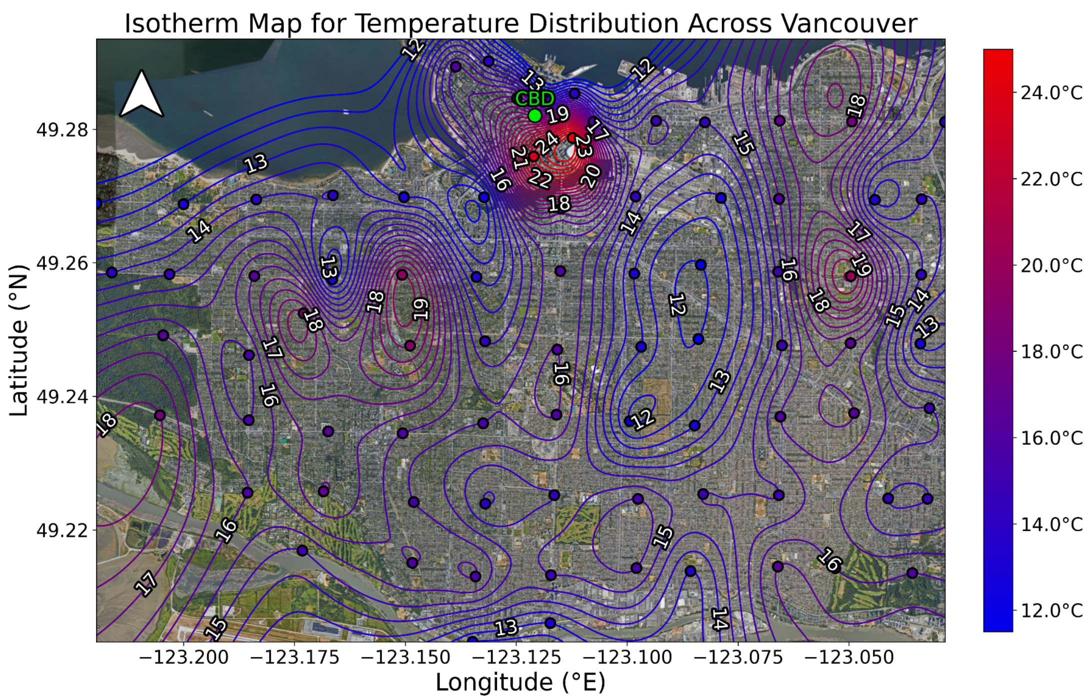

Figure 6. Isotherm map for collected data across Vancouver, generated with custom software built by the author of this paper. Satellite image taken from Google Earth (Google, n.d.).

This isotherm appears to suggest a strong urban heat island effect in Vancouver. With that being said, the heat island also does not appear to be centered around the Central Business District (CBD), but rather is located to the Southeast, in an area known as Yaletown. The dense contour lines around the heat island show a dramatic drop in temperatures outside of the heat island. Additionally, there appear to be more, less significant heat islands around (49.26 °N, -123.050 °E), and (49.25 °N, -123.150 °E).

A more intuitive visual of Vancouver's heat islands, that assists in interpretation of the prominence of the heat islands, can be found, by looking at a 3d surface and contour map, as seen in Figures 7 and 8. Here, it is clear that there is one, major heat island in Downtown Vancouver. All other heat islands visually do not have the same, significant prominence. This evidence supports the existence of a strong urban heat island effect.

