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# A Possible Heat Island Effect from a Small Rural Community

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***Abstract:*** *The purpose of this paper is to understand whether or not heat that is radiated from the business district of a very small community impacts the local temperature field in the outer and inner portions of the community as a function of one or more variables (wind speed, wind direction, and degree of cloud cover). Previous studies of larger communities in the region showed that wind speed, direction, or cloud cover could lead to differences in the strength of the heat island effect even for a community of about 20,000 to 25,000 residents. Here we study the impact of a community which has fewer than 10,000 residents, and demonstrate that there was circumstantial evidence for a heat island effect.*

**Keywords:** *Heat island effect, climatology, microclimate, urban influences*

## 1. Introduction

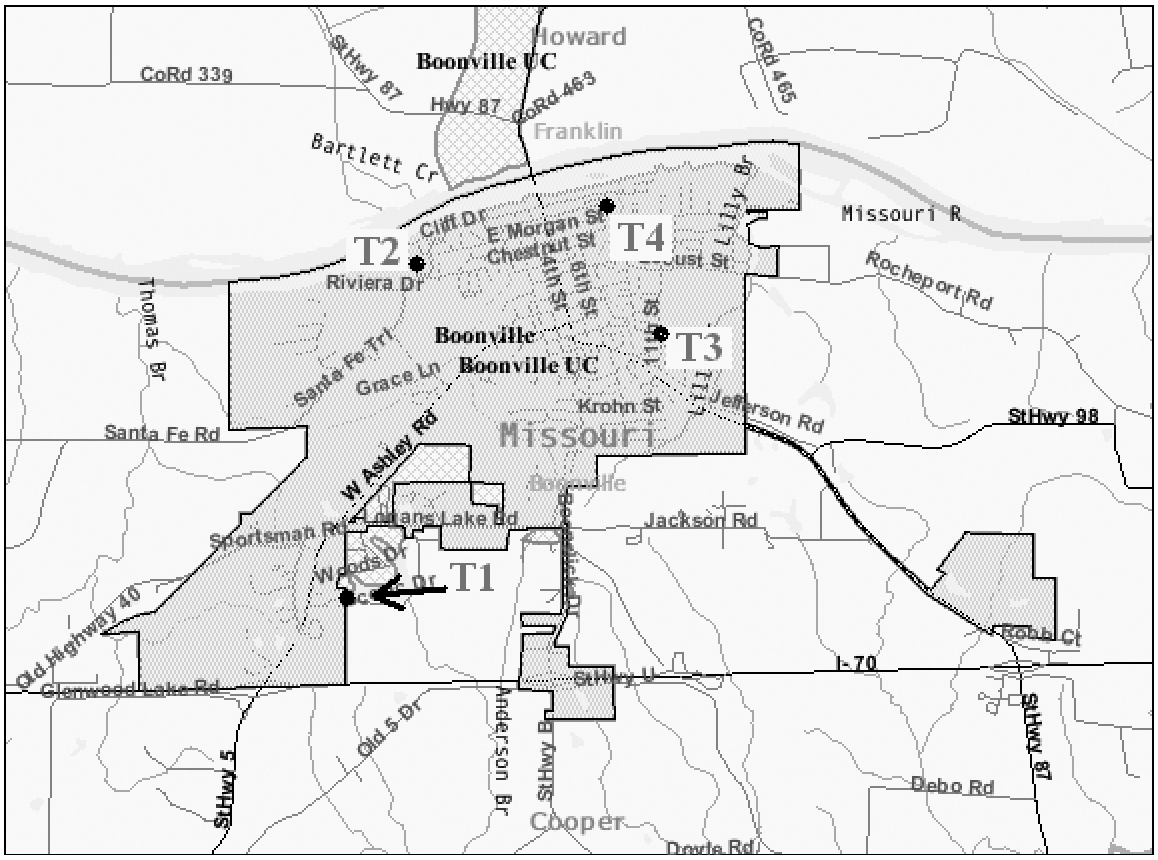
Previous studies of the heat island effect have shown that cities in Missouri smaller than St. Louis or Kansas City can have a significant impact on the surrounding environment (e.g., Akyuz et al., 2004; Grathwohl et al. 2006; Buckley et al. 2008). Akyuz et al. (2004) demonstrated that the city of Columbia, MO was on average 0.6°–1.8° C (1°–3° F) warmer than its surroundings, and could be as much as 10° F warmer, and Buckley et al. (2008) found a similar impact. Neither study found a large impact on local precipitation distributions. Additionally, other studies such as Ackerman (1985), Melhuish and Pedder (1998), and Pinho and Manso-Orgaz (2000) find a significant heat island effect for Chicago, Reading, UK, and a city in Portugal somewhat smaller than Columbia, MO, respectively. Here we define the heat island effect as the difference between the mean surface temperature for a thermometer placed in an urbanized area and a properly sited instrument in a rural location (e.g., Changnon, 1981). Then Grathwohl et al. (2006) found that Sedalia, MO impacted the temperature fields nearly as much as Columbia, MO during the spring season of 2005. Their study also showed that variables such as wind speed and cloud cover impacted the intensity of the heat island effect. They showed that sunny, less windy days display a larger heat island effect.

