

Thermographic Study on Thermal Performance of Rural Houses in Southwest China

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ABSTRACT

The thermal performance assessments of rural houses are often inaccurate by thermal calculation or simulation due to complicated micro climates of rural settlements and the informal processes of selfbuilt structures. Infrared (IR) thermography is an effective and efficient tool to evaluate building and material performance. This study aims to show the possibilities of using IR imaging to better understand the thermal process of rural houses. Several typical rural houses with different kinds of building envelopes in the Southwest of China were selected. A series of thermographs were taken under various circumstances, including different seasons, time periods and weather conditions. Continuous outdoor and indoor air temperature measurements were conducted simultaneously. The results show that the correlationship between envelope surface temperature distributions and air temperature variations of adjoining rooms, as well as the heat gaining and losing processes of different building envelopes.

INTRODUCTION

The study on the thermal environment of rural houses is of great significance. On the one hand the rural structures are often well-acclimated with low energy consumption. On the other hand they may still need improvements to meet higher thermal comfort requirements. However, the thermal performance assessments of rural houses by using regular thermal calculation or simulation tools are often inaccurate. Because the microclimates of rural settlements are often complicated and the informal processes of these self-built structures cannot ensure the fully use of material properties. Furthermore, most rural houses are free running which means natural ventilation is enhanced. Especially in the southwest of China, the locals like having doors and windows open all day long even during the cold winter due to their living habits. Therefore, the simulation results which based on an enclosed-space model and laboratory parameters have low reliability.

Infrared (IR) thermography is an efficient tool to obtain the superficial temperature distribution of the inspected object. It has a broad range of applicability and has been applied to buildings for a couple of decades [1]. IR inspections of building envelopes can be used to detect heat losses, insulation defect, thermal bridges, air leakage and moisture sources, HVAC and electrical installations can also be

inspected [2]. It's a very cost effective tool for building diagnostic and retrofit. In addition, this technique can visualize the dynamic heat transfer process through the envelope.

This study aims to show the potential use of IR imaging to better understand the thermal process of rural houses. A four-year field study was undertaken in Wulong County (Chongqing Province) since 2011. A number of research results have been published [4-7]. It is part of Hot Summer and Cold Winter (HSCW) climate zone of China. The outdoor temperature can reach 40°C in summer while it often falls below 0°C in winter, with high humidity all year round. In this study, several typical rural houses with different kinds of building envelopes were selected. A series of thermographs were taken under various circumstances, including different seasons, time periods and weather conditions. Continuous outdoor and indoor air temperature measurements were conducted simultaneously. The results show that the correlationship between envelope surface temperature distributions and air temperature variations of adjoining rooms, as well as the heat gaining and losing processes of different building envelopes.

THE ASSESSED BUILDINGS

The five representative rural houses we chose to take thermographs include two modern ones (built after 1990s) and three traditional ones (built before 1980s), as shown in Figure 1. House (a) and house (b) are three-storey reinforced concrete frame structures, infilled with 390mm x 390mm x190mm cement bricks. The exterior walls are 400mm thick approximately, covered with glaze ceramic tiles. The exterior windows are single-glazed aluminum alloy windows. The ground floors used as garage or store enclosed with metal shutter doors. House (c) was two-storey stone structure built in the 1950s, as the dormitory for slaughterhouse workers. The exterior walls are 500mm-600mm thick with lime plaster layers. The exterior windows and doors are single-glazed framed with wood. House (d) and house (e) are timberwork houses represent the most common vernacular architectural styles in the Southwest China. The exterior windows and doors are same as house (c). The exterior walls are 20-30mm thick wooden boards. House (d) was built in the1930s and house (e) was built in 1961. Some alterations have been made for house (e) and the exterior walls are partly replaced by exposed cement bricks. None of these exterior walls or roofs has thermal insulation layers.



Figure 1 Five typical rural houses of different envelopes (a) and (b) Cement brick with ceramic tiles; (c)Stone; (d) Wood; (e) Partly wood and partly cement brick

METHODS

Four field surveys were conducted on August 26th~27th (2011), April 13th~15th (2012), January 26th~27th (2013) and February 16th~20th (2014), respectively. Both thermographic images and visual images were taken every two hours from 8:00 to 20:00. The indoor and outdoor air temperatures were recorded every 30 minutes. To increase comparability of results, the indoor temperatures have been measured in rooms on the second floor and adjacent to the objective façades. The infrared thermographic camera used in this research is VarioCAM HR Inspect. The information of the instruments is **shown in Figure 2 and Table 1** in details. Thermography is a very cost effective tool, and several methods were applied to prevent inaccuracies.

1. To mitigate the effect of incident solar radiation, we chose the façades facing north or northwest.

2. Parameters that could impact the accuracy of the measurement like material emissivity, ambient temperature and distance from the target are also considered and corrected using software.

