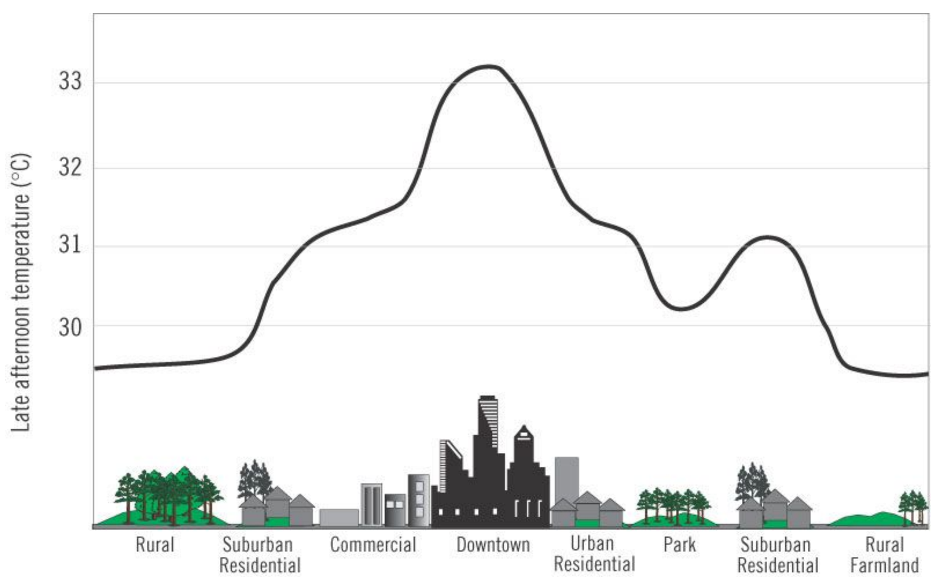
Urban Heat Island

Geog 2306 - Brad Cutshall

Urban centers have been known to be warmer than their surrounding areas and because of the plume of heat that urban centers create, the term urban heat island (UHI) has been coined to describe the effect that urban centers have on their atmospheric environment. The effect that urban centers have on their surrounding environments can been seen through studying surface temperature, atmospheric temperature, measuring precipitation, and the concentration of airborne particles from localized pollutants. In this paper we will discuss the history behind UHI, the effects it can have on its own and surrounding environment and look at real data collected to see the magnitude of Minneapolis MN's UHI.



The image is a generic representation of the effect UHI can cause (EPA 2008)

UHI has been studied for over 100 years, the the first person to understand and analyze the effects of UHIs was Luke Howard in 1810. Even though he was not the first person to coin the term, he was the first person to do a detailed analysis of the phenomenon. UHI was first seen in large urban areas that removed lots of their natural grassland and trees for cultivation but also for roadways and buildings. By modifying the land by laying concrete and rocks, these materials hold heat a lot more efficiently and do not reflect or consume as much of this heat as plants and other vegitation. Today we now have even larger urban centers with manufacturing and power plants which span large areas and are characterized by large flat roofs and expansive parking lots. The term urban heat island is used because of the 'island' shape that a line generates when measuring the temperature over a lateral space of the urban area and its surrounding areas. For example in the image above one can imagine that the island emerging through an ocean surface is the peak temperature in the center of the urban area.

