2017

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STUDY OF MICROCLIMATE TEMPERATURE DISTRIBUTION IN AN ARTIFICIAL STRUCTURE

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ABSTRACT

This research investigated temperature distributions inside a parking structure across from the University Library on the campus of Eastern Michigan University. Using an infrared thermometer, we recorded temperature data at specific points on all floors of the structure. We will present the interpretation of our data in light of heat flow mechanisms to gain insight on how heat flow affects local climate. We will discuss how this analysis might be used to predict internal temperature based on external conditions. This technique is also applicable to other features, both natural and artificial, providing us with a tool to study microclimates in ecosystems and other technologic advancements.

INTRODUCTION

Microclimates are relatively small regions that can range from a simple dormitory room, a standard sized home, or an urban metropolis, that have climates that differ from their surrounding counterparts. In urban communities, microclimates make important contributions to building performance in terms of energy, the indoor thermal environment, and the potential of passive cooling measures (Runming et al., 2011). For example, the amount of sunlight that enters through cave entrances can affect the internal temperatures of the cave (Figure 1). Microclimates even exist under blades of grass (Figure 2).
Figure 1: Parque Nacional de las Cavernas del Río Camuy. This figure displays a small region under the influence of a microclimate. The cave itself is being exposed to the wind, sunlight, and humidity from the outside. These simple factors all can have effects on the microclimate inside the cave.

Figure 2: Microclimate on a smaller scale is shown beneath blades of grass, which are subject to the amount of sunlight, humidity, wind, and other factors that affect their temperature.
Many factors influence microclimates, such as geographical topography, differences in air pressure, the presence of large objects, exposure to sunlight, and countless others. Further research into microclimates could open doors to a better understanding of basic weather patterns inside urban communities, enhancing techniques in improving the energy efficiency of buildings, or helping us predict temperatures within our microclimate, based on external factors.

**Urban Heat Island Effect**

Urban heat islands (UHIs) are a prime example of microclimates at work. UHIs are a natural phenomenon in which urban areas are generally warmer than their rural counterparts, and occur when numerous buildings, roads, automobiles, and other structures capture the sun’s heat during the day and radiate that captured heat during the night. Within this time frame, buildings don’t have enough time to fully cool, which in turn leaves urban areas warmer. According to the Environmental Protection Agency (EPA) (2017), the annual temperature of a city with one million people or more can be 1.8 to 5.4°F (1-3°C) warmer than its surroundings. As a result, UHIs can impact urban communities by increasing summertime peak energy demand, air conditioning costs, air pollution, greenhouse gas emissions, heat-related illness, mortality, and water quality.

Many metropolitan communities are affected by UHIs. According to Climate Central (2014), an independent organization of leading scientists and journalists, summers in the U.S. have been warming since 1970. Cities are much hotter and have more rapidly increasing temperatures than adjacent rural areas. Due to climate change and rising greenhouse gas emissions, global warming will make metropolitan areas more prone to the urban heat island effect, increasing their temperatures. In Las Vegas, a metropolis that is located in a predominately dry, hot climate, temperatures can be 24°F hotter in the urban proximity than in nearby rural areas (Climate Central, 2014). Similar temperature ranges occur in cities such as Denver, Louisville, Albuquerque, and Chicago. With more than 80% of Americans residing in cities and other densely
populated areas, UHIs can have serious health effects for millions of Americans during the warmest parts of the year.

Heat is the number one weather-related cause of death in the U.S. The Centers for Disease Control (2013) recorded a total of 7,233 heat-related deaths in the U.S between 1999-2009. During that period, an average of 658 deaths were linked to heat-related causes each year. The 1995 heat wave in the Midwest exemplified the dangerous effects of urban heat islands. Several cities, particularly Chicago, experienced extremely high temperatures that led to hundreds of heat-related deaths. Over a 5-day span the number of reported deaths increased by 85%, and the number of hospital admissions increased by 11%, compared to numbers recorded during the same period in the preceding year. The excruciating heat levels led to at least 700 deaths. Since then, the city of Chicago has undertaken a number of proactive measures to reduce the UHI effect (Centers for Disease Control 2013).

Green roofs have been constructed on many buildings in downtown Chicago, replacing conventional roofing systems. The plants and soil on the roofs capture thermal energy radiated from the sun, and use it for their biological processes. As a result, buildings, roads, and other artificial structures are better able to maintain cooler temperatures during the high summer temperatures. Chicago also planted a substantial number of trees to help combat the heat in the city. Between 1991 and 1998, Chicago planted over 500,000 trees, and in 1998 the city of Chicago had more than 4.1 million trees within city limits. Chicago’s Bureau of Forestry plants a minimum of 5,000 new trees per year (City of Chicago, 2016).