3. For building diagnostic, the measurements should performed before sunrise or after sunset to minimize the effect of incident solar radiation. In this case we chose late evening

Table 1. Detailed Information of the Instruments							
Physical quantity	Instrument	Range	Accuracy				
Surface temperature	VarioCAM HR Inspect	7.5µm~14µm	0.05°C				
Air temperature	WSZY-1	-40°C ~100°C	0.1°C				



Figure 2 The instruments for measurements. (a) is infrared thermographic camera and (b) is hygrothermograph meter

RESULTS

Diurnal variation of different envelopes

The inspection of exterior surface temperature can illustrate heat gaining and loosing process from dawn to sunset. After sunrise, the external building surfaces start to absorb solar radiation and surface temperature will increase. When environment temperature fall below external surfaces temperature, especially after sunset, heat will dissipated by radiation and the surface temperature will decrease. As the consequence of this heat exchanging process, the indoor air temperature fluctuates along with it. This process can be impacted by material, colour, weather condition and etc.



Figure 3 Thermographs taken on February 16th (cloudy day) and 20th (sunny day), 2014. (a) is wooden board wall; (b) is stone wall with lime plaster; (c) are cement brick walls with glaze ceramic tiles (in the middle) and cement plaster (on the left).



Figure 4 Average surface temperatures of different building envelopes

Figure 3 shows a series of thermographs illustrating thermal processes of four different building envelopes in winter affected by the parameters mentioned above. During the period of the measurements, the sunrise time is 7:20 am and sunset time is 6:40 pm. The outdoor air temperatures range from -2.3°C to 2.0°C on cloudy day and -2.1°C to 5.2°C on sunny day. The average outdoor air temperatures are 0.02°C and 1.17°C respectively. The average surface temperatures of different building envelopes were measured through these thermographs, **as shown in Figure 4**. It's important to note that

only opaque surfaces were taken into account for calculating the average temperature. That's because it is hard to obtain accurate temperature of glazing unit due to the influence of reflection. Besides, the glaze ceramic tiles can also reflect sky and buildings around it which may lead to errors on the thermographs. Figure 4 can give us a direct impression that there are great differences in the average exterior surface temperature between different envelopes on sunny day, but little differences on cloudy day. On cloudy day, wooden envelope has the highest average surface temperature of -0.9°C, with the maximum value of 1.24°C. While on sunny day, the temperature of cement brick wall with mortar plastering is the highest, the average value is 1.36°C and the maximum value is 5.21°C. In contrast, the surface temperature of cement brick wall with glaze ceramic tiles is the lowest on both cloudy and sunny days because its light-colored and polished surface has high reflectivity. The average values are -1.02°C and -1.4°C respectively. The surface temperature of wooden and mortar plastering envelopes fluctuate strongly, with the values of 2.93°C and 3.63°C on cloudy day and 10.14°C and 9.14°C on sunny day, respectively. The amplitude of temperature fluctuation of the stone wall is the smallest due to large thermal mass and thermal resistance. On cloudy day, the highest exterior surface temperature is reached around 2:00 pm, while it peaks at 6:00 pm on sunny day except for tiled brick walls. The accumulation of solar radiation is one reason for the difference. Another significant factor is the northwest orientation led the envelope to a western exposure before sunset.

Figure 5 to Figure7 shows the comparison of exterior surface temperature and outdoor/indoor air temperatures of these buildings. It is obvious that the fluctuation of exterior surface temperature is consistent with the outdoor air temperature. No heating equipment has been adopted in the rooms we measured which are adjacent to the envelopes. The interior air temperatures of these rooms are more stable and relatively low. The building with wooden envelope has the lowest temperature but has the highest amplitude of temperature fluctuation valued at 2.3°C. The average temperature is 0.42°C on cloudy day. While on sunny day, the average temperature is even lower (0.28°C). Despite the average temperature of exterior surface is higher than others, the distribution of temperature is uneven. The upper part of the wooden façade adjoining the testing room is shaded by eaves thus has a relatively low temperature. The average interior temperature of building with tiled cement brick walls is the highest (valued at 2.01°C on cloudy day and 2.22°C on sunny day). Even so, the interior air temperatures are far below the thermal comfort range of local residents. According to previous study, the 90% acceptable range in winter is 6.85-13.60°C in operative temperature [5].

From that mentioned above, we can see that the exterior surface temperature is mainly determined by the colour and smoothness of the outermost layer of wall. The light-coloured and smooth surface has a relatively low temperature (as lime plaster and glaze ceramic tile). On the contrary, the temperature of dark and rough surface is higher (as wood and cement plaster). As a consequence, for a higher surface temperature in winter, one should use a dark and rough outer layer for the wall. While in summer, a light and smooth surface is better to avoid overheating. One other thing to note is that the differences between different envelopes is greater on sunny days, but on cloudy days the differences are not distinctive. In consideration of that in this area, most of the days in winter are cloudy, a light-coloured and smooth wall surface is a balanced choice.