In this study, which follows Akyuz et al. (2004) and Grathwohl et al. (2006), we will examine the possibility of the heat island effect occurring as due to a rural community of around 8,000 residents. The test site is Boonville, MO, which is located on the southern banks of the Missouri River and is about 32 km (20 mi) west of Columbia, along Interstate 70 (which runs along the southern side of town). Boonville is situated on the bluffs overlooking the river and has an approximate elevation of 180–245 m (approximately 600–800 ft) above sea level. The dimensions of Boonville are about 13 km (8 mi) east-to-west and about 10 km (6 mi) north-to-south, including the town and residential areas.

## 2. Data Analysis and Methods

Collection of the temperature data took place from 1 September through 30 November 2006 (91 days). This covered the fall season and is longer than the six week period used by Grathwohl et al. (2006), but shorter than the year period studied by Akyuz et al. (2004) or Buckley et al. (2008). Each day, the 24-h maximum (91) and minimum temperatures (91) were observed at each station and were collected at approximately 5:00 pm CDT/CST (2200/2100 UTC). Once these data were collected, the thermometers were reset for the following day. There were four thermometers situated at one of four corners of the town area primarily in the residential areas (Fig. 1). The second thermometer (T2) and fourth thermometer (T4) instruments were located closest to the town center, while the first thermometer (T1) was located in a more "rural" locale. The third thermometer (T3) was located in a less urbanized area. As in the Columbia, MO study, we could not place a thermometer in the center of the business district where the impact should be strongest. We could not guarantee the integrity of the instrument and proper siting at the same time. T1 was positioned near the southwest corner of town. T2 was positioned near the

Figure 1. A map of Boonville, MO and the surrounding regions. The location of each thermometer is marked with a gray "Tx", where x is the instrument number referred to in our study.




northwest corner, T3 was positioned near the southeast corner, and T4 was positioned near the northeast side of town. The instruments at stations T1, T2, and T4 used digital Sper-Scientific thermometers. Station T3 used a Fisher Scientific maximum / minimum mercury thermometer. Based on the calibration of the thermometers in a controlled temperature room of 21.6° C (71.0° F), each thermometer was within the margin of error for the control room temperature (Table 1). This calibration was performed once and at this one temperature. There was a slightly larger difference between T1 and T3. The digital thermometers are accurate to within (+/− 1° C) or [+/− 1.8° F] as stated in the literature which accompanied the instruments. Additionally, as proposed by Akyuz et al. (2004) and references there-in, any measureable heat island effect should be larger than the thermometer error to be significant. Finally, the discussion will use English units rather than metric since in the United States English units are still the standard for surface temperature observations, and the exact units are not germane to the findings.