PURPOSE OF THE RESEARCH

This project investigated temperature distributions inside a parking structure across from the University Library on the campus of Eastern Michigan University. Using an infrared thermometer, we recorded temperature data at specific points on all floors of the structure. We will present the interpretation of our data in light of heat flow mechanisms to gain insight on how
heat flow affects local climate. We will discuss how this analysis might be used to predict internal temperature based on external conditions.

The parking structure on Eastern Michigan University’s main campus is a compact rigid structure of basic design. Typically, in the summer season it is relatively cool, due to its large shaded
areas, and in the fall and early winter, it may be slightly warmer than the outside air temperature. **Figures 3, 4,** and **5** display exterior and interior views of the entire structure.

**Heat Transfer Mechanisms**

In order to begin, we must first visit and explain basic mechanisms of heat transfer that were used to model our research. Heat transfer is the exchange of thermal energy between two systems. Heat transfer requires a temperature difference between the two regions. The direction of heat flow is *always* from higher to lower temperatures. Generally, heat flow can be between gases, liquids, solids, or a combination of these phases. This research will focus on three common heat transfer mechanisms: conduction, convection, and radiation. All of these have a major influence on microclimates, and must be examined to understand the temperature distribution in the parking structure.

**Conduction**

Heat conduction is the process by which two systems at different temperatures exchange heat due to direct contact with each other (Thomsen et al., 2015). If you place a metal pot on a hot stove and keep your hand on the handle, you will notice that the handle’s temperature rises. This is a prime example of heat conduction. On the atomic scale inside the metal, the atoms in the hotter regions have more thermal energy than their cooler counterparts. As time passes, this energy traverses the material, while the

![Figure 6: Simple Diagram of Conductive Heat Transfer for a Rectangular Column](http://commons.emich.edu/mcnair/vol10/iss1/3)
atoms themselves are stationary. However, most metals are able to use another mechanism to conduct heat. Metals, which are excellent conductors, contain free electrons that can carry energy from the hotter to cooler areas of the metal. **Figure 6** represents the conduction process for columns inside the parking structure under study.

**Figure 6** shows a column with cross-sectional area $A$ and length $L$. On a cold day, the top of the column will be at temperature $T_L$, which is likely to be close to the air temperature. The bottom of the column, at temperature $T_H$ is likely to be warmer, due to its proximity to the ground. As a result, heat is flowing from the bottom to the top. This figure shows that heat loss also occurs from the column to its surroundings. However, it may be reasonable to approximate the conduction through the column as the dominant heat flow mechanism.

To calculate the amount of heat $dQ$ that is transferred through the material in a time interval $dt$, also known as the heat flow rate ($dQ/dt$), we use the following heat conduction equation,

$$\frac{dQ}{dt} = kA \frac{T_H - T_L}{L}$$  \hspace{1cm} (1)

where $A$ is the cross-sectional area, $L$ is the length of the conductive column, $(T_H - T_L)$ is the temperature difference, and $k$ is the thermal conductivity.

The heat conduction process is prevalent within the entirety of the parking structure, specifically with the ground. Normally, the ground can sustain a constant temperature at certain depth beneath the ground. Therefore, in the winter season, the ground can potentially act as a heat source, whereas in the summer season it can be a heat sink, all of which contribute to conductive heat transfer within the structure. A heat sink is a reservoir that heat can flow into.

**Convection**

Convection is the transfer of heat by mass motion of a fluid (**Figure 7**) from one region of space to another (Young, 2012).

If, for example, the sun warms a land mass, that land will in turn warm the air above it. The hot air rises, and when the temperature decreases the air becomes denser, sinks to be
reheated, and the cycle continues. This resulting convection current, which transfers thermal energy upward, is a natural process called *natural convection*. In contrast, a fan blowing hot air through heating ducts as a means to deliver thermal energy to a room, is *forced convection* (Thomsen, et al., 2015). Other familiar examples include the flow of blood in the body, and using antifreeze in a car engine.

Since convection requires fluid flow, it can be difficult to model. How well a fluid can transport energy depends heavily on its ability to flow, its own temperature distribution, the geometry of the region through which the fluid flows, and its density (Thomsen, et al., 2015). Although convective heat transfer may seem very complicated, there are plenty of equations to model convection. They tend to be fairly complex; an example of how this could affect the microclimate of the structure would be the effect of warm or cold winds entering the structure. As a result, there can be several exchanges of thermal energy between the moving air and the structure itself.