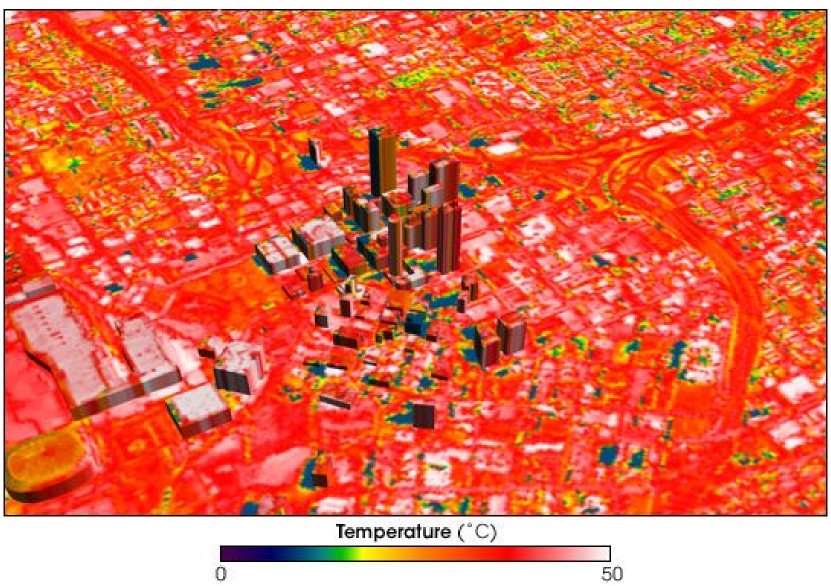
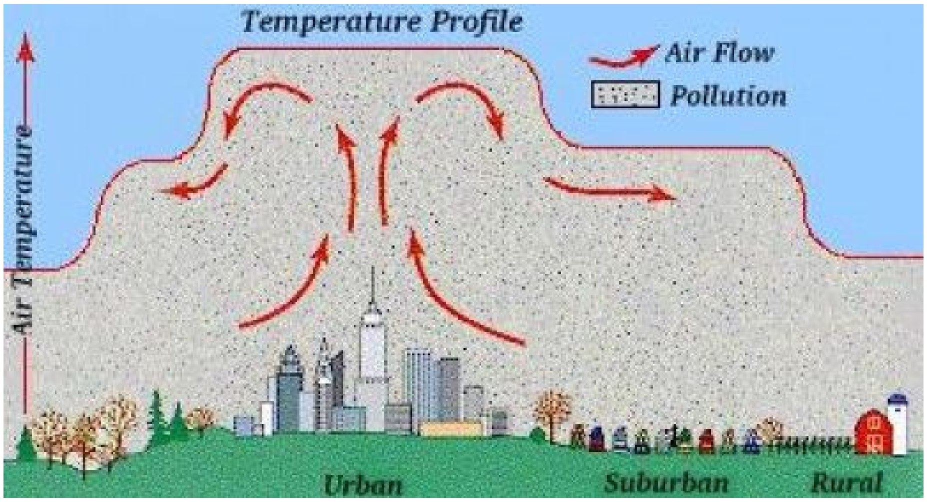


Image of Atlanta, Georgia (Wikipedia)

In the image above it's easy to notice how the large expansive buildings in the bottom left corner are by far the hottest area in the city. The reason why the area in the center with all of the skyscrapers is much cooler is because these types of buildings are usually constructed out of glass or reflective materials which reflect the energy back into the atmosphere or into other locations. It is important to notice that there are areas which are much cooler, most of the coolest areas are parks or lakes. There has been an effort to reduce the impact UHI can have on a city, this is primarily because during a heat wave in a city lives can be lost because of the increased heat in the area, for example, in 2008 over 1,000 lives were lost due to heat exhaustion in Atlanta over a couple days during an extreme heat wave. It is believed that by adding large parks into the city can greatly reduce the amount of heat a city generates, this is one of the practices that are used today to combat this effect. Other forms of UHI reduction are methodologies which include painting buildings white and growing grass on top of large buildings.

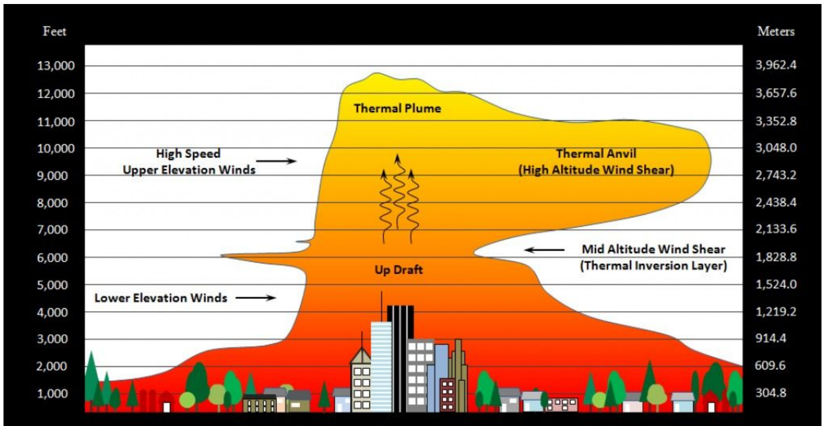
Green roof of city hall in Chicago (Wikipedia)

Places which have a large urban impact generate large quantities of heat and particulates trap the heat within a certain area. This has always been a problem in the past hundred years, however now have hundreds of thousands of vehicles which produce their own type of emissions. In a situation like this on a calm day warm day the particulates from emissions will be trapped to cause another effect called the “dust dome” which is amplified by the temperature difference because these particulates are unable to dissipate. The particulates will enter into a circulation above the city by rising with the heated air at the surface and fall back again once the air cools.



Glossary of Meteorology (2009)

If winds greater than 8 m.p.h exist, the winds can push the particulates from the urban area and flow over downwind suburban and rural areas which can have extreme respiratory effects of the humans and animals living in these ‘fallout’ areas. In addition to the particulates moving downwind from an urban center, the excess heat generated by the UHI flows downwind as well.



