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TOOLS TO INVESTIGATE BUILDING ENVELOPE THERMAL BEHAVIOUR FOR URBAN HEAT ISLAND MITIGATION (UHIM)

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ABSTRACT:

Urban areas tend to have higher air temperatures than their rural surroundings, as a result of continuing surface change that include replacing the natural vegetation with building structures, sidewalks and roads. The surfaces of buildings and pavements absorb solar radiation and become extremely hot, causing the surface temperature of urban structures to be 50-70 ^{o}F (10 to 21 ^{o}C) higher than ambient air temperature which in turn warms the surrounding air. (Taha, Akbari and Sailor 1992).

The term "Urban Heat Island" describes this phenomenon. As a result, urban structures absorb a large quantity of thermal energy during the daylight hours and slowly re-emit this stored heat during the late afternoon and night. Although the urban heat island effect is prevalent in many cities, intensities vary from community to community according to such variables as climate, topography, degree and pattern of urbanization in a given geographical area. These variables contribute to urban climate in different weights. Buildings and building elements such as walls, balconies and arches, also may have a significant impact on the UHI formation. Consequently, new tools should be utilized to have a more detailed thermal analysis for building envelope elements and to understand closely the envelope-climate complex relationship.

This paper was intended to investigate the potential of Infrared Thermography to evaluate building envelope thermal behavior and its contribution to urban climate.

تحليل الأداء الحرارى لغلاف المبنى بالتصوير للحد من ظاهرة الجزر الحرارية

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الملخص العربى

أن دراسة الأداء الحرارى للغلاف الخارجي للمبنى كان دائما أحد الوسائل المطروحة للحفاظ و ترشيد الطاقة داخل المباني. مع تفاقم المشكلات البيئية و ظهور بعض الظواهر الطبيعية الضارة مثل ظاهرة الجزر الحرارية، دعت الحاجة الى دراسة تأثير استخدام الأسطح و المواد المصنعة المختلفة و المستخدمة في عمليات التشييد و دراسة مدى مسئوليتها لتفاقم تأثير هذه الظاهرة. و حيث أن استخدام القياسات الميدانية لدراسة الاداء الحرارى للمباني هو أحد أهم الوسائل للحصول على نتائج حقيقية ذات درجة عالية من المصداقية، ألا أنها من الصعوبة و التعقيد تنفيذها و ذلك لاختلاف حجم و تكوين و توجيه المباني و مفرداتها المعمارية المكونة للغلاف الخارجي للمبنى مثل البروزات (البلكونات و الكوابيل) و الارتدادات و الممرات المفتوحة أو المغطاة و ما غير ذلك.
لذا، دعت الحاجة الى التفكير في وسيلة متطورة لدراسة الأداء الحرارى للغلاف الخارجي للمبنى باستخدام تقنية التصوير بالأشعة الفوق بنفسجية والتي هي أحد الوسائل المتطورة التي تم استخدامها في دراسة الانبعاثات الحرارية من سطح الكرة الارضية و التي تتم من خلال وكالة ناسا الامريكية للفضاء. و قد قام الباحث بالتعاون مع قسم العمارة و التخطيط البيئي بجامعة أريزونا بالولايات المتحدة الامريكية بوضع عدد من الدراسات لكيفية استخدام هذه التقنية باستخدام كاميرا للتصوير بالأشعة فوق البنفسجية لتحليل الاداء الحرارى للمباني و المناطق المفتوحة المحيطة بها. و قد خلصت الدراسة الى كيفية تسجيل الأداء الحرارى للمباني و قياس درجات حرارة الاسطح للغلاف الخارجي بصريا و أيضا رقميا من خلال تحليل صور الاشعة فوق البنفسجية ببرنامج الكمبيوتر المعد خصيصا لهذا الغرض. و قد تم عرض النتائج في صورة عدد من المنحنيات البيانية بالمقارنة بالصور فوق البنفسجية.

INTRODUCTION:

Paved surfaces within the city do not receive the benefit from the natural cooling effect of vegetation. The difference in temperature from rural to urban areas ranges from as little as 1.1 degree to 4.4 degrees C (2 degree to 8 degree F) in St. Louis Missouri, to 5.6 C (10 F) in New York City, to as much as 10C (18F) in Mexico City (ref.).

