

Time-lapse of Cavity Brick Wall Temperature Profiles Using Infrared Thermography

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Exterior wall surface temperature is one important factor that significantly affect the energy consumption through building envelops. However, there are not much data collected on how exterior wall temperature continuously changes over time. Limited data found in this area were mostly collected using thermocouples placed at specific exterior wall surface locations. While useful thermal couple measurements cannot provide full thermal picture of large wall surface temperatures. In this paper, the authors present an infrared thermography method to measure exterior wall temperature profile continuously to identify how surface temperatures of brick cavity wall changed over 5-6 hours. Then the exterior brick wall surface temperature profile was compared against the ambient temperature profile and solar intensity profile during the measured period of time. The profile comparisons provide us with insights into timings of different profile peaks. The collected wall surface temperature data together with the ambient temperature and solar intensity data will provide researchers with needed boundary data to conduct energy related simulations. In this particular case study the results showed that the temperature of south wall and the ambient temperature reached their peaks at almost the same time; and there was about two hours lag when the west wall reached its peak surface temperature.

Keywords: infrared thermography; cavity wall temperature; peak temperature timing; temperature profiles

Introduction

Brick cavity wall is a widely used exterior wall type in the U.S. Since the external wall temperature is a crucial factor that determines the quantity of the heat flux into the building. Obtaining the wall temperature profile is often a prerequisite of evaluating the thermal performance of building façade. The traditional measuring method is placing thermocouples at different surface locations of the exterior wall (Elias-Ozkan et al. 2006; Seferis et al. 2011; Charde and Gupta 2013). However, this method has many limitations. The major limitation is that it is difficult to use thermal couples to cover the whole wall all the time. Another limitation is that many surface areas are hard to reach for installing thermal couples.

Infrared thermal cameras have been widely used recently in building inspections to detect abnormal temperature spot to identify building defects. Infrared cameras were also used as non-destructive testing (NDT) techniques in other industries. In an experimental study, a method of detecting the debonded building-finish area using an infrared camera was presented (Li et al. 2000). A similar study was conducted to inspect the hidden structure irregularities such as detachment moisture, insulation deficiency and thermal bridge (Grinzato et al. 1998). In a study of inspecting the unintentional opening in building envelope, infrared thermography technique was used with the fan depressurization test, then the dimensions of the cracks were estimated using image processing method (Dufour et al. 2009). Despite these well-studied thermal imaging application, we found little literature on continuously recording wall surface temperatures across seasons, a seemingly simple and important task. Therefore, the authors aims to employ thermography techniques in obtaining the continuous temperature profile for wall surface to understand different influences of the weather conditions (ambient temperature, solar intensity, and etc.) on the temperature profile of building facades. One particular answer we would like to find out is when the peak temperature would appears on south and west walls, and how they related to the peak solar intensity and peak ambient temperature on a particular day. As a case example the authors only presented one day data to show how the measurements were conducted. A long term study is scheduled to study the same measurements across the four seasons.

Methodology

The Measurement Set-up

The thermal camera used in this case study is FLIR A8300sc with an accuracy of ±1 ℃, sensitivity of 0.02 K, and image resolution of 1280×720 pixel. The basic physics principle of thermal imaging can be found in (FLIR 2015). The Jorgensen Hall of university of Nebraska-Lincoln was chosen as a test building because the brick masonry building has an L shape corner so we can take videos of both sides of walls (South and West) at the same time (Fig 1). The south and West walls were chosen for measuring because they contribute the most to the cooling load of the building in summer. The camera was set on a safe corner where both the south and the west walls of the building could be monitored in a same thermal image. The tested building is located at Lincoln, Nebraska with the latitude of 40.81 ° N and elevation of 1,219 ft., in the cold zone according to the division of climate region by Building America. In this case study, the thermal images of the two walls were captured every 30 seconds from 1:00 PM to 7:00 PM in a warm fall day on September 30th 2015, so we made sure that we can measure even the small changes over time. The results shows that the 30 seconds interval might be an overkill. But the small interval ensured us on the safe side in terms of data collection.