**Radiation**

Radiation is the transfer of heat by electromagnetic waves such as visible light, infrared, and ultraviolet radiation. Examples of radiation include the heat we feel from the sun’s emitted rays, and the radiation coming from a fire pit. The human body also radiates energy, which is one reason we cool down when we are not wearing many layers. Relevant examples of radiation we will focus on are the emission rays from the sun that come into contact with the parking structure, the infrared radiation (IR) emitted by large objects near the parking structure, and the IR emitted by the structure itself.

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*Figure 7: Simplified Convection Diagram*
The rate of energy radiation from a surface is proportional to the surface area $A$ and to the fourth power of absolute (Kelvin) temperature $T$. The rate is also dependent on the nature of the surface; this can be defined by the quantity $e$, called the emissivity. The emissivity is a dimensionless number between 0 and 1, which represents the ratio of the rate of radiation from a particular surface to the rate radiation from an equal area of an ideal radiating surface at the same temperature (Young, 2012). The heat flow rate caused by radiation can be expressed as

$$\frac{dQ}{dt} = Ae\sigma T^4$$

where $A$ is the surface area, $e$ is the emissivity, and $\sigma$ is the Stefan-Boltzmann constant:

$$\sigma = 5.670400(40) \times 10^{-8} \text{ W/m}^2\text{K}^4$$

Radiative heat transfer can alter our microclimate in many ways. During the day the structure receives radiation from the sun, but at night it receives very little radiation from the direction of the night sky, unless the sky is cloudy, in which case it obtains IR from the clouds. Since all objects can emit IR, the structure can receive IR from nearby trees, buildings, and from the presence of automobiles. In return, the structure also emits radiation to its surroundings.

These three heat transfer mechanisms can help us visualize the complexity of microclimates, regardless of their size. Many factors, variables and assumptions must be made when modeling such an intricate natural phenomenon. We approached investigating this microclimate with a cohesive lens in order to discover which potential factors could alter our analysis of the structure.

**METHODOLOGY**

**Data Collection**

Data was taken using a Dual Laser Infrared (IR) Thermometer. The design of the IR thermometer is based on the radiation equation 2. The IR thermometer is capable of measuring the amount of infrared radiation (the left side of equation 2), and of using that value to solve for the temperature of the surface being measured. We then recorded the measurements in Microsoft Excel.

On each floor of the parking structure we recorded temperatures at five columns (marked $X$ on Figure 5), and on the
landings of Stairwells A, B, and C (Figure 5). We measured 3 areas on the ground inside the parking structure and 3 areas on the top of the structure to obtain their average temperatures. Using local weather data, we also recorded the high and low temperatures for the day, and the current air temperatures outside. The timeline for our data collection extended from late February 2017 to mid-late March 2017.

The structure’s number of cars might have played an influential role in the temperature of the capture columns. The percentages of parking spaces in which cars were parked adjacent to the columns were recorded to capture any effect from warm car engines. The date and time of the measurements were recorded before every data trial. Table 1 and Table 2 show several data sets we acquired.

<table>
<thead>
<tr>
<th>Time: 2/22/17 3:10am</th>
<th>Tair (°C)</th>
<th>Ground T (°C)</th>
<th>Column 1 (°C)</th>
<th>Mid Column Avg 5 (°C)</th>
<th>Top T (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor 1</td>
<td>6</td>
<td>7.5</td>
<td>7.4</td>
<td>6.6</td>
<td>7.6</td>
</tr>
<tr>
<td>Floor 2</td>
<td></td>
<td>7.8</td>
<td>7.3</td>
<td>7.1</td>
<td>7</td>
</tr>
<tr>
<td>Floor 3</td>
<td></td>
<td>8.2</td>
<td>7.1</td>
<td>7.5</td>
<td>7.5</td>
</tr>
</tbody>
</table>

Table 1: Temperature readings inside parking structure.

<table>
<thead>
<tr>
<th>Time: 2/22/17 3:10am</th>
<th>Stairwell A (°C)</th>
<th>Stairwell B (°C)</th>
<th>Stairwell C (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor 1</td>
<td>7.4</td>
<td>10.7</td>
<td>7.1</td>
</tr>
<tr>
<td>Floor 2</td>
<td>9.0</td>
<td>10.3</td>
<td>7.5</td>
</tr>
<tr>
<td>Floor 3</td>
<td>9.7</td>
<td>9.7</td>
<td>8.5</td>
</tr>
<tr>
<td>Floor 4</td>
<td>9.7</td>
<td>9.5</td>
<td>8.6</td>
</tr>
<tr>
<td>Floor 5</td>
<td>10.2</td>
<td>9.5</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Temperature readings inside stairwells.