As ambient air temperature rises, so does the demand for the indoor cooling loads and of course the energy generated for that reason. This leads to higher emissions by power plants, as well as increased smog formation due to warmer temperature. While Heat Island Reduction (HIR) strategies can reduce cooling energy use in buildings and lower the ambient air temperature, cooling the ambient air temperature has the additional benefit of reducing urban smog concentration, and hence, improving urban air quality.

Lately, a number of strategies were documented to mitigate and reduce the heat island effect. These strategies are first, planting shade trees and other vegetation and second, incorporating high-albedo materials for roofs and pavements into the urban landscape. Building envelope also can be incorporated as UHI mitigation strategy because of its considerable part of the urban context.

The objective of this paper was to introduce new techniques to evaluate and better understand building envelope thermal behavior, a step towards new generation of heat island mitigation building envelopes

Cooler building envelopes and objects near it (streets, trees and sidewalks) in the urban context, can offer direct saving potentials from an energy-saving point of view and also for smog and air quality issues consideration. A concept of cooler building envelops was established in a previous study by the author (Elhinnawy,2004) with the objective to lower the ambient air temperature by understanding and investigating the thermal behavior for different building envelope surfaces in relation to its urban climate.

PREVIOUS STUDIES:

While there is a considerable research on the thermal behavior of building envelope and its contribution to indoor climate, very little exists for building envelope surfaces and its overall performance in relation to urban climate. However, after reviewing literature, it was observed that a number of studies used surface temperature for paving materials to evaluate their contribution to urban climate. In this paper, the same concept was used to evaluate building envelope surfaces as function of their surface temperature.

Most of studies evaluate heat island mitigation potential through either using site measurement or energy simulation tools. These tools study the overall thermal performance and building energy budget. Whereas, visualizing building surfaces thermal performance using IR thermography will be very helpful for envelope design process and guidelines.

While surface-based measurements are preferable for land use and urban warming analysis, surface temperatures may be measured through remote sensing techniques to facilitate the collection of very large number of thermal observation. In May 1997, scientists from NASA collected high resolution thermal data (10 meter by 10 meter) over a major metropolitan region for the first time. Due to its exceptionally rapid rate of urban growth and deforestation over the last several decades, Atlanta, Georgia was selected as the site for the pilot study later has been named "Project Atlanta". At that spatial resolution of 10 meters, surface temperature changes can be identified between different categories of land use. The development of high resolution thermal sensors permits the relationship between urban design and heat island formation.

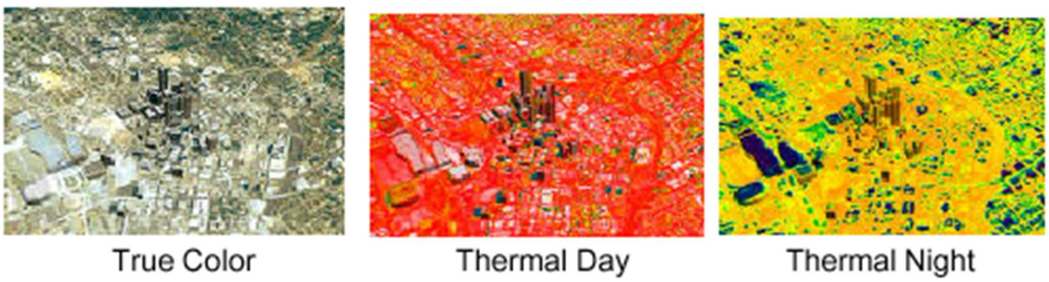

Fig. 1 : Atlanta's True and Thermal Remote Sensing Images

In 1999, a project named the Urban Heat Island Pilot Project (UHIPP), was created by the UHI Group, Lawrence Berkeley National Laboratory LBNL and NASA with the objective to investigate the potential of HIR strategies in residential and commercial buildings in three initial UHIPP cities: Baton Rouge (LA), Sacramento (CA) and Salt Lake City (UT).