**Table 1.** The temperature recorded on each thermometer at calibration time.

| Instrument | Reading | Difference from the Control |
|---|---|---|
| Grathwohl (T1) | 22.4° C / 72.4°F | 0.8° C / 1.4° F |
| Neckermann (T2) | 22.4° C / 72.4°F | 0.8° C / 1.4° F |
| Bradshaw (T3) | 21.2° C / 70.1°F | −0.4° C / −0.9° F |
| Moore (T4) | 21.9° C / 71.5°F | 0.3° C / 0.5° F |

## 3. *Results*

### 3.1 Average temperatures

Once all of the data had been collected, analysis began by first taking the averages of the maximum and minimum temperatures and the overall means (Table 2 and 3). Upon analyzing the averages of the raw data, the overall mean temperatures within the Boonville area were different by 3.7° F with the greatest mean temperature being found for a site closer to the town center (T2) and the lowest temperature found in a less built-up area (T3) (Table 2). An examination of these numbers

**Table 2.** The monthly and seasonal mean temperatures (°F) for the Boonville stations.

| | T1 mean (°F) | T2 mean (°F) | T3 mean (°F) | T4 mean (°F) | Max Diff (°F) |
|---|---|---|---|---|---|
| September | 67.6 | 68.9 | 65.4 | 68.2 | 3.5 |
| October | 56.5 | 57.4 | 53.6 | 56.4 | 3.8 |
| November | 51.9 | 49.8 | 45.5 | 49.4 | 6.4 |
| avg daily | 58.8 | 58.9 | 55.1 | 58.0 | 3.7 |

**Table 3.** The monthly and seasonal mean maximum and minimum temperatures (°F) for the Boonville stations.

| | T1 max (°F) | T1 min (°F) | T2 max (°F) | T2 min (°F) | T3 max (°F) | T3 min (°F) | T4 max (°F) | T4 min (°F) |
|---|---|---|---|---|---|---|---|---|
| September | 77.3 | 57.8 | 80.5 | 57.3 | 77.3 | 53.5 | 80.1 | 56.2 |
| October | 66.4 | 46.6 | 68.5 | 46.3 | 64.6 | 42.6 | 68.4 | 44.3 |
| November | 63.4 | 40.4 | 60.1 | 39.5 | 55.0 | 36.0 | 62.4 | 36.4 |
| avg daily | 69.1 | 48.4 | 69.9 | 47.8 | 66.0 | 44.2 | 70.4 | 45.5 |
| Std. Dev | 11.5 | 11.1 | 13.0 | 11.1 | 13.7 | 11.3 | 11.9 | 11.6 |

demonstrates that this difference is larger than both instrumental differences found during the calibration and the instrumental error. While this is a fairly small sample (but larger than the number of instruments used by Grathwohl et al. (2006) and Buckley et al. (2008)), the heat island effect for the town of Boonville is likely real and consistent with values predicted in Aguado and Burt (2001) for a town of this size. The month-by-month results were similar to that of the overall result, with T2 consistently being the largest or second largest value, and T3 recordings the smallest values.

A breakdown of the results using the maximum and minimum temperatures demonstrated that the maximum temperatures were larger most of the time for both T2 and T4, which were closer to the town center. This result is consistent with that of Grathwohl et al. (2006). For the minimum temperatures, T3 and T4 were consistently smaller while T1 was larger than the others. This may be due to elevation differences, as T1 is farthest from the river valley. Cooler temperatures at lower elevations are most noticeable during the morning hours when the atmosphere is least turbulent. This cooling may be overwhelming any heat-island effect for this early time of day.

Additionally, an examination of the daily values of the heat island effect found that the largest daily values in the dataset were on the order of 10–15° F. This was observed on 9 individual days. The largest daily value (15° F, 19 Nov) is consistent with those found in other studies and were as large as those for daily heat island values observed in big cities.

### 3.2 Average temperatures in relation to wind speed

One problem with completing this study for a town like Boonville is that there is no official weather station to record variables such as temperature, precipitation, or average wind speed. Akyuz et al. (2004) found that the heat island effect in Columbia, MO was stronger under light wind conditions, which is consistent with the findings of Oke (1982). In order to assign a wind speed and direction for Boonville, it was useful to find an average by utilizing observations at official weather stations in close proximity (less than 50 miles) to Boonville, such as Columbia and Sedalia. This provides a general idea of the larger-scale wind conditions likely to be occurring at Boonville. During the three-month study, the greatest daily average wind speed was about 14 mph, while the lowest was about 4 mph. This made it practical to divide the data into three categories: Category 1 (0–5 mph), Category 2 (6–10 mph), and Category 3 (10 mph and greater). Days were classified into each category as long as the average wind speed was in that category and the majority of the hours during the day fell into that bin (similar to Akyuz et al., 2004). Using this scheme for wind speeds, six days fell into Category 1, 34 fell into Category 2, 30 fell into category 3, and 21 days were unclassified. By choosing not to classify days that had wind speeds that fell into more than one category, it allowed for better dependability in the results (Table 4).

