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The effect of urban density on nocturnal canopy-layer air temperatures

Abstract

As human population increases, so does the drive for humans to become more urbanized. This urbanization has lead to an increase in urban density, causing a demand to support this growing population with living spaces, food and water. In this study we will examine if urban density has an effect on nocturnal canopy-layer air temperatures. Previous work has succeeded in proving that there is a correlation between urban density and nocturnal canopy-layer air temperatures and this study aims to strengthen this hypothesis. In order to determine this correlation, nocturnal canopy-layer air temperatures were collected. These samples were obtained on March 16th 2015 by a mobile truck taking air temperature samples around a specified route in Vancouver, Canada in the time frame of 18:00- 21:00 hours. Following this data collection, local climate zones were determined at all 65 marker points along the route. With this data set, an analysis was completed and the results are described in more detail below. The implications of this analysis can be useful for better designing of cities in order to lower urban air temperatures, as well as, providing a better comprehension of the above topics which will allow scientists to find solutions to this problem.

Research Question

What is the effect of urban density on nocturnal canopy-layer air temperatures?

Analysis of Procedures

In order to determine if there is any correlation between urban density and nocturnal canopy-layer air temperatures a detailed procedure was conducted:

1. Collect nocturnal canopy-layer air temperature samples along a specified route in Vancouver, Canada
2. Classify each route marker from 0-65 with its corresponding local climate zone using Google Earth
3. Group each route marker point based on its local climate zone determination and temperature reading for the corresponding marker
4. Within each local climate zone grouped determine the average, range and variation of nocturnal canopy-layer air temperatures.
5. Compare this data by visualizing it graphically/look for correlations
6. Explain the results and provide conclusions based on the findings

Justification of Chosen Data Set

For this analysis, the data set on March 16th, 2015 was chosen. The reason this data set was chosen was due to the fact that on the above date, clear conditions were observed as well as during the traverse. This provides accurate nocturnal canopy-layer air temperature data since weather did not impede incoming shortwave radiation absorption throughout the day of the surface of the study area. Only one data set was used and analyzed and this is because urban density does not drastically change over a short period of time. I considered studying a traverse in 2015 to compare it to 2008 but there was a lack of density data for 2008 so this comparison was not possible.

Results

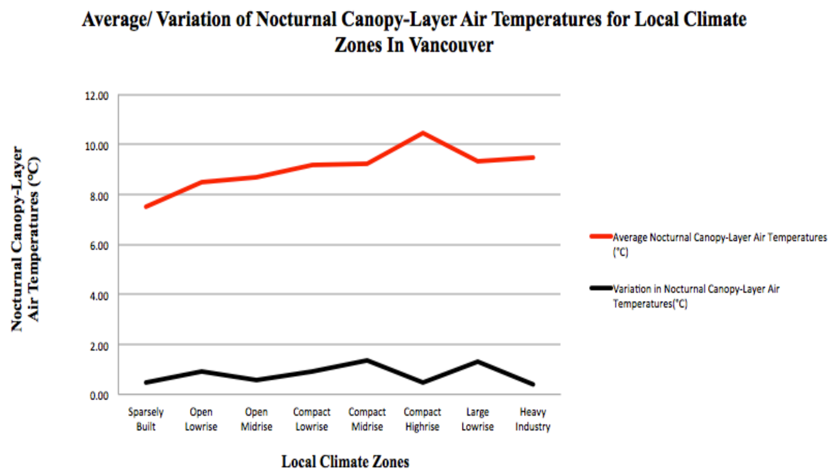
After the collection and analysis of this data the following was produced:

Local Climate Zone Classification	Average Nocturnal Canopy-Layer Air Temperatures (°C)	Variation in Nocturnal Canopy-Layer Air Temperatures(°C)	Range in Nocturnal Canopy-Layer Air Temperatures(°C)	Average Building height (m)
Sparsely Built	7.50	0.45	6.8- 8.0	6.5
Open Lowrise	8.51	0.90	6.8-10.0	6.5
Open Midrise	8.68	0.57	7.7-9.6	17.5
Compact Lowrise	9.17	0.92	8.5-9.8	6.5
Compact Midrise	9.24	1.36	7.3-10.9	17.5
Compact Highrise	10.49	0.47	9.8-11.0	37.5
Large Lowrise	9.31	1.30	7.3-10.8	6.5
Heavy Industry	9.46	0.40	9.0-10.1	10