The project was intended to quantify and evaluate ground surfaces temperature and thermal emissions in these three cities through remote sensing data from the Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER), which is an imaging instrument that is flying on Terra, a satellite launched in December 1999 as part of NASA's Earth Observing System (EOS). One of the goals of the project to coordinate data collection and to use these flyover thermal maps to analyze urban fabric and ground covers for the three cities.

In a study by Department of Civil and Environmental Engineering, Arizona State University, a field measurement was acquired to investigate both the level of accuracy of the use of handheld thermography and to quantify the thermal variability of different types of paving materials. The study used a number of concrete and asphalt mixes for analysis. A weather station was placed at the research site to acquire diurnal metrological data. A district weather station was also utilized to validate conditions. Also, thermocouples sensors were utilized to verify the accuracy of handheld thermography. For the period of 33 hours starting from midnight June 26 to 9 am June 27, ambient temperature humidity, wind direction and strength, rain fall and solar irradiance were collected every 20 minutes. The results were consistent with a percent of accuracy with surface temperature readings within 5%.

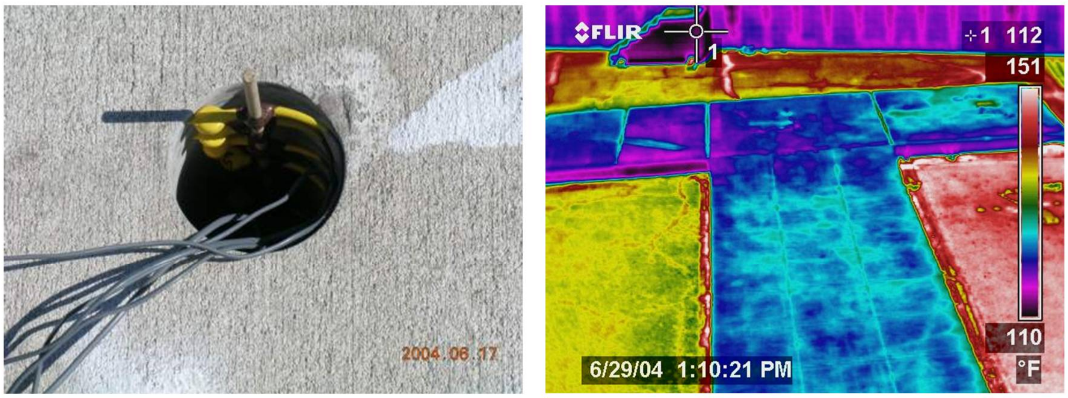

Fig.2 : Testing and IR Image for the Concrete Pavements Mixes at June 29, 04
Source: Department of Civil and Environmental Engineering, ASU.

In another study by (Bryan, Agarwal and Antia, 2004) models a building in downtown Tempe area, Arizona, on a typical hot summer day (August 21^{st} at 9:00 PM) using a simulation program called RadTherm to optimize the interaction between building materials, surface properties and resultants surface temperatures. The performance of the building was compared with thermal images generated using infrared camera to demonstrate the possible application for developing urban design guidelines to mitigate urban heat island. The surface temperature map of the building were compared with thermal images ranging from 43^{o} C for concrete sidewalks, 42^{o} C for black asphalt, 40.5 for concrete roof and 38.7 for red brick wall. The collected temperature maps from thermal images confirming night time characteristics of urban heat island phenomena for hot arid climates.

THE PROCEDURE:

The release of radiant energy from surfaces is generally measured in one way. One approach is to measure the quantity of radiant heat emitted per unit of area. This measure is known as the radiant flux density and is generally calculated in watts (Joules per second) per square meter (W/m2). Similar to other density measures, the radiant flux density provides a measure of average intensity of a specific surface per unit area. However, the temperature difference is considered the driving factor that affects the amount of heat released to the urban climate.

The surface temperature measurements in this paper will be collected through handheld thermography on the ground level to investigate temperature changes for different wall orientations and elements relative to ambient air temperature.