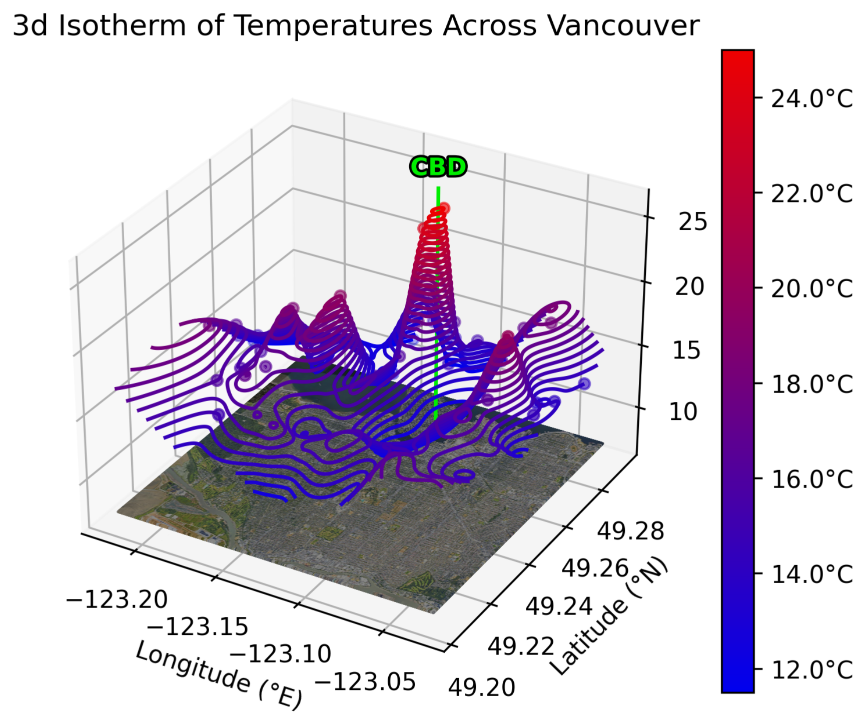

Figure 7. 3d contour map for collected data across Vancouver, generated with custom software built by the author of this paper. Satellite image taken from Google Earth (Google, n.d.).

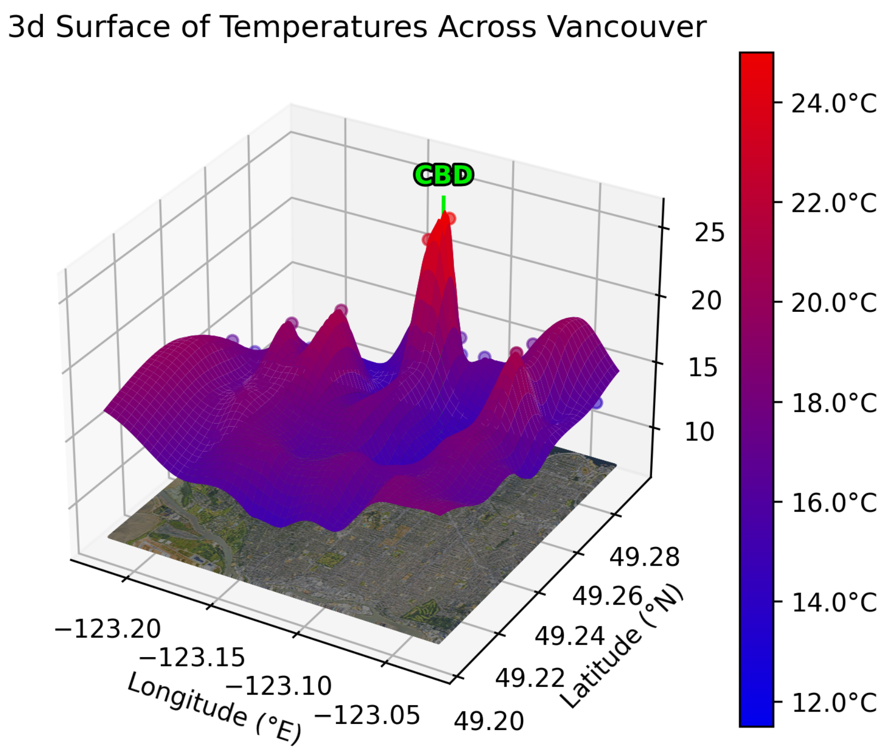

Figure 8. 3d surface map for collected data across Vancouver, generated with custom software built by the author of this paper. Satellite image taken from Google Earth (Google, n.d.).

To gain a more concrete understanding, we can plot a scatter plot, seen in Figure 9, showing temperature, vs. distance from the Central Business District, for each data point. Then, we can find Spearman's Rank Correlation Coefficient. Spearman's Coefficient is a measure of how well a monotonic function (a function that consistently rises, or decreases) fits our data (UT Austin, n.d.; Stover, n.d.). In our case, finding Spearman's Rank Correlation Coefficient will allow us to evaluate whether or not there is a statistically significant decreasing trend in temperature from the Central Business District, and thus whether or not there is a prominent urban heat island.