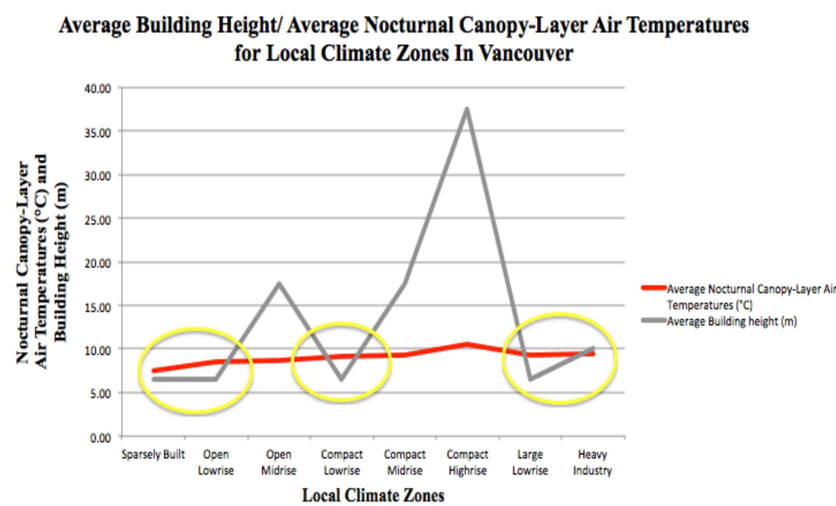
(Figure 2)

Manual markers	Air Temperature (°C)	Local Climate Zone Classification
00 - Start of first control run at UBC	8.97779	Open Midrise
01 - End of first control run at UBC	8.62221	Open Midrise
02 - West Mall - NW Marine	8.78512	Open Midrise
03 - Chancellor Blvd. - Wesbrook Mall	8.94999	Open Lowrise
04 - Chancellor Blvd. - traffic lights at school entrance	8.12545	Open Lowrise
05 - Chancellor Blvd. - Blanca	7.64143	Open Lowrise
06 - W 4th Ave. - NW Marine Drive	7.78755	Sparsely Built
07 - W 4th Ave. - Alma	8.51427	Compact Lowrise
08 - W 4th Ave. - MacDonald	9.81777	Compact Lowrise
09 - W 4th Ave. - Burrard	10.817	Large Lowrise
10 - Cornwall - S.-end Burrard Bridge	9.97249	Large Lowrise
11 - Burrard - Pacific	10.0093	Compact Highrise
12 - Hornby - Davie	10.3064	Compact Highrise
13 - Hornby - Robson	10.8139	Compact Highrise
14 - Robson - Jervis	10.8827	Compact Midrise
15 - Robson - Denman	10.4014	Compact Midrise
16 - Robson - Lagoon Drive	8.61712	Compact Midrise
17 - W.-end of Lost Lagoon	7.21893	Sparsely Built
18 - Causeway/Georgia - Chilco	7.28683	Compact Midrise
19 - Georgia - Jervis	9.76701	Compact Highrise
20 - Georgia - Howe	10.9558	Compact Highrise
21 - Howe - Nelson	10.9119	Compact Highrise
22 - N. end Granville Bridge	10.6483	Compact Highrise
23 - Granville - W Broadway	10.4656	Compact Midrise
24 - Granville - Angus Dr.	9.85722	Open Lowrise
25 - Angus Dr. - W King Edward Ave.	8.45312	Open Lowrise
26 - Angus Dr. - W 33rd Ave.	8.07987	Open Lowrise
27 - Angus Dr. - W 41th Ave.	7.40035	Open Lowrise
28 - Angus Dr. - W 49th Ave.	7.45979	Open Lowrise
29 - W 49th Ave. - Cartier St.	8.06599	Open Lowrise
30 - Cartier St. - W 50th Ave.	7.52746	Open Lowrise
31 - W 50th Ave. - Selkirk St.	7.77064	Open Lowrise
32 - Selkirk St. - W. 54th Ave.	7.56396	Open Lowrise
33 - W. 54th Ave. - Oak St.	7.41647	Open Lowrise
34 - Oak St. - Park Dr.	8.06156	Open Lowrise
35 - Oak St. - 70th	9.02812	Open Lowrise
36 - S. end Oak Street Bridge	9.59543	Open Midrise
37 - Hwy 99 - Off ramp 38	8.842	Open Lowrise
38 - Shell Rd. - Cambie Rd.	9.14532	Large Lowrise
39 - Cambie Rd. - No 5 Rd.	9.31159	Large Lowrise
40 - No 5 Rd. - Vulcan Way	9.22015	Heavy Industry
41 - Vulcan Way - No 6 Rd.	9.57915	Heavy Industry
42 - River Rd. - No 7 Rd.	9.01044	Heavy Industry
43 - No 7 Rd. - Cambie Rd.	8.01121	Sparsely Built
44 - No 7 Rd. - Overpass over Hwy 91	7.81608	Sparsely Built
45 - No 7 Rd. - Westmister Hwy	7.38058	Sparsely Built
46 - Westmister Hwy - Knight St.	7.3101	Large Lowrise
47 - Knight St. - S. End of Knight Bridge	9.41116	Heavy Industry
48 - Knight St. Bridge - Mitchell Island	10.0643	Heavy Industry
49 - Knight St. - E 57th Ave.	9.89459	Open Lowrise
50 - Knight St. - E 51th Ave.	10.0406	Open Lowrise
51 - E 51th Ave. - Prince Albert St.	9.55499	Open Lowrise
52 - Prince Albert St. - E 49th Ave.	9.48529	Open Lowrise
53 - Prince Albert St. - E 41th Ave.	9.25503	Open Lowrise
54 - E 41th Ave. - Main St.	8.90366	Open Lowrise
55 - W 41th Ave. - Cambie St.	9.10148	Open Lowrise
56 - W 41th Ave. - Oak St.	9.46739	Open Lowrise
57 - W 41th Ave. - Angus Dr.	8.57454	Open Lowrise
58 - W 41th Ave. - West Blvd.	8.8803	Compact Midrise
59 - W 41th Ave. - MacKenzie St.	8.31782	Open Lowrise
60 - W 41th Ave. - Dunbar St.	8.14277	Compact Midrise
61 - W 41th Ave. - SW Marine Dr.	6.79775	Open Lowrise
62 - SW Marine Dr. - W 16th Ave.	6.79501	Sparsely Built
63 - NW Marine Dr. - University Blvd.	7.70442	Open Midrise
64 - Start of second control run at UBC	8.45903	Open Midrise
65 - End of second control run at UBC	8.62102	Open Midrise