Infrared Thermography: The Technology:

All objects with a temperature above absolute zero emit infrared radiation. The hotter an object gets, the more infrared radiation it emits. These emissions cannot be seen with the naked eye. However, the infrared camera senses that infrared radiation and electronically displays a visual image of the thermal patterns. Surface heat patterns can be determined from this image. A thermal imager is extremely sensitive and reportedly can detect temperature variations as small as 0.1 degrees centigrade. The images created by the device can be projected onto a small viewing screen or preserved on video tape or photographs. The thermal imager is small enough to be hand-held, but often is mounted under a helicopter and flown over its target.

Temperature measurements in this paper were collected on the ground level (1-2m from the ground) due to unavailability of aerial thermo-graphic images for that specific location. This technology gives visible proof and a record of thermal performance of the buildings elements and building envelop specifically.

The Tool:

Thermal images in this study were collected using a FLIR Therma-CAM PM 695 infrared camera. An important feature of this camera is the ability to save thermal images digitally. Each pixel (of a 76800 pixels) in the thermal images (320x240) is stored as a temperature value containing pixel-by-pixel temperature data. This allows the easy post-processing of collected images using Therma-CAM Researcher software, which allows for the examination of actual surface temperature with heating and cooling overtime. This technique allows non-contact sensing and a more global range than traditional mechanical testing. In addition, infrared imaging can identify otherwise hidden changes on building envelope, infiltration, moisture and heating or cooling leak which is not within the scope of the research.

Using The Tool:

The concept in this paper was to investigate the potential of utilizing infra-red thermography as tool to evaluate temperature changes between different wall orientations within building envelope as well as surface materials.

For that purpose, a surface temperatures were collected through field measurements for different wall orientations for a number of educational buildings at ASU campus for a period of 2 hours after sun-set on 26th, June,04. The collected surface temperatures were analyzed relative to other similar reading along with ambient air temperature. Also, surface temperatures for the sidewalks and ground pavements near to the envelope were collected for correlation relative to building envelope.

RESULTS:

The goal of building envelope investigation was to identify the elements in the envelope that offer higher surface temperatures and releasing there heat to urban air and ambient air temperature during night time at summer-overheated period. Thus the thermal merit was expressed as a numerical value ΔT. The highest and longer standing at night was the worst performer. That number is also represents the difference in surface temperature related to ambient or dry bulb temperature.

A field campaign was undertaken of a collection of more than 50 IR image to a number of educational buildings for the purpose to investigate building envelope thermal behavior. The collected field investigations were performed for different wall orientations, sidewalks and landscape elements throughout a period of 2 hours after sun set (from 8:00 PM to 10:00 PM) at 26th June, 04. The infrared images were collected under actual summer outdoor conditions on a day with full sun. The process of IR imaging was selected intentionally after sun set to investigate the contribution of different surfaces to urban heat island.

Post processing of the collected imagery was utilized to allow for surface temperature collecting with the utilization of Therma-CAM Reporter 2000 Pro. software. The advanced software allows for multiple cross hair spots that capture surface temperatures and emissivity with individual adjustments for ambient temperature and relative humidity.

Every one of the collected surface temperature maps was plotted in a line graph to visualize the surface temperature change between different building elements and materials relative to ambient air temperatures.

Metrological Influences:

Surface material evaluations were made in conjunction with detailed meteorological observations. For the period of 00:00 hours on 26 June 2004 to 09:00 hours on 27 June 2004, ambient temperature, humidity, wind direction, wind strength, rainfall and solar irradiance were collected every twenty minutes. The presented data was selected due to the very calm, clear days with low humidity and average elevated ambient temperatures. During the diurnal cycle, maximum wind speeds reached an un-sustained 6 mph (9.654 km/hr) at 12:00 hours and 16:00 hours with a diurnal average of 2 mph (3.28 km/hr) wind speed. Humidity reached a maximum percent of 27 at 09:00 hours with and average of 16% relative humidity. Minimum ambient temperature was 27.0°C at 04:00 on 26 June 2004. That temperature was sustained for twenty minutes. Maximum temperature reached 40°C at 14:20 hours on 26 June 2004 and was sustained for twenty minutes. Sunrise for that date was 05:20 hours with sunset at 19:42 hours. Solar irradiance as measured in W/m^2 was first recorded at 06:45 on 26 June 2004 at 9 W/m^2, reached a maximum of 945 W/m^2 from 12:20 hours to 12:40 hours and with a last recorded reading of 4 W/m^2 at 19:45 hours.