Temperature boundary layer, elevation cross section profile for a urban heat island induced thermal plume (notional).

Once the heat rises into the middle atmosphere, it is easily transported by winds aloft and can travel hundreds of miles downwind from the UHI. The heat being transported in the atmosphere has been detected up to 300 miles downwind from the UHI generated by Chicago, IL. Because the air is warmer than its surrounding areas it will rise into a cooler atmosphere and move over an area which usually causes the air to condense. Since this air is rising with the excess pollutants, the air now has a surplus of particulates from exhaust to use as condensation nuclei creating heavier rainstorms for areas downwind of the UHI.

Determining the UHI of a city can be time consuming and tedious because of the shear quantity of data that must be analyzed before meaningful information must be examined. To solve this problem I decided to create a program which will give me monthly averages of the temperature existing in and around Minneapolis so I can build a graph displaying it's own unique UHI. The program was developed in Java and is run by using a command line interface, it takes only one input parameter, the folder containing the input data to be calculated. Input data was collected from http://www.ogimet.com/metars.phtml.en which collects historical weather data, this data can be queried and gathered. The data offered by oidmet.com is meterological reports or when abreviated they are called METARs, in raw data form they take the following format:

> KDLH 010514Z 10010KT 5SM -RA BR FEW010 BKN022 OVC035 01/M01 A2990 RMK AO2 DZE03RAB03SNE03 P0000 T00111006

Most weather stations generate one METAR on 15 minute to 1 hour intervals. There is a lot of interesting information in this string, but we are primarily interested in the temperature, you can determine this by splitting the METAR apart and analyzing the data piece by piece. When a metar is decoded it takes the following format:

Conditions at:	KDLH (DULUTH , MN, US) observed 0514 UTC 01 December 2015
Temperature:	1.1°C (34°F)
Dewpoint:	-0.6°C (31°F) [RH = 88%]
Pressure (altimeter):	29.90 inches Hg (1012.6 mb)
Winds:	from the E (100 degrees) at 12 MPH (10 knots; 5.2 m/s)
Visibility:	5 miles (8 km)
Ceiling:	2200 feet AGL
Clouds:	few clouds at 1000 feet AGL broken clouds at 2200 feet AGL overcast cloud deck at 3500 feet AGL
Weather:	-RA BR (light rain, mist)

Decoded METAR

The input data was organized into one file for each month for each weather station which can consist of, on average about 1800 METARs per month per station. For simplicity the input files do not have a file extension (ex .txt). Therefore an example, here are a few of the input file names for the KANE weather station on the Anoka county Blaine airport:

```
KANE_june_2015
KANE_july_2015
```

KANE_august_2015 KANE_september_2015

I was able to collect METARs from 17 weather stations for a total duration of 4 months, June through September, this gave a sum total of 68 input files with about 122,900 METARs. Each metar is converted into a object in computer memory and each METAR's temperature from one month of one weather station is summed and divided by the number of METARs in that weather station's month. Once the program has completed reading and calculating averages there will be a single file consisting of one line per weather station per month. For example here is the final output data produced with the calculated averages:

```
Temperature: KFCM_june2015: 20
Temperature: KCFE_june_2015: 20
Temperature: KCBG_september_2015: 19
Temperature: KMSP_june2015: 21
Temperature: KCBG_june_2015: 20
Temperature: KANE_july_2015: 22
Temperature: KHCD_july2015: 21
Temperature: KLUM_june_2015: 19
Temperature: KCBG_august_2015: 20
Temperature: KCFE_august_2015: 20
Temperature: KANE_june_2015: 19
Temperature: KRNH_june2015: 19
Temperature: KGYL_july2015: 22
Temperature: KSTP_july2015: 22
Temperature: KSTP_september2015: 19
Temperature: KSGS_august_2015: 21
Temperature: KLVN_september2015: 18
Temperature: KMIC_september2015: 20
Temperature: KMSP_august2015: 21
Temperature: KLVN_july2015: 20
Temperature: KSTP_august_2015: 20
Temperature: KOEO_august_2015: 19
Temperature: KRNH_july2015: 21
Temperature: KANE_september_2015: 19
Temperature: KFBL_july_2015: 21
Temperature: KGYL_august2015: 20
Temperature: KHCD_june2015: 20
Temperature: KFBL_september_2015: 19
Temperature: KMSP_july2015: 23
```

Output data for each input file, temperature is expressed in celsius.