Fig.1 The experimental set-up

Data analysis

Before measuring the camera were calibrated using FLIR's ResearchIRMax software. The environmental condition statistics including the ambient air temperature, transmittance, the humidity, etc. were obtained from the local weather station; the emissivity of brick veneer was referred to the emissivity tables of building materials; other parameters, such as the reflected temperature and distance between the camera and the walls, were measured by each case. These collected data were entered into ResearchIRMax as part of the calibrations. In order to better illustrate the temperature variation, major regions of interest (ROIs), including both horizontal and vertical sample lines as well as cursors at different locations on each line(as shown in Fig.2), were drew on the two walls. For the horizontal lines, the first pixels are the leftmost points; for the vertical lines, the first pixels are the lowest points. The length of the Line 1 and Line 2 are approximately 15 m; the length of Line 3 is approximately 6.5 m; the length of the vertical Line 4 and Line 5 are approximately 25 m; the length of Line 6 and Line 7 are approximately 4.5 m and 2.5 m respectively.

After the recording the captured temperature data were exported from ResearchIRMax to Matlab for data analysis. The temporal temperature profile for the ROIs are both presented in 3D and 2D Cartesian systems. In the 3D Cartesian coordinate, temperature variation with time and location were observed; in the 2D coordinates, the temperatures of the cursors were plotted so as to better compare the temperature change at different locations on each sample line.

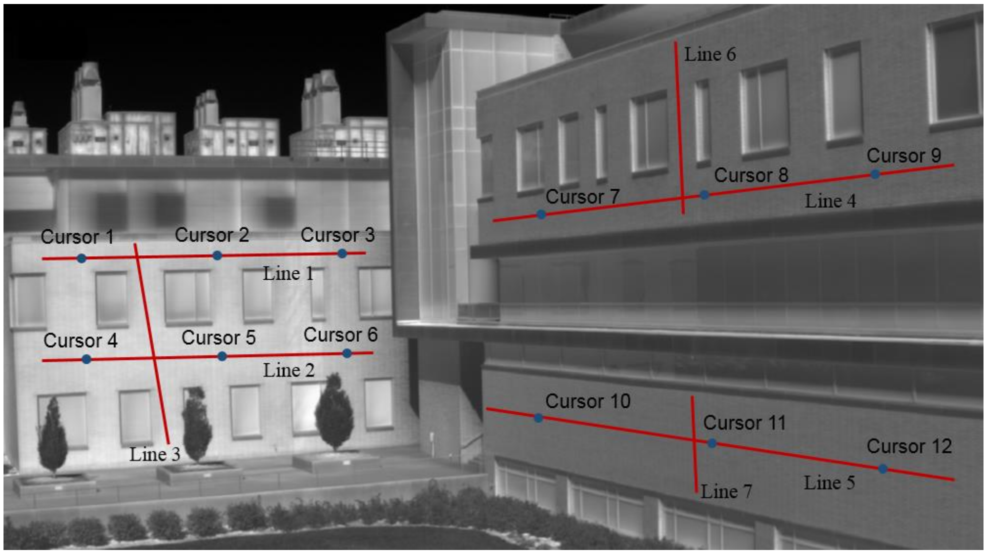


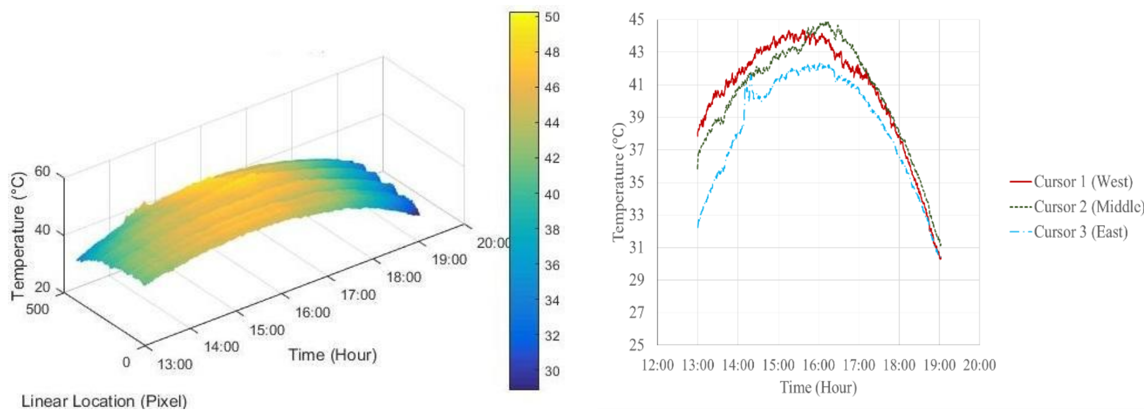
Fig.2 Representative sample lines on the west (right) and south (left) walls

