Spatial Distribution of Urban Heat Islands and Development of a Lab Exercise Using Satellite Images and Infrared Thermometers

Muhammad A. Tak, MSCE, Luke M. Snell, MSCE, and Mark L. Hildebrandt, Ph.D.
Southern Illinois University Edwardsville
Edwardsville, Illinois

Urban areas tend to be warmer than surrounding rural areas due to urban heat islands. Building materials, such as concrete, asphalt, steel and brick, contribute in various ways towards urban heat island formation. Materials darker in color absorb more solar radiation and thus are hotter than light colored materials. Satellite images are an important tool in studying spatial distribution of heat islands. Temperature measurements are one of the parameters that can be used to select environmentally sustainable building materials. Research done at Southern Illinois University Edwardsville have shown that concrete reflects greater amounts of solar radiation when compared to other building materials, such as asphalt, steel and brick.

Key Words: Heat Island, Remote Sensing, Infrared Thermometer, Temperature

Introduction

The heat island effect is the warming of temperatures in summers that occurs in urban areas. It takes place when temperatures in cities, especially in central business districts, get warmer than temperatures in surrounding suburban and rural areas. With the advent of science and technology, humans have migrated towards urban areas, and new technology has brought many changes in our lives. Along with industrial and commercial activities, human movement by itself generates heat. Thus in a city we observe warmer temperatures than we do in other surrounding areas. A typical urban heat island profile developed by Heat Island Group of Berkeley Lab shows how the temperature varies over different areas (see Figure 1).

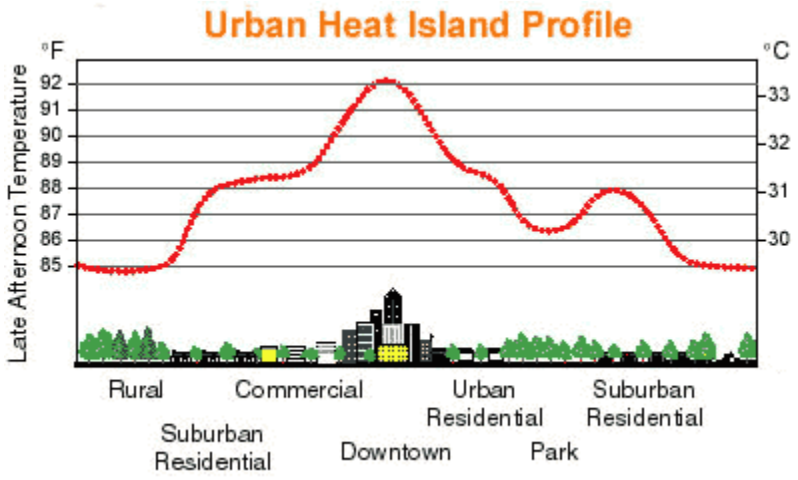


Figure 1: Typical Urban Heat Island Profile

A considerable amount of solar energy evaporates moisture from flora and soil. This process takes place continuously and helps to keep the land temperature relatively constant. Heat is drawn up by the evaporating moisture and the temperature remains cooler. Cities usually do not have large open areas where this process may take place. Due to that, the rates of evaporation and transpiration do not contribute towards lowering the temperatures, therefore, the incoming solar radiation reflects back and is trapped in the urban covering. This urban covering or canopy lacks soil and vegetation and keeps the temperature warmer than the surrounding open and green areas. Building materials such as asphalt, wood, concrete and bricks all contribute in a different way towards heat island formation. For instance, materials darker in color absorb more heat and are hotter than light colored materials.

Difference between Heat Island and Global Warming

The urban heat island effect is little different from global warming. Both contribute to temperature increase, but there are some features that distinguish urban heat island effect from global warming. United Nation's Earth + 5 Summit in 1997, identified global warming is the average increase in world temperature and is due to human activities. It contributes towards changed rainfall patterns, rise in sea level and other ecological problems. There has been a debate over the actual cause of global warming and its long-term impacts. However, it is a general perception that this phenomenon takes place due to green house gases that are emitted in human activities. The heat island effect - a local phenomenon in the cities - is also a consequence of human activities. However, it is linked to urban areas where there is less vegetation and building materials that absorb the solar energy are in abundance. The heat island effect is one of the contributors towards global warming.