Computer tech specs for nerds:

- CPU: AMD FX 8350 - 8 core 4.0GHz
- RAM: 16GB DDR3 1600MHz
- HDD: RAID 0 3x Western Digital 7200 RPM

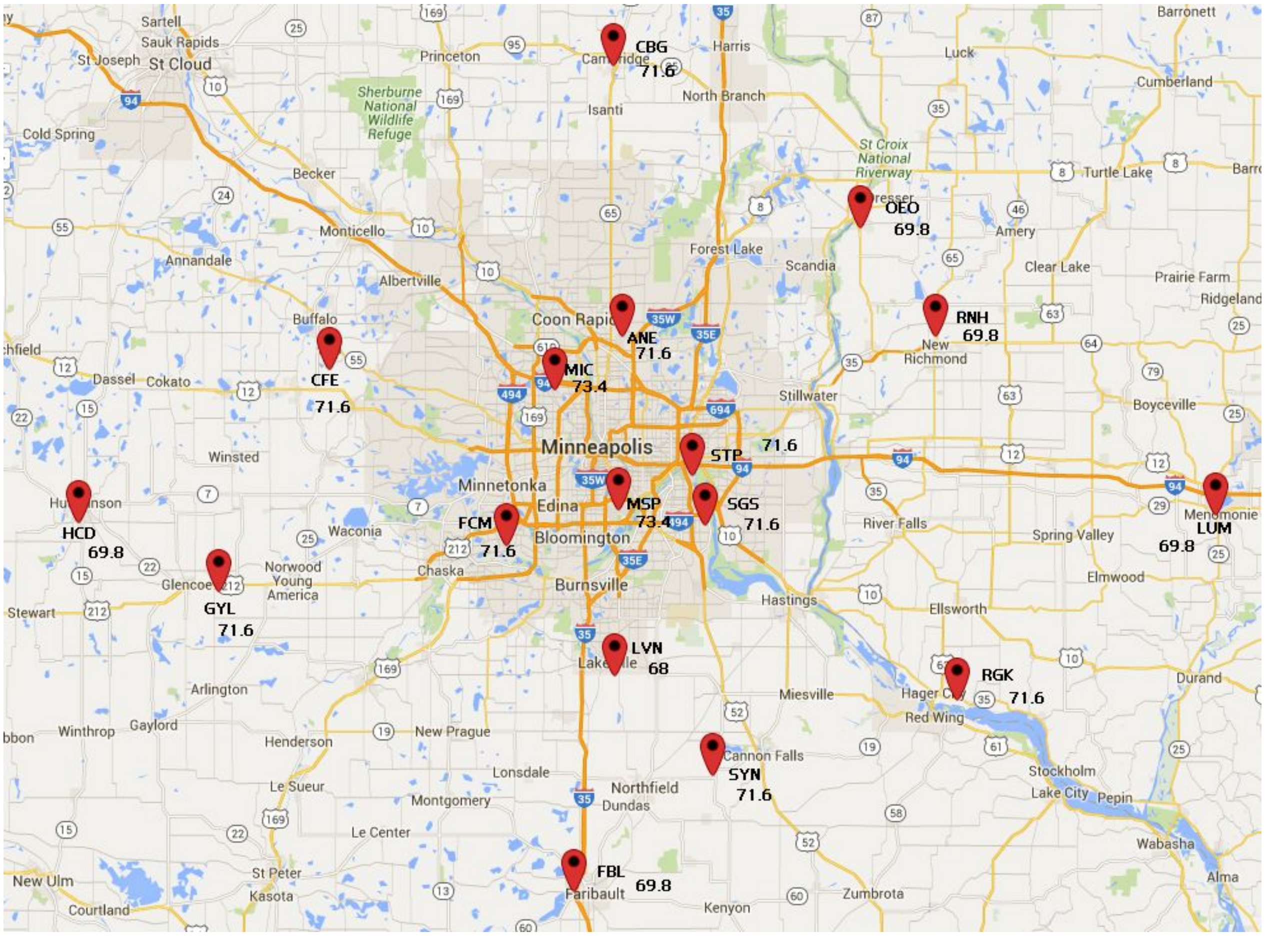
Overall the program used 95-100% of the CPU, 4GB of RAM and took a total of 30 minutes for execution time.

Using excel I organized the data into a chart which will allow us to easily examine the UHI of Minneapolis. With this data I mapped the locations of the weather stations with their respective monthly average temperature. Finally, I created a lateral graph which moves from West to East across the metro for about 110 miles, consisting of the weather stations as input data: HCD, GYL, FCM, MSP, SGS, STP, and LUM. Based on the graph it is very clear that Minneapolis creates a large UHI, but on average the UHI does not create a noticeable heat plume after the city.