Infrared Images Analysis:

As it is common that building envelope orientation affected by the falling solar radiation through the day, west and south façades are always higher surface temperatures then the east and finally north.

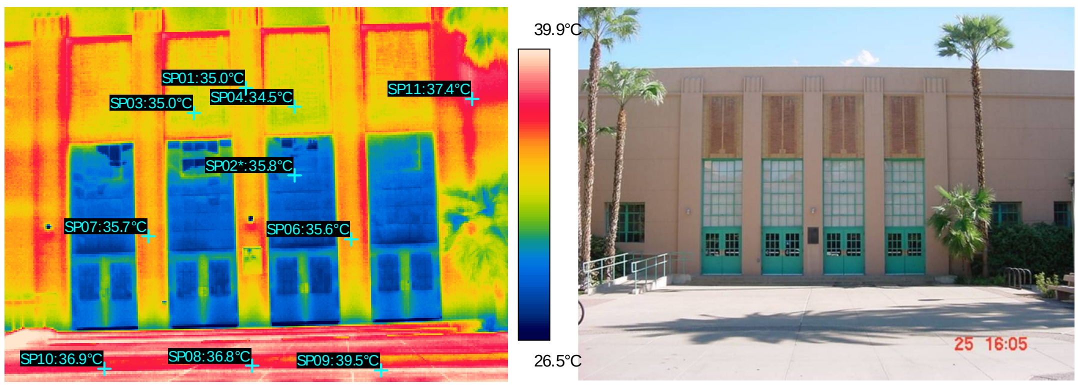

Fig. 3 : IR and Life Image for North Elevation at 8:56:16, June 26, 04
Air Dry Bulb Temperature 35 ^{o}C

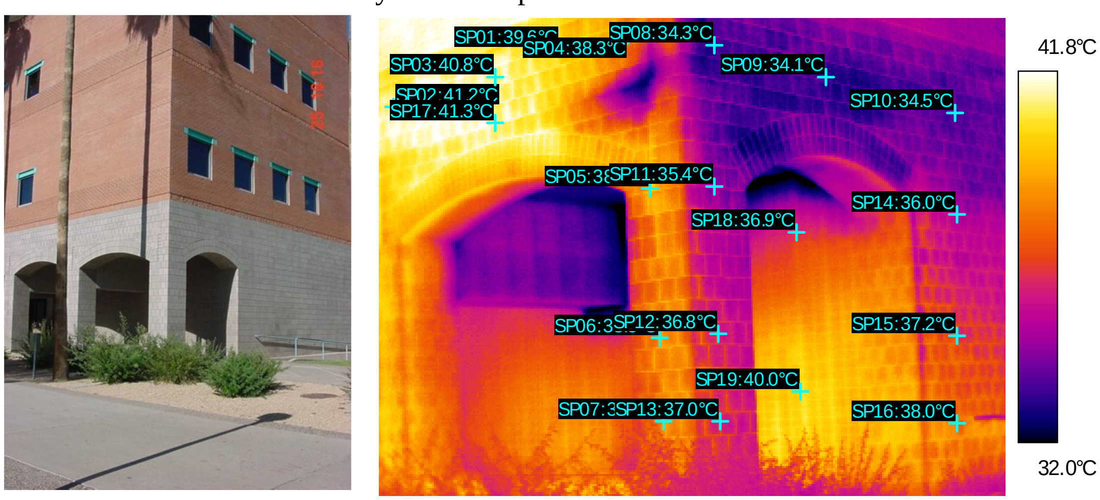

Fig. 4 : IR and Life Image for South West Corner at 8:29:52, June 26, 04
Air Dry Bulb Temperature 36.1 ^{o}C

Figure (3) shows the infrared image of the north elevation of an a educational building captured at 8:56:16 PM. A number of cross hair spots were selected to investigate temperature differences between materials and different building elements. The results show temperature ranging from 35 ^{o}C to 37.4 ^{o}C when air dry bulb temperature was 35

C. Also, a number of temperatures of the side walk surfaces were captured ranging from 36.8 ^oC to 39.5 ^oC with average difference than wall surface temperature by about 2 ^oC.