Albedo

Thermodynamic properties of materials determine the influence towards formation of heat island. According to US Environmental Protection Agency (USEPA), albedo is "the fraction of the total solar radiation incident on a body that is reflected by it." Surfaces that have high albedo values absorb less incident radiation. Albedo values of some materials found in the urban areas are shown in Figure 2 (USEPA). Even if two surfaces have a similar albedo, the incident energy does not always result in similar temperatures because the thermal capacity of those surfaces may differ. Concrete, which is used as construction material extensively all around the world, has many benefits. Concrete has an albedo value ranging from 0.1 to 0.35 (see Figure 2). These values are higher than those of some other materials, and it is also lighter in color. Other benefits of concrete that make it environment friendly material include, its having low energy requirements for its production, its being recyclable and its components being abundant in nature (water, sand and aggregates et. al.)

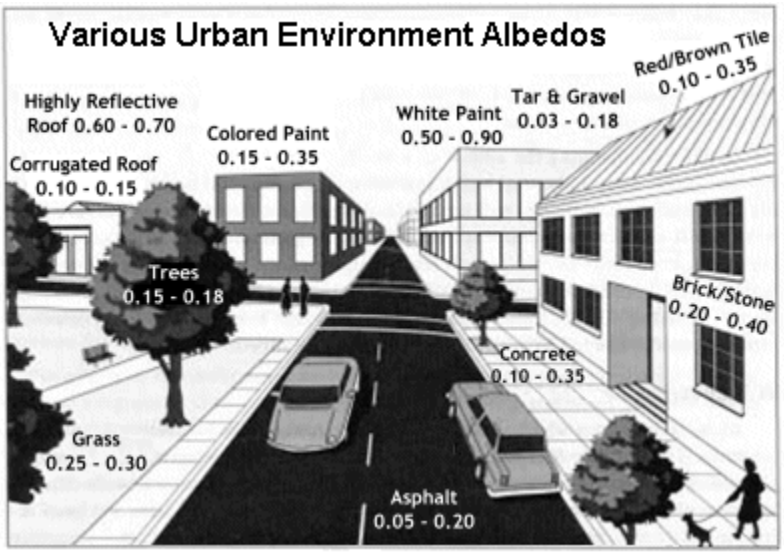


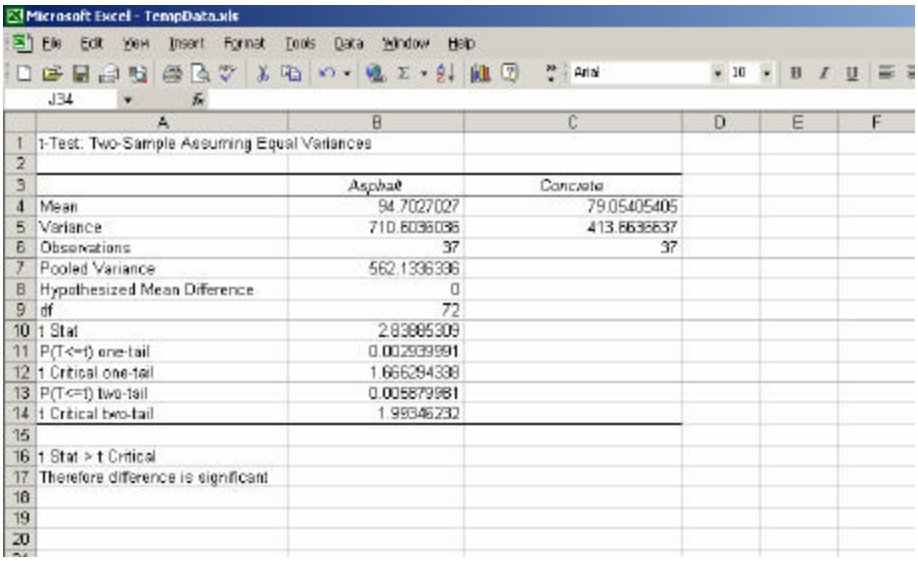
Figure 2: Typical Albedo Values of Different Materials