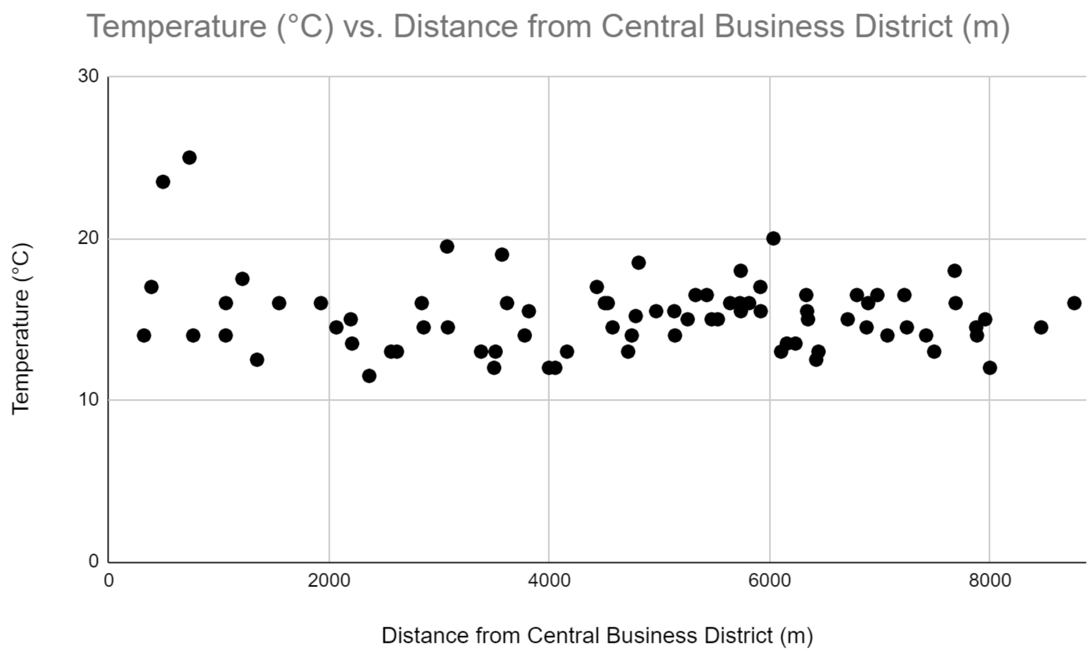

Figure 9. A scatter plot of Temperature vs. Distance from the Central Business District, generated with Google Sheets. We expect a negative Spearman's Coefficient, as a heat island implies a dropping temperature with an increase in distance. With that being said, at first sight, it is clear that aside from the two outliers warmer than 20 °C, there appears to be no significant decrease or increase, rather the data appears to be random noise.

Using a Spearman's Coefficient calculator (Social Science Statistics, n.d.), we can calculate the Spearman's Coefficient for Figure 9 to be 0.00598. This shows slight, yet statistically insignificant positive correlation (Barcelona Field Studies Centre, n.d.). The size of Spearman's Coefficient shows no statistically significant correlation between temperature and distance from the Central Business District.

While at first counter intuitive, this result makes sense. Looking back up at Figures 6, 7, and 8, we can see that the primary heat island is extrapolated from only two points. This is not statistically significant enough to make a conclusion, as these two points may simply be outliers.

Moving on, in order to tackle the second part of the hypothesis, we can investigate the effects of building density and vegetation on urban temperature. First, we will create two contour maps, one for vegetation (Figure 10), and one for building density (Figure 11). This will give us a visual aid to compare with our isotherm (Figure 6).