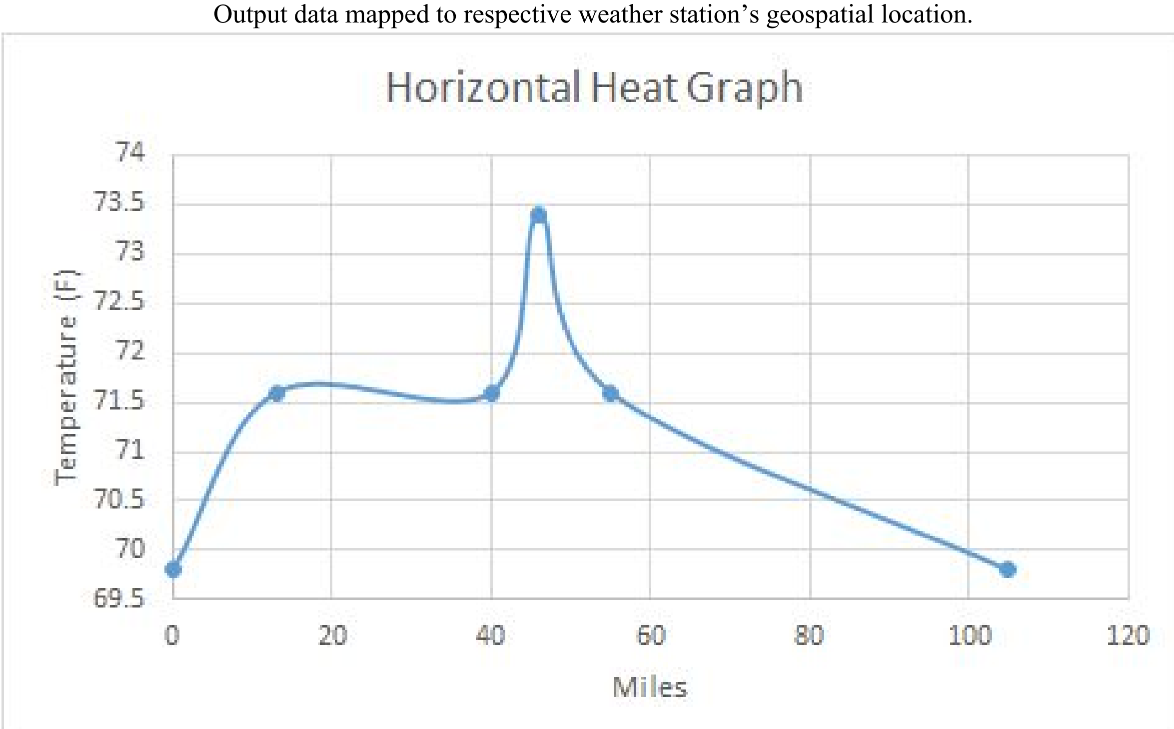
Station	ANE	CBG	CFE	FBL	FCM	GYL	HCD	LUM	LVN	MIC	MSP	OEO	RGK	RNH	SGS	STP	SYN
June	66.2	68	68	68	68	68	68	66.2	66.2	69.8	69.8	66.2	68	66.2	68	68	68
July	71.6	71.6	71.6	69.8	71.6	71.6	69.8	69.8	68	73.4	73.4	69.8	71.6	69.8	71.6	71.6	71.6
August	68	68	68	66.2	69.8	68	66.2	68	66.2	69.8	69.8	66.2	68	66.2	69.8	68	68
September	66.2	66.2	64.4	66.2	68	64.4	66.2	64.4	64.4	68	66.2	64.4	66.2	64.4	66.2	66.2	66.2

Year Average	2015	Variance	2015
June	67.68235	June	3.6
July	71.07059	July	5.4
August	67.89412	August	3.6
September	65.77647	Septembe	3.6

Excel table with output data organized by weather station and month with values expressed in fahrenheit. The lower table shows the yearly average temperature with variance expressed in fahrenheit.



Output data mapped to respective weather station's geospatial location.



Graph showing the lateral temperature difference when moving from West to East.

Urban heat islands are something that have been studied over the last few hundred years and will continue to be an issue as long as urban areas exist. These urban areas create dust domes, urban thermal plumes and damage to population within and around the urban area. While it is possible to reduce the impact of the urban area by reducing the amount of pollution and modifying existing buildings to reduce the amount of heat energy that they absorb and re-radiate back into the environment. One very important question that remains unanswered throughout this paper, does UHI cause stronger storms or more precipitation, is a recent developing focus area and will lead UHI studies into the future.