Research Overview

A research program was initiated at Concrete Construction Resource Unit (CCRU) of Southern Illinois University Edwardsville (SIUE). Key features of this research were to study urban heat island effect in detail, compare spatial distribution of heat islands using remote sensing and satellite imagery and develop a lab exercise for undergraduate students of construction engineering at SIUE. First segment of this research was to collect temperature data for various building materials such as concrete, asphalt, brick, steel and wood with the help of infrared thermometers. Temperature measurements were taken over a span of one year at various locations around Southern Illinois University Edwardsville with the help of infrared thermometers. Varying environmental conditions were also considered while collecting the data. Infrared (IR) thermometer measures surface temperature without any physical contact with the object. It measures infrared radiation emitted by an object. Infrared thermometer is a simple, fast and efficient device to measure temperature of objects that are physically hard to access. Infrared thermometer used in the research was Raytek Corporation's Minitemp® MT2 non-contact thermometer.

Data Analysis

The data was analyzed by running t-tests (assuming equal variances) on Microsoft Excel® for the building materials temperatures. T-test is a parametric test of data analysis which compares mean values of variables. From the data analysis it was found out that there was significant difference between mean temperatures of concrete and asphalt. Figure 3 shows one batch of data with mean temperatures of concrete and asphalt as 79.05 F and 94.70 F respectively.



Microsoft Excel - TempData.xls

File Edit View Insert Format Tools Data Window Help

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	A	B	C	D	E	F
1	t-Test: Two-Sample Assuming Equal Variances					
2						
3		Asphalt	Concrete			
4	Mean	94.7027027	79.05405405			
5	Variance	710.6036036	413.8636637			
6	Observations	37	37			
7	Pooled Variance	562.1336336				
8	Hypothesized Mean Difference	0				
9	df	72				
10	t Stat	2.83885309				
11	P(T<=t) one-tail	0.002939991				
12	t Critical one-tail	1.666294338				
13	P(T<=t) two-tail	0.005879981				
14	t Critical two-tail	1.99346232				
15						
16	t Stat > t Critical					
17	Therefore difference is significant					
18						
19						
20						

Figure 3: Data Analysis for Concrete and Asphalt

T-test performed on the data (see Figure 3) showed that the difference between the mean temperatures was significant for concrete and asphalt. Similar t-tests were done to find the significance among mean temperatures of black matt steel, wood and brick against asphalt. It was found that mean temperatures were not significant in case of black matt steel, brick and wood when compared to asphalt.

In second part of the research, spatial distribution of urban heat island was studied using satellite images of various large cities of USA. Remote sensing principles were applied to study the distribution of temperature gradients in and around cities. It was found out that temperatures were higher in downtown areas and other places where asphalt and other darker materials were in abundance. Areas having materials of lighter colors such as grass and concrete showed lower temperatures. Similarly suburban and rural areas had lower temperatures than nearby urban areas.

Development of Lab Exercise

Satellite images were combined with infrared temperature measurements to develop a lab exercise for undergraduate students of construction engineering at Southern Illinois University Edwardsville (SIUE). Focal point of this exercise was to introduce urban heat island as a major urban problem with regard to selection of building materials since building materials, such as concrete, asphalt, steel and brick, contribute in various ways towards urban heat island formation. Remote sensing concepts were also incorporated so that students could widen their perspective about materials selection in construction with respect to their color and heat absorption. This exercise was introduced in fall of 2003 to an undergraduate course - Materials Sampling and Testing - in construction engineering program at SIUE.

The success of this exercise led to a suggestion for a more refined and simplified version for high school students. This version is yet to be introduced to high schools and is planned for late fall of 2004 or spring of 2005. Knowledge about the heat island effect will also help students in considering career choices in addition to basic introduction to the problem of temperature rise.

Conclusion

Based on our research and data collected, darker materials showed higher temperatures, and cities had higher temperatures in central business districts. Due to high variance in the data, it was not possible to establish order of variation among mean temperatures of building materials. The reasons for higher temperatures include less vegetation, lack of moisture and use of darker materials such as asphalt pavements and darker rooftops.

Future Outlook

Introduction of heat island effect can help in selection of building materials by construction industry that can help reduce the adverse effects of temperature rise. Our results suggest that concrete can reduce the inner-city temperature and help cut high-energy costs.

Community participation can help in reducing the adverse effects produced by human activities. These problems require lot of time and dedication. If local communities including students start working towards better understanding and sharing information about the environment at their local level, they can make a huge difference.

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