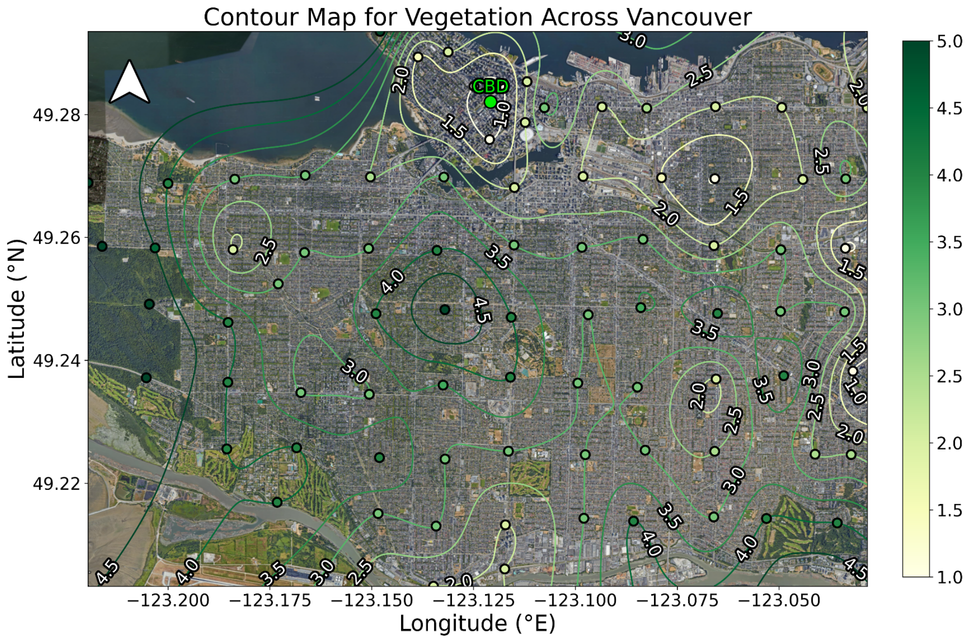

Figure 10. Vegetation contour map. There is a noticeable decrease in vegetation around the Central Business District. Satellite image taken from Google Earth (Google, n.d.).

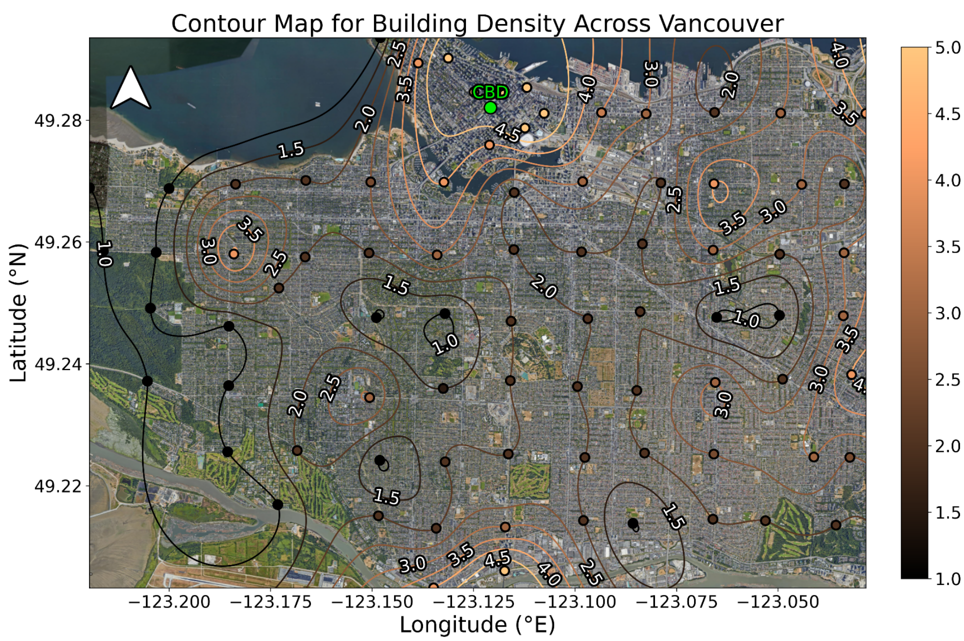

Figure 11. Building density contour map. There is a noticeable increase in building density around the Central Business District, contrasting with the decrease in vegetation density. Satellite image taken from Google Earth (Google, n.d.).

There is an apparent decrease in vegetation, and increase in building density around the Central Business District. This matches up with the apparent heat island seen in the isotherm map on Figure 6, thus also supporting our hypothesis that temperatures will be higher in areas with high building density and low vegetation.

Next, to gain a more concrete understanding, we can repeat the same process that we used to analyze the isotherms, and create a scatter plot, followed by a Spearman's Coefficient. This time, we will generate two scatter plots, one that is Temperature vs. Vegetation, and the other which is Temperature vs. Building Density.