Results and Discussion

Temperature profile on the south wall

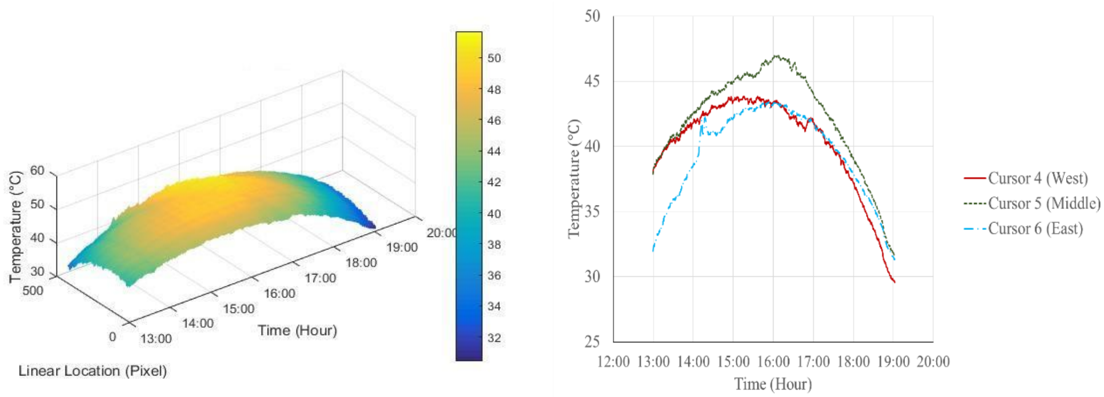
The measured temperature range of the south wall is from 29 ℃ to 47 ℃ on September 30th, 2015. The peak temperature of 47 ℃ of the south wall was observed at about 4 PM. (Fig.3 and Fig.4). Different from the west wall where the temperature distribution is very uniform, the temperatures in the horizontal direction exhibits larger variations on the south wall. Firstly, as a result of the L shape geometry of the test building, the east part of the south wall was shaded by the west wall for a long time during the measurement time, so as shown in Fig.3 (b) and Fig.4 (b) the east points Cursor 3 on Line 1 and Cursor 6 on Line 2 were cooler than other places for roughly one hour. In addition to the horizontal direction, the vertical temperature distribution of sample line on the south wall also shows different pattern from the vertical sample lines on the west wall. As shown in Fig.5, the temperatures on Line 3 were uniform at the beginning of the measurement; then as time went on, the temperatures on the lower part of Line 3 became warmer.

The impact of ground radiation is quite obvious in this case, especially in the noon time. One reason is that the ground area near Line 3 was always under the direct sunlight, so the ground is heated due to the solar radiation; the other reason is that the lower part of Line 3 is much closer to the ground than Line 6 and Line 7 on the west wall where the lower part of the wall are windows. Although different wind velocity at different height could also play a role in some cases, in the studied case we can almost rule out the wind velocity influence due to two reasons: 1) the vertical wall profile (along line 3) did not demonstrate much variations before the peaks (see Fig. 5); 2) Line 6 and 7, which extended across a greater height did not show much variations (if different wind velocities play a big role Line 6 & 7 profiles should show some variations instead of almost identical. For the same reason, Line 4&5 profiles are almost identical even they are at different heights).