Both of these tables illustrate one data set. We obtained a total of ten data sets to use for data analysis. When outside columns were within one degree of each other, the temperatures were averaged into an average of the middle column. Qualitative
observations of the weather were also recorded to examine whether external conditions had an effect on the structure.

**Data Analysis**

We averaged the temperature readings from the columns to calculate the temperature difference between the average of the columns, the average of the ground, and then the air temperature (To). This procedure was repeated among all ten data sets. This was done to examine whether the structure was more consistent with the ground temperature, compared to the air temperature. **Figure 8** presents the data using a plot to find any consistency in the temperature difference patterns.

![Figure 8: Frequency of temperature differences between columns and the ground.](image)

**Figure 9:** Frequency of temperature between columns and air.

![Figure 9: Frequency of temperature between columns and air.](image)
The most frequent temperature difference between the average columns and the ground is 1 degree, and we can observe that the majority of the temperature difference values converge to the value -1, resembling a bell curve. In contrast to Figure 8, we see in Figure 9 that the frequencies of the temperature differences between the columns and the air appear to give more irregular results. With this data on the temperature differences between the columns, air, and ground, we can safely conclude that the parking structure temperature is more consistent with the ground temperature. In addition, this also suggests that the main component of heat transfer is conduction from the ground to the structure, although it is difficult to distinguish between this and the possibility that the parking structure columns respond to air temperature in a manner that is similar to the ground.

In Figure 10, we see that measurements on the ground floor of stairwell B have the highest temperature. This pattern was frequent in most of the ten data sets. All the stairwells are similar in geometrical shape, size and temperature distribution patterns. Figure 10 represents the temperature on each floor in the stairwells, relative to the ground temperature from one of the data sets.

![Figure 10: Stairwell temperatures compared to floor level temperatures relative to the ground.](image-url)
Surprisingly, on February 10, 2017 at 7:00 p.m., stairwells A and B both behaved in the same manner. Their temperatures both decreased and increased at each floor, often at about the same rate. Stairwell C, however, shows a different behavior, compared to its counterparts, by having a negligibly small increase in its temperature.

![STAIRWELL VS FLOORS 2/11/17 11:00AM](image)

**Figure 11:** Stairwell temperatures compared to floor level temperatures relative to the ground.

In a different data set (Figure 11) we observed that at 11:00 a.m. on February 11, stairwell B has a small temperature decay to the ground temperature. Stairwells A and C are gradually approaching the ground temperature. All stairways are converging to the ground temperature of the structure, resembling TG, as the asymptote for this plot. Both of these measurements were taken within a time frame of 18 hours. Within this time frame, there is a lag time for the conductive heat transfer. The lag time exists due to the conductivity of concrete and the other transfer mechanisms, such as convection and radiation present. After 18 hours, including overnight cooling, Stairwell B still produced the same decaying pattern as before. The fact that the ground level of stairwell B is the warmest spot in all of the stairwells for most of the data sets suggests the existence of a heat source. By contrast, stairwells A and C both have an increasing temperature as one moves up the structure.
CONCLUSIONS

Although this artificial structure may seem very basic from its design, the microclimatic behavior is very complex and intricate to model and grasp. Collecting data by hand proved to be very tedious. Using thermocouples to capture data at more intervals of time would provide more data at a much faster rate. The main feature brought out in our analysis is the likelihood that thermal conduction between the parking structure and the ground plays an important role in this microclimate. Other factors are also likely to have affected the microclimate, particularly from convection and radiation. As stated in the introduction, the amounts of sunlight and the flow fields of the wind will affect the parking structure’s microclimate. The influence of these factors could be examined through additional analysis of the data taken, or by analysis of additional data targeting those factors. Lastly, for the anomaly in the ground floor stairwell temperatures, further investigation is needed. We suspect that there may be a heat source causing the consistently warmer temperatures, compared to the other areas of the structure.

The purpose of this research was to determine the possibility of modeling microclimates in artificial structures. Investigating the parking structure showed that it is within the realm of possibility to produce a feasible model. The first steps to the construction of our model will be more qualitative. After future studies, we can determine whether the modeling could be made more quantitative for extensive purposes. Making an efficient model would grant us the ability to predict temperatures inside structures based on external conditions. Research in microclimates could be the answer to mitigate the impact of global climate change on our society. We could potentially dramatically change the impact of urban heat islands across the globe. Research in microclimates leads to energy efficient practices in buildings, projects, and roads. Cities such as Chicago, St. Louis, and several others maintain a concise heat emergency response plan. Research in microclimates could give us the tools to foresee potential heat wave warnings in other areas.
REFERENCES