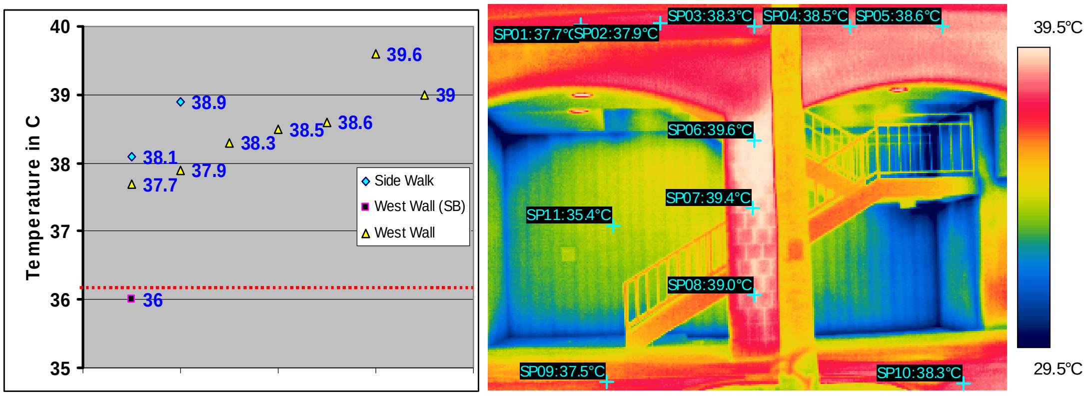

Fig. 5: IR Image and Surface Temperature Analysis for West Elevation at 8:19:21, June 26, 04. Air Dry Bulb Temperature 37.2 ^oC

In a different IR image for the south west corner of a building (figure 4), a temperature differences were observed between the two orientations. The temperature for the south wall ranged from 35.9 ^oC to 39.6 ^oC where for west wall the surface temperature ranged from 40 ^oC to 42.9 ^oC when air dry bulb temperature was 36.1 C.

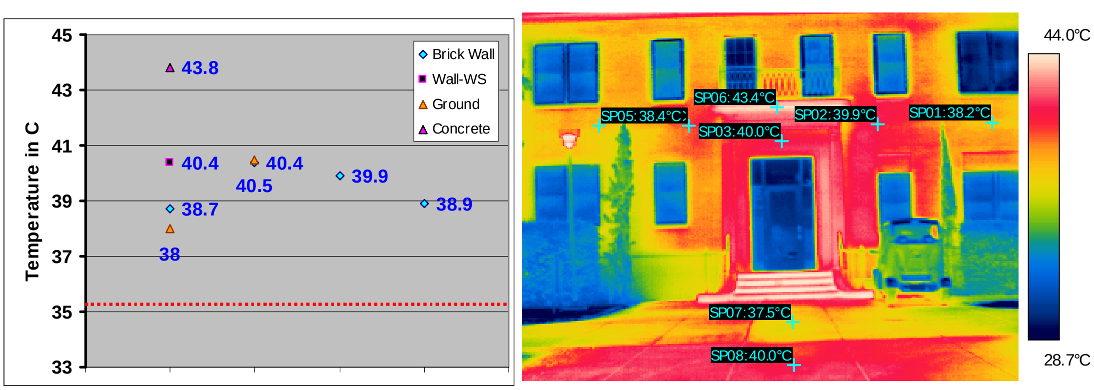

Fig. 6 : IR Image and Surface Temperature Analysis for West Elevation at 9:09:16, June 26, 04. Air Dry Bulb Temperature 35 ^oC

Ground surfaces experience temperature ranging between 36.8 ^oC to 42.5 ^oC for concrete surfaces and 37.3 ^oC for loose materials like gravel and 35 ^oC for green areas and grass. In one of the extreme cases, a surface temperature of 43.8 ^oC was observed for a concrete balcony in a west wall. The west wall surface temperature ranges from 37.7 ^oC to 42.9 ^oC when an air dry bulb temperature was 35 ^oC. IR image on figure (5) shows a surface temperature of 40.4 ^oC in the wind shadow area (south of the concrete balcony) as a proof of the lack of cooling due to wind flow obstruction by the balcony.