(a) (b)

Fig.3 Variation of temperature on Line 1 (south wall upper horizontal line) with location and time (a) 3D view (b) temperature profile of cursor 1, 2, and 3 on Line 1



(a) (b)

Fig.4 Variation of temperature on Line 2 (south wall lower horizontal line) with location and time (a) 3D view (b) temperature profile of cursor 4, 5, and 6 on Line 2

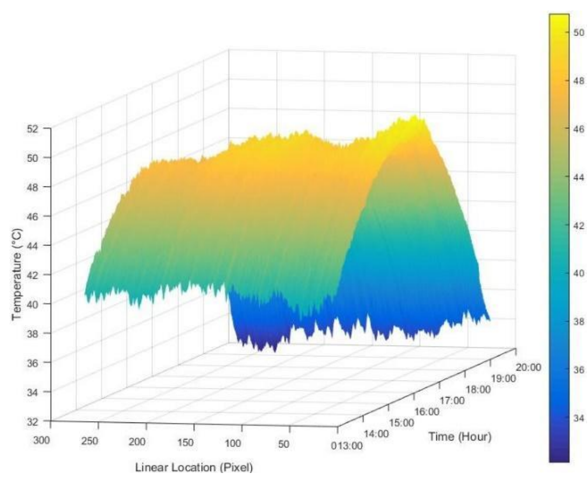
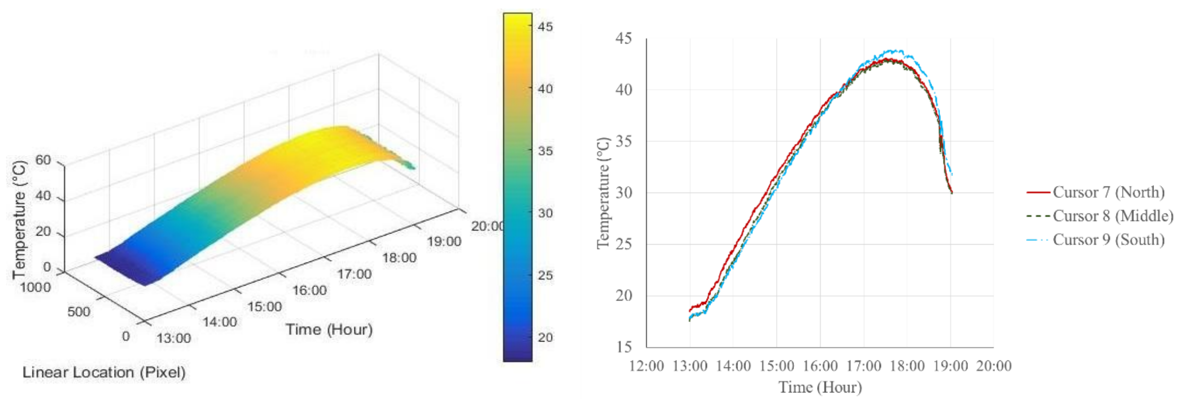


Fig.5 Variation of temperature with location and time on Line 3 (south wall vertical line)

Temperature profile on the west wall

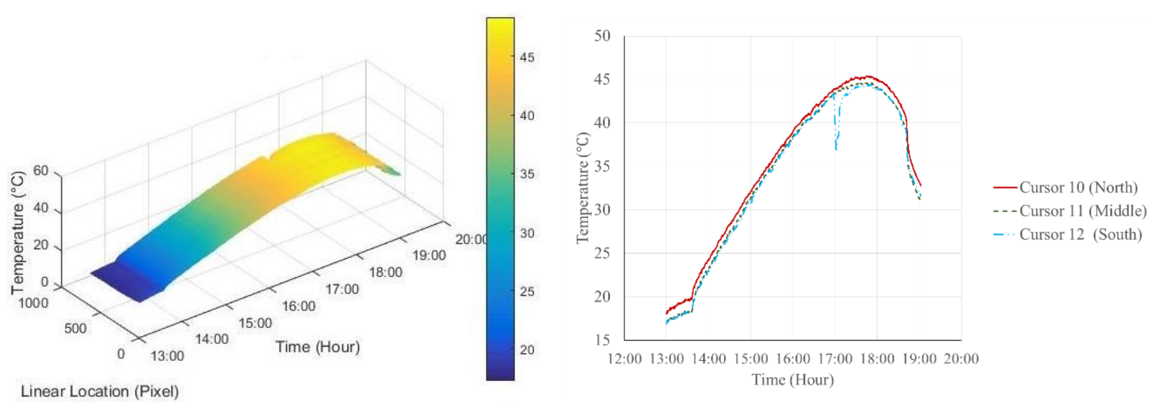
Line 4 and Line 5 are two parallel sample lines on the upper and lower west wall respectively. As shown in Fig.6, the temperature of Cursor 7 (North), Cursor 8 (Middle) and Cursor 9 (South) of Line 4 were almost the same during the observation period, which indicates that the variation of the location on the north-south direction of the line did not have a great impact on the temperature distribution. However, the temperature of the line varied with time change. The temperature range during the observation period is between 16 ℃ and 44 ℃. Generally, the temperature on Line 4 is relative low at the start time 1:00 PM when the whole west wall is shaded. With the change of sun angle, the sunlight gradually fell directly on the west wall, then the temperature on Line 4 reached its peak value at about 5:30 PM. This indicates that more cooling load might be required for the rooms adjacent to the west wall around this time. The same trend could be found for the lower horizontal line on the west wall Line 5 (Fig.7). One small difference between two temperature profiles is that the temperature of Cursor 12 (South) on Line 5 has a small fluctuation around 5 PM due to the shading of the street lamp on the west side of the building (not in view).