Akyuz et al. (2004) and Grathwohl et al. (2006) showed that less windy days resulted in larger differences among their urban and rural stations. The results here demonstrate that there is only a 0.6° F reduction in the heat island effect as wind speed increases. While this may be a real effect, we feel this is too small a value to state with any confidence that wind speeds were influential since the spread between the calibrated instruments was larger than this value. Two points of interest to note in these results are: a) for the lightest wind speeds the T1 maxima are closer to the T3 values than to the T2 or T4 values, and b) the temperatures were lower as the wind speeds became higher. This second result could be explained by the fact that September values primarily made up the lighter wind categories, while

**Table 4.** Average Temperatures (°F) for the Boonville based on wind speed.

| | (T1 max °F) | (T1 min °F) | (T2 max °F) | (T2 min °F) | (T3 max °F) | (T3 min °F) | (T4 max °F) | (T4 min °F) |
|---|---|---|---|---|---|---|---|---|
| Cat 1 | 71.8 | 54.0 | 76.3 | 53.2 | 71.5 | 50.8 | 74.5 | 53.3 |
| Cat 2 | 69.3 | 48.7 | 70.0 | 47.9 | 66.3 | 44.2 | 70.7 | 46.0 |
| Cat 3 | 68.8 | 47.8 | 69.4 | 47.5 | 65.7 | 43.7 | 69.7 | 43.3 |
| Unclass. | 64.4 | 45.8 | 64.3 | 44.8 | 60.5 | 41.5 | 65.8 | 43.8 |

stronger winds were found in November. This is likely due a difference between the synoptic character of the prevailing winds during the warm weather regime (lighter and southerly) and cold weather regimes (stronger and northwesterly) that prevail in this part of the United States.

### 3.3 Average temperatures in relation to wind direction

Calculating the average wind direction for Boonville was done the same way as it was for wind speed. By taking a common and average mean wind direction for each day, it made it simple to divide the days into four categories for wind direction. This study did account for days when the wind direction crossed between northwest and northeast (we did not take an arithmetic average during these days). These days were separated by category, and the number of days observed for each category are shown in Table 5.

**Table 5.** Categories for wind directions.

| Category | Degrees | Days |
|---|---|---|
| Category 1 | 0–90 | 9 |
| Category 2 | 91–180 | 36 |
| Category 3 | 181–270 | 17 |
| Category 4 | 271–359 | 29 |

In this section, the data in Table 6 is displayed by using the relative rank of each instrument for the maxima and minima along with the largest differences found among the temperature data. Interestingly, T3 was consistently the coolest temperatures measured by an instrument, except when the winds were coming from the southwest. There is a large shopping center and parking area to the southwest of T3.

With a northeast wind, it was hypothesized that T1 might be warmer due to this same shopping center. However, in contrast with T3, the impact of the shopping center was not as pronounced with the maximum temperatures. The minimum temperatures did become warmest at T1 under the northeast wind. It was also surprising that T2 maintained a high ranking since to the north and west there is the Missouri River and nothing but trees and farms in those directions. However, warmth from Boonville could be influential under the northeast wind scenario. These results show a possible displacement of the heat island effect which is consistent with the observations of Akyuz et al. (2004).

### 3.4 Average temperature in relation to cloud cover

The only station in close proximity to Boonville that records cloud cover was the Columbia weather station. With the understanding that the cloud cover over Columbia should be

**Table 6.** Rank of each instrument based on wind direction (1=warmest 4=coolest), along with the largest temperature differences (°F) between each.