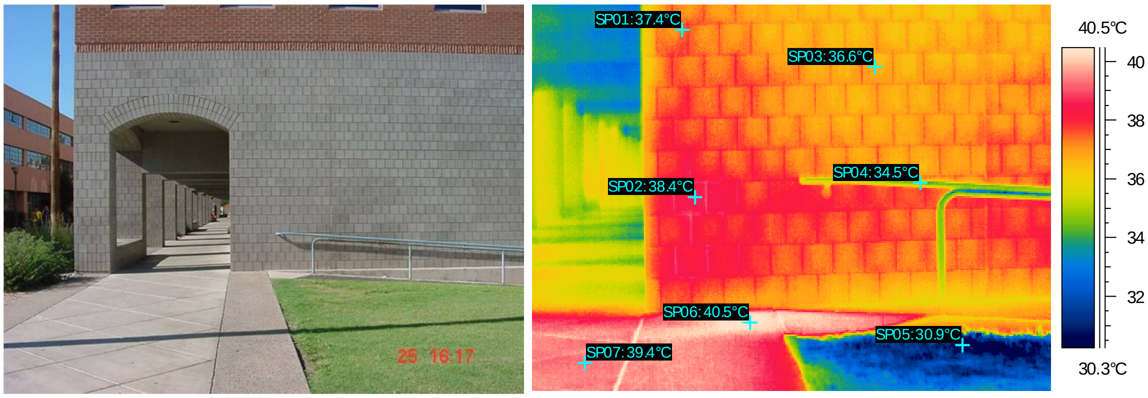

Fig. 7 : IR and Life Image for South Elevation at 8:35:01, June 26, 04, Air Dry Bulb Temperature 36.1 ^{o}C

Figure (8) shows surface temperatures for different groups of wall orientations and materials. The maximum temperature was observed on the concrete balcony on west wall 43.8 ^{o}C followed by the west brick wall with temperature 40.1^{o} C. Some walls located on the wind shadow area on west wall where it doesn't take full cooling effect from north wind on west wall was slightly higher 40.4 ^{o}C. Also, set-back west wall was lower than west wall temperature by 2 ^{o}C. Temperatures for east, north and south walls