Except for that, the overall temperature of Line 5 is almost the same as Line 4, which means the impact of vertical location on the temperature distribution is ignorable on the west wall. This also can be observed from the temperature profile of the vertical lines (Fig.8). One reason is that in fall the effects of ground radiation on the vertical temperature distribution is not very significant. The other reason is that all the sample lines on the west wall are above a certain height due to the fact that the lower part on this wall are windows. The impact of the ground heat decreases as the wall height increases.



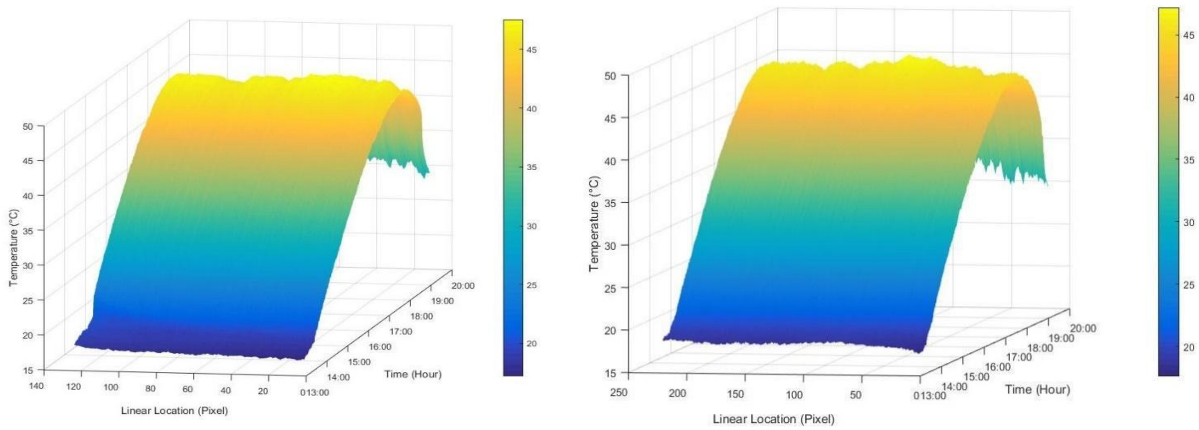
(a) (b)

Fig.6 Variation of temperature on Line 4 (west wall upper horizontal line) with location and time (a) 3D view (b) temperature profile of cursor 7, 8, and 9 on Line 4



(a) (b)

Fig.7 Variation of temperature on Line 5 (west wall lower horizontal line) with location and time (a) 3D view (b) temperature profile of cursor 10, 11, and 12 on Line 5



(a) (b)

Fig.8 Variation of temperature with vertical location and time (a) Line 6 (west wall upper vertical line) (b) Line 7 (west wall lower vertical line)

The Timing of Peak Wall Temperature, Ambient Temperature and Solar Intensity

In order to find out the timing of peak temperatures on the south and west walls in relative to peak ambient temperature and peak solar intensity, Line 1 and Line 4 with similar heights were chosen to represent the average temperature of the two walls. Due to the limitation of the wall configurations, the two sample lines on south and west walls are not at the same height. But since the vertical temperature distribution on the west wall is relatively uniform, the small height difference for Line 1 and Line 4 could be neglected.