| | T1 | | T2 | | T3 | | T4 | |
|---|---|---|---|---|---|---|---|---|
| **0–90** | Max | Min | Max | Min | Max | Min | Max | Min |
| | 3 | 1 | 1 | 1 | 4 | 4 | 2 | 2 |
| Largest temperature difference= | | | | Max: 4.6° F | | | Min: 4.0° F | |
| **91–180** | Max | Min | Max | Min | Max | Min | Max | Min |
| | 1 | 1 | 1 | 2 | 4 | 4 | 1 | 3 |
| Largest temperature difference= | | | | Max: 5.6° F | | | Min: 6.1° F | |
| **181–270** | Max | Min | Max | Min | Max | Min | Max | Min |
| | 3 | 1 | 1 | 2 | 3 | 3 | 2 | 3 |
| Largest temperature difference= | | | | Max: 5.1° F | | | Min: 6.0° F | |
| **271–359** | Max | Min | Max | Min | Max | Min | Max | Min |
| | 2 | 1 | 1 | 2 | 4 | 4 | 1 | 2 |
| Largest temperature difference= | | | | Max: 7.3° F | | | Min: 4.6° F | |

reasonably close to what Boonville would typically observe for an entire day under the same synoptic regime, we used these observations in order to correlate temperatures to cloud cover.

The cloud cover observations are recorded by the National Weather Service using the following descriptions for cloud cover; Fair, Sunny, Clear, Partly Cloudy, Mostly Sunny, Mostly Cloudy, Partly Sunny, Cloudy. The type of precipitation that was falling at the particular hour is also recorded but not used here. Splitting these descriptions into two categories made it easier to see how cloud cover might play a role in influencing temperature variance. Category 1 consisted from fair to mostly sunny (less than 50% cloud cover), while Category 2 consisted of mostly cloudy and overcast (greater than 50% coverage). The observations at Columbia were augmented by visual observations from the authors.

Finally, a breakdown of these temperatures for cloudy (more than 50% sky cover) versus less-cloudy days (less than 50% sky cover) (not shown) would reveal similar results to those in Tables 2 and 3, with the exception that the diurnal cycle is clearly larger (higher maxima and lower minima) for the less cloudy days. The relative differences among the warmest and coolest stations were 0.6° F larger for the less-cloudy days. Thus, it is difficult to determine if cloud cover was a factor in a manner similar to Akyuz et al. (2004) and Grathwohl et al. (2006). Roughly 50% for the days (42) were clear, while the remainder (49) were considered cloudy.

## 4. *Summary, discussion and conclusions*

An examination of a possible heat island effect for the small town of Boonville, MO was performed following Grathwohl et al. (2006). The data were collected at four sites in and near Boonville over the fall months (September, October, and November) in 2006. Three instruments were digital (T1,T2, T4) and one was a mercury thermometer (T3). These were calibrated in a room in order to determine the spread of the instruments. Instrument T3 was approximately 2.3° F cooler than the other instruments.

In spite of this, T3 was on average 3.7° F cooler than the rest of the instruments indicating a possible heat-island effect on the order of 1.5° F for Boonville, MO. While this does not prove that Boonville does impact the local temperature field, there is strong evidence that the heat island effect suspected here is real. These points should be considered as strong circumstantial evidence;

a) this mean value (1.5° F) is consistent with some of the observations found by Akyuz et al. (2004) for the larger community of Columbia, MO,
b) the value is consistent with that predicted for a small community shown in Aguado and Burt (2001),
c) instruments T2 and T4 were located close to the downtown and consistently warmer than T1 and T3. T3 and T1 were located near less urbanized areas. An instrument was not placed in the heart of Boonville due to logistical issues (see Akyuz et al., 2004).
d) instrument T3 was no longer the absolute coolest instrument, in spite of the calibration under a southwest wind (shopping center located to the southwest).

However, it is cautioned that there are points which provide evidence against stating with certainty that there is a heat island effect for Boonville and these are the;

a) lack of a dense instrument network,
b) small sample size, and
c) lack of statistical significance for these results.

In our experiment, it was difficult to determine whether or not there was a significant impact due to cloud conditions and wind speed as in Akyuz et al. (2004) and Grathwohl et al. (2006). The difference between instruments T2 and T4 versus T3 was 0.6° F greater for sunnier days and calmer days than for cloudier and windier days. While this result is physically consistent with what would be expected, the small value and the small sample size preclude making a definitive statement about the impact of a small community like Boonville on the environment. Additionally, the elevation differences across Boonville make identification of the heat island effect difficult for such a small town. In closing, future studies are needed in other Missouri communities of this size in order to substantiate the idea of the heat island effect for a small rural community.

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