Because the influence factors of interior air temperature are more complicated, the relationship between exterior surface temperature and interior air temperature is uncertain. The building with wooden board wall has the lowest indoor temperature while its surface temperature is relatively high. Whereas the glaze ceramic tiles has the lowest surface temperature but the indoor temperature is higher than the others.



Figure 5 Surface temperature distribution and indoor/outdoor air temperature of building with wooden walls



Figure 6 Surface temperature distribution and indoor/outdoor air temperature of building with stone walls



Figure 7 *Surface temperature distribution and indoor/outdoor air temperature of building with tiled cement brick walls*

Seasonal variation of different envelopes

The seasonal variation is distinctive, **as shown in Table 2 and Figure8**. The differences between different envelopes are more significant at higher temperatures. In February, the average exterior surface temperature of wooden façade is 0.66°C higher than that of stone wall. In April, the average exterior surface temperature of wooden façade is still the highest, valued at 13.96°C. While the stone façade and the brick façade have the similar temperature valued at 12.99°C and 12.97°C respectively. The temperature gradient is approximately 1°C. In August, the temperature gradient reaches 5.13°C. Wood façade still gets the highest temperature of 27.45°C. And the temperature spans are wider in summer than the other two seasons.

Table 2. Thermographic Records of Different Seasons (10:00 am)							
°C	Avg	Min	Max	Span	SDev		
WINTER (19th February, 2014)							
Wood	-0.23	-1.13	1.81	2.94	0.34		
Stone	-0.89	-1.87	0.94	2.81	0.35		
Tiled Brick	-0.87	-2.24	0.49	2.73	0.74		
SPRING(15th April, 2013)							
Wood	13.96	12.75	14.51	1.75	0.31		
Stone	12.99	12.54	13.75	1.20	0.18		
Tiled Brick	12.97	12.56	13.62	1.07	0.15		
SUMMER(27th August, 2011)							
Wood	27.45	24.17	30.94	6.77	1.86		
Stone	25.34	23.45	27.33	3.88	0.83		
Tiled Brick	22.32	18.81	25.77	6.95	2.44		



Figure 8 Seasonal differences. (a) is the building with wooden walls; (b) is the building with stone walls; (c) is the building with tiled cement brick walls

Building diagnostics

The most common use of IR thermography is for building diagnostics. It can be used to identify air leakage through openings, heat losing areas and moisture problems. To minimize the effect of incident solar radiation, the measurements for detecting building defects were performed at late evening (at 8:00 pm, on February 20th, 2014), **as shown in Figure 9**. Thermographs (a) and (b) show windows or a door frame viewed from exterior. The "red lines" along the top of the openings show the locations for hot air exfiltration. Thermograph (b) also indicates the possible water damages at the foot of the stone wall. The surface temperature is higher in this area, since the heat is conducted through wet mass more rapidly from interior. The red part of the façade in thermograph (c) is exposed cement brick wall with no insulation. (d) is the thermograph of a reinforced concrete building. The brighter parts under the eave and balconies are exposed concrete slab. There's no obvious air leakage around the openings, which may explain the fact that the indoor air temperature is higher than timberwork and stone houses even if the heat gains through the building envelopes are less. These resluts suggest that to improve building performance in this area, some measures should be adopted. Fill up the wall cracks and gaps around openings. The building foundation should be dampproof and waterproof. Thermal insulation mortar or polystyrene board can be used for building exterior walls.



Figure 9 Detailed thermographs of building defects (a) shows the second floor window of a timberwork house; (b) shows the window and door of a stone house; (c) shows the exposed cement brick wall of a timberwork house; (d) shows windows and balconies of a reinforced concrete house

CONCLUSIONS

In this study, the infrared thermographic measurements of rural houses were conducted in the Southwest of China from 2011 to 2014. The results show that there are significant daily variation and seasonal variation differences between different building envelopes. The common defects have been revealed with the help of infrared thermography. Following conclusions can be made

1. The exterior surface temperature is mainly determined by the colour and smoothness of the outermost layer of the wall. Light-coloured and smooth surface has a relatively low temperature, while the temperature of dark and rough surface is higher. The differences between different envelopes is greater on sunny days, but on cloudy days the differences are not distinctive. In consideration of that most of the days in winter are cloudy, a light-coloured and smooth wall surface is a balanced choice for this area.

2. The fluctuation of exterior surface temperature is consistent with the outdoor air temperature. On the contrary, the correlationship between exterior surface temperature and indoor air temperature is not obvious. The indoor temperature is also related to the envelope structure, thickness of wall, type of openings and other factors.

3. The seasonal variation is distinctive. And the differences of surface temperature distribution

between different envelopes are more significant at higher temperatures. The temperature spans more widely in summer than the other seasons.

4. To improve building performance in this area, some measures should be adopted. Fill up the wall cracks and gaps around openings. The building foundation should be dampproof and waterproof. Thermal insulation mortar or polystyrene board can be used for building exterior walls.

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