(Figure 1)



(Figure 3)



(Figure 4)

Discussion and Analysis

The above figures show a clear correlation between urban density and nocturnal canopy-layer air temperatures. ***(Figure 1)*** provides a visual of each marker point on the traverse and the corresponding air temperature and local climate zone classification. There are eight different local climate zones that were determined in the experimental area. ***(Figure 2)*** displays the average, variation and range of nocturnal canopy-layer (NCL) air temperatures as well as building heights for each local climate zone (LCZ). From the results, the sparsely built LCZ had the lowest average NCL air temperature at 7.50 °C compared to the compact highrise LCZ with an average NCL air temperature of 10.49°C. This is expected and can be explained because in the sparsely built LCZ there is a greater number of trees and vegetation, which respires, cooling the air around them and lowering the air temperature. The albedo in this LCZ is also higher meaning more light is reflected than absorbed causing less incoming shortwave radiation to be stored at the surface. In the compact highrise LCZ there is little to no vegetation thus the incoming shortwave radiation that strikes the surface during the day gets absorbed and stored and then released at night as long wave radiation causing the air temperature to increase. The lower albedos of pavement and concrete in the compact highrise LCZ also explain why temperatures are greatest due to greater shortwave radiation absorption than reflection. As you can see in ***(Figure 2)*** the denser an area becomes, the higher the average NCL air temperature is. There are some exceptions to this. Heavy industry and large lowrise LCZ do not follow this pattern, yet they still have high average NCL air temperatures. The reason for this is because these are areas of industry and production, which emit pollution into the atmosphere. The pollution particles emitted act as a sponge and absorb incoming shortwave radiation from the sun during the day and long wave radiation from the earth at night forming a warm microclimate above these LCZ's thus causing high average NCL air temperatures. ***(Figure 3)*** displays some interesting findings about average NCL air temperature and the variation from this average. From the above graph the average NCL air temperature and variation of NCL air temperature are almost mirror images of each other. As stated before, the highest temperatures are located in the highest density areas and we can also conclude that the variation from the average in these dense areas is very low as illustrated in ***(Figure 3)***. This means that in the compact highrise LCZ the temperature is relatively constant and does not fluctuate. If we compare this to the greatest variation from the mean in the compact midrise and large lowrise LCZ we can conclude that there are underlying meteorological factors that are causing these variations from the mean and big temperature ranges. Lastly, ***(Figure 4)*** displays a relationship between average NCL air temperatures and building height. As we can see in the above highlighted yellow areas for lower building configurations, the average NCL air temperatures almost equal the height of the building itself. The opposite is found for higher buildings. One reason for this could be because due to urban geometry. As solar radiation enters a small urban canyon the radiation is emitted and reflected off all the walls before reaching the surface depending on the time of day. So for smaller scale building configurations the radiation is more likely to strike the ground than in the taller more dense building areas. The smaller buildings are closer to the ground. As you can see there are a few relationships and correlations we can draw from the above data and analysis but there are also problems and limitations that go along with these results. In the paragraph below these problems/limitations are outlined and explained.

Problems and Limitations

There are a few limitations that have to be discussed. The first limitation in this experiment is that the determination of each local climate zone at all 65 marker points is completely subjective to the individual doing the analysis. The second limitation is that there is an over generalization of data for each local climate zone. Most of the characteristics of each local climate zone are over generalized due to the fact that every urban area is different and it's almost impossible to describe each different urban area in very fine detail. This made it difficult to classify each LCZ and find correlations between temperature, height and vegetation of each local climate zone.

Conclusions

In conclusion, the above data and analysis does support the previous hypothesis that the more dense an urban area is the higher the nocturnal canopy-layer air temperatures are and the less dense an area is the lower the nocturnal canopy-layer air temperatures are with some exceptions. There may also be a correlation with nocturnal canopy-layer air temperatures and height of buildings. With this data and analysis we can now begin to conduct more analysis and mitigate this issue. If there is one thing that is certain, urban density is going to continue to increase so steps should be taken now to lower nocturnal canopy-layer air temperatures for the future.

References

1. Christen, Andreas. *GEOB 401 Urban Meteorology. "Car Traverse Data*".Web.April 8, 2015. <_http://ibis.geog.ubc.ca/courses/geob401/data/2015.html_>