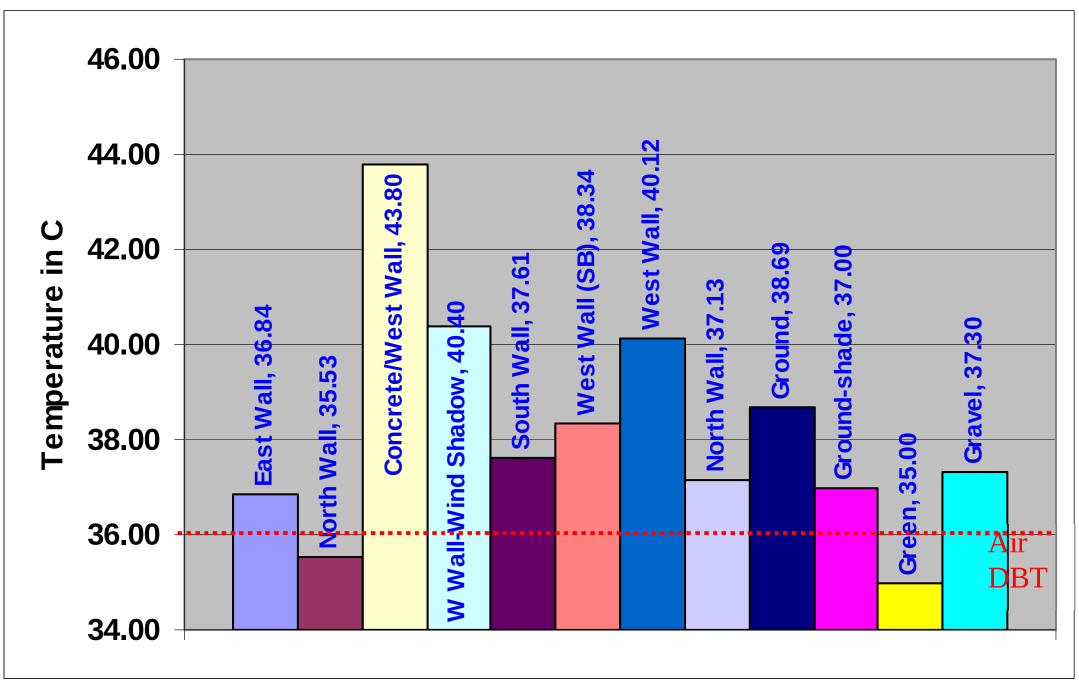

Fig. 8: Average Surface Temperatures Collected from IR Images for Different Elevations at for 2 Hours Period (8 to 10 PM), June 26, 04. Average Air Dry Bulb Temperature 36^{o}C

are respectively 36.8 ^{o}C, 36.5 ^{o}C and 37.6 ^{o}C. Additionally, loose materials such as gravel and green areas were the lowest temperatures of all groups. The average air dry bulb temperature was about 36 C for the 2 hour period of investigation. Temperatures differences ranges from -1 ^{o}C for green areas to 7.8 ^{o}C for concrete balcony on west wall. Figure 7 show the temperature differences ΔT for all cases.

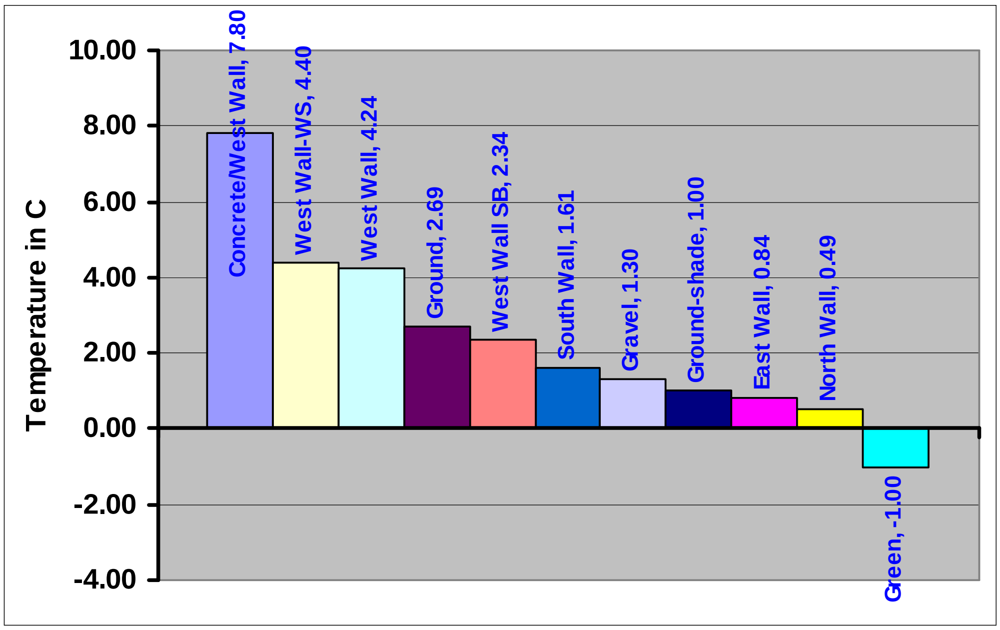

Fig. 9 : Average Surface Temperatures Collected from IR Images for Different Elevations at for 2 Hours Period (8 to 10 PM), June 26, 04.
Average Air Dry Bulb Temperature 36^{o}C

CONCLUSION:

As presented, hand -held IR cameras provide a relatively easy to use instrument to acquire surface temperatures on a as-needed basis. Additionally, IR thermography allows for the acquisition of data from multiple areas of interest without evasive instrumentation such as thermocouples.

The goal of this study was to examine building envelope and urban fabric in urban setting surface temperatures as well as their thermal behavior. Therefore, a new methodology was presented utilizing handheld thermography in an effort to visualize and evaluate the actual thermal behavior of building envelope elements. A series of surface temperatures were collected using infrared camera for the purpose to compare different building orientations, elements and materials. The presented effort considered as a step towards establishing new guide lines for urban heat island mitigation.

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