As shown in Fig.9, the peak temperature 43 ^{o}C of the south wall appears at around 4 PM, while the ambient temperature reached its peak 20 ^{o}C between 2 PM and 6 PM. West wall, on the other hand, reached its peak temperature at around 6 PM, which is 2 hours after the south wall's peak time. Then both south and west wall temperatures lines joined together at around 7 PM, which indicated the west wall cooled down faster than the south wall due to the disappearing of solar radiation. On that particular day the peak times of both south and west walls were within the peak duration of the ambient temperature.

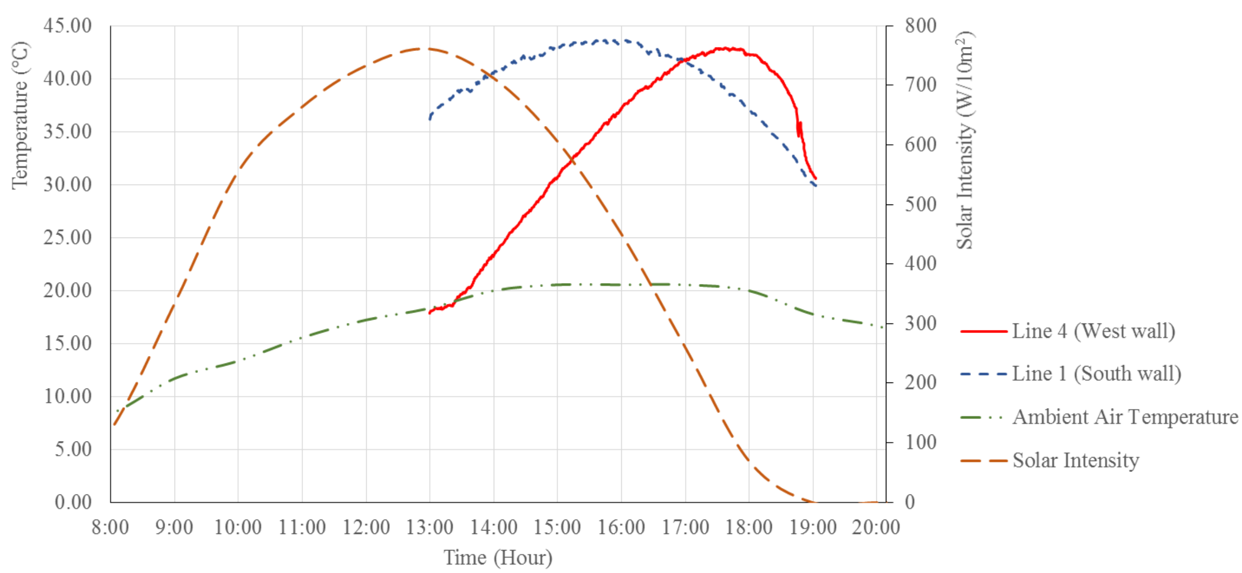


Fig.9 Timing of Different Peak Temperatures and Peak Solar Intensity

Summary

In this case study, we investigated brick cavity wall temperature changes associated with ambient temperature, solar intensity on south and west sides of the building using continuous thermal imaging. We compared the measured wall temperature profile side by side with the ambient temperature profiles and solar intensity profiles of that day. The side by side comparison with detailed temporal-spatial wall surface temperature profiles allows us to discuss how wall surface temperatures changes at different locations during a long time span as necessary. The investigation provided answers regarding the timing of the peak temperatures on south and west walls in relate to the peak ambient temperature and peak solar intensity. As we understand that the timing will change from season to season, and from place to place. This study just shows that the thermal imaging can be very useful in providing us with needed data for further quantitative studies on energy efficient buildings and green technology. In this pilot case study we just presented one day data. Multi-season continuous wall temperature data is needed in future study to draw some more helpful conclusions. Nevertheless, in this case study we presented a solid starting point into more meaningful scientific quantitative study of green buildings.

The major limitation of this case study is its single day data on a particular brick wall veneer type. Also we did not monitored wind velocity and the moisture contents of the environment. These limitations prevent us to further extrapolate the result to more general cases.

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