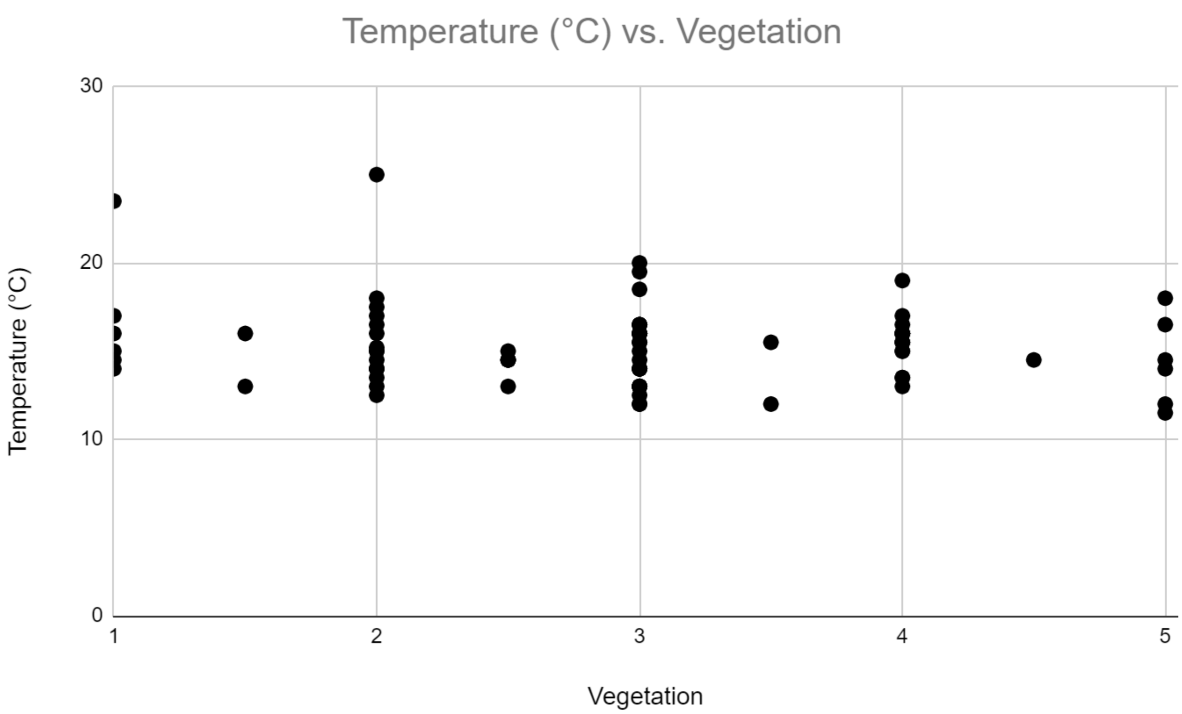

Figure 12. A scatter plot of Temperature vs. Vegetation, generated using Google Sheets. There appears to be no visible correlation between the two.

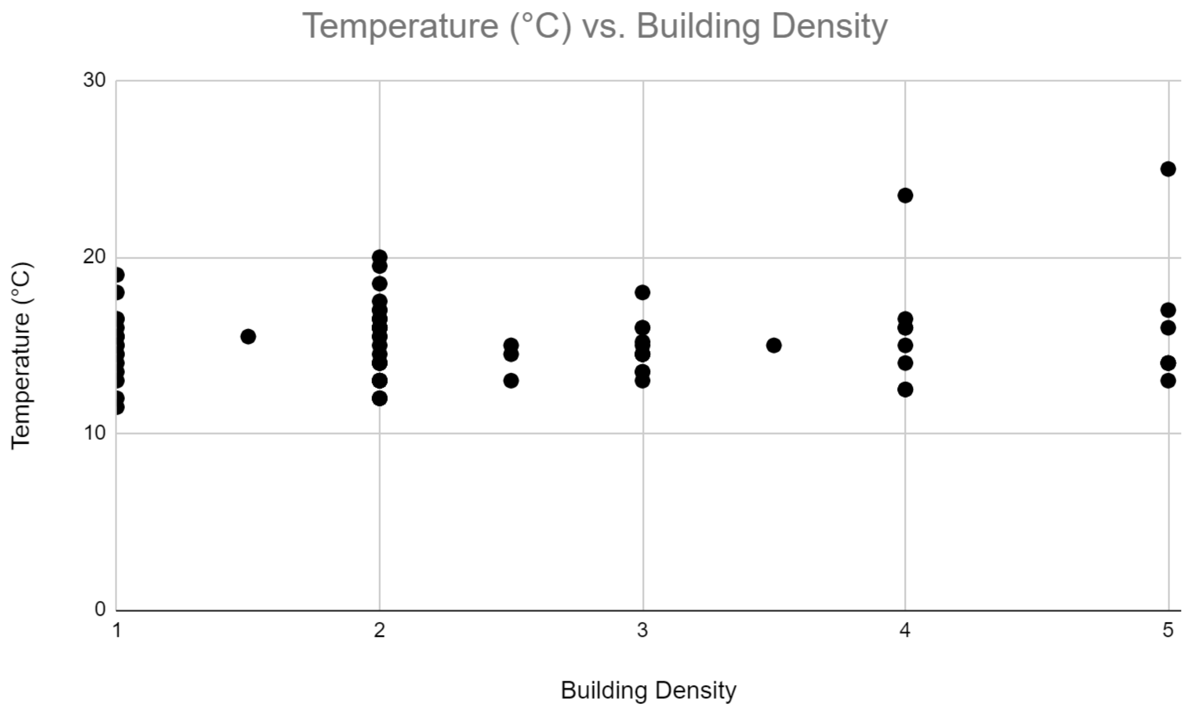

Figure 13. A scatter plot of Temperature vs. Building Density, generated using Google Sheets. There appears to be no visible correlation between the two.

Using a Spearman's Coefficient calculator (Social Science Statistics, n.d.), we can calculate the Spearman's Coefficient for Figures 12 and 13 to be -0.03297 and -0.02371. This shows negative, yet statistically insignificant correlation for both graphs. This is likely for the same reason our temperature vs. distance graph yielded such a low coefficient. Our perceived heat island is based on solely two potential outliers, thus, there is no statistical significance in our results.

Conclusion

In response to the first part of the hypothesis, while it appears visually through 3d and isotherm maps that Vancouver exhibits a significant urban heat island effect, this conclusion lacks solid statistical significance. Additionally, the exhibited heat island appears Southeast of the Central Business District by a significant margin, deviating from our hypothesis. Our hypothesis is neither refuted, nor supported, due to a lack of statistical significance.

In response to the second part of the hypothesis, while it appears visually on contour maps that there is a correlation between building density and temperature, and a negative correlation between vegetation and temperature, a Spearman's coefficient again reveals the statistical insignificance of the results. Additionally, the measures for vegetation and building density are not reliable, as they are subjective on the basis of the student collecting the data. The second part of the hypothesis is neither refuted, nor supported, due to a lack of statistical significance.

In conclusion, while visually, Figures 6, 7, 8, 10, and 11, show that:

1) Vancouver does exhibit a defined heat island, Southeast of the central business district
2) An increase in building density leads to increase in temperature, and vice versa
3) A decrease in vegetation leads to an increase in temperature, and vice versa

While this supports our hypothesis, further analysis through Spearman's coefficient shows us that:

1) There is not enough data to make a conclusive argument for or against a defined heat island (Spearman's coefficient for the relationship between temperature and distance from CBD is extremely low, combined with solely two points responsible for making up the primary heat island)
2) Conclusions about the relationships between vegetation and temperature, or building density and temperature, cannot be made. (Spearman's coefficients are extremely low)

The results of this investigation are inconclusive.

Evaluation

One advantage of this investigation is the large amount of data collected within a short time frame. In most experiments, 81 datapoints is enough to reach some significant conclusion. With that being said, there is a notable lack of repeat trials in this procedure, leading to the inability to differentiate between outliers, and heat islands. This ultimately led to inconclusive results. In an idealized procedure, we might repeat the experiment 3 to 5 times, and standardize all temperatures relative to the CBD to minimize the effect of daily variations. On a more extreme scale, one could hypothetically set up devices to monitor the temperature across Vancouver constantly for a long period of time, allowing for more data, and thus more significance of results.

Another major flaw in the experimental procedure is the quantification of qualitative data. Since qualitative data is dependent on the observer, the quantified data cannot be relied on, so building density and vegetation measurements were unreliable. A more conclusive, directly quantifiable method. Potentially, one could take satellite images, and average the color values over an area to achieve a number representative of the albedo that area exhibits. Thus, the effect of albedo on temperature patterns could be directly observed.

While measuring all data points in a small time interval was useful for obtaining consistent data, one factor towards the extent to which Vancouver experiences the Urban Heat Island Effect is the time of day. This is another reason the results of our investigation are inconclusive, as we simply judged whether or not Vancouver has a defined heat island at noon, not in general. In an ideal situation, another independent variable could be added, being time. Then, the prominence of the Urban Heat Island Effect could be compared against it for additional results and conclusivity.

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