Shading Effect and Heat Reflection Performance of Green Façade in Hot Humid Climate Area: Measurements of a Residential Project in Guangzhou, China

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Abstract. In response to the problem of high-density urbanism and urban heat island (UHI), vertical greenery system (VGS) applying in building design and construction is regarded as one of the solutions. Green Façade (GF), with the climber plants growing on the building façade, is one branch technology of VGS. This research is focused on the shading effect and the heat reflection performance of the GF in Hot humid Climate Area. A high-rise residential project with the GFs on east and south façade is chosen to measure and analyze. Results reveal that the air Ave. temperature (Temp) shading by the GFs in sunny days is reduced by $0.6°C$(E) and $0.7°C$(S), and the Max. reduction is up to $3.2°C$(E) and $3.8°C$(S). The surface Ave. Temp of GF is reduced $4.7°C$ comparing to the bare wall, and the Ave. Temp of the whole façade is decreased about $3-4°C$ with GFs. This research has proved the effects of GFs and also show the GFs' potentials for energy reduction and urban heat environment improvement.

1. Introduction

High-density urbanism is one of the trends in the fast-developing countries and areas. The spread of the cities reduces a large amount of the green land, which is important for the air cleaning[1], rainwater collecting[2] and UHI reducing[3]. As a response to this trend, VGS applying in building design and construction is more and more regarded as one of the technologies of the UHI reducing[4][5]. Recent researchers have also pointed out that the VGSs have good effects on building thermal environment improvement[6], energy saving[7], urban acoustic reducing[8] and urban biodiversity[9].

VGS could be divided into two typologies as living wall system (LWS) and green facade (GF) [10] [Figure 1]. The LWS is a complex technology which includes the construction system on the existing wall, the waterproof layer, the module plant and soil containers or plant substrate, the irrigation and drainage system and the water control machine. Various small shrubs could be used in the LWS in order to shape different patterns. The GF is much simpler technology supporting the climber plants to grow on the building façade, which normally includes the support structure, the plant and soil container, the irrigation system and the drainage system[11]. Compare to the LWS, the GF is less paid attention to because of the weaker thermal insulation effect and lower influence to the environmental

Temp [12]. In fact, the GF has a much longer history in application, especially growing on the walls or fences in a natural situation[11]. As the performance of shading devices (SDs), more and more buildings with GF are built up and concentrated by researchers lately[13]. With the lower cost of construction and maintenance, the GF still has the potential in the application area[14].

Figure 1. Cases of the LWS and GF (a, b. Detail and façade of LWS; c, d. Detail and façade of GF; e. Thermal image showing that the Temp of the SDs is higher than the GF)

This research is focused on the shading effect and the heat reflection performance of the GF in Hot humid climate area through measurements in situ. Measurements of the LWS and the GF have been tested by several researchers, including tests with experimental walls, contrasting rooms and building facades [15-17]. However, the results are various because of the influences of several factors such as differences of the façade construction, the building height and orientation, plant typologies, the growth situation of plants and so on. Thus, in order to evaluate the effects of GF in application for a typical climate area, the measurements in situ are still necessary. This research takes the measurements in Guangzhou, China. Guangzhou lies in southern China (23°08′N, 113°16′E), whose Ave. max Temp is 33.3 ℃ and Ave. relative humidity(RH) is 82% in summer [18] [Figure 2]. It also belongs to the humid subtropical climate according to the Köppen climate classification [19].

In Guangzhou, SDs are widely used in order to reduce the solar radiation on the building façade [Figure 1, d-e]. Various of SDs, which are installed on the edge of the openings, balconies, and windows on the buildings, offer efficient effects of the surface Temp reduction. However, with the physical characteristics of the SDs materials such as aluminium, the heat reflection of which still could affect the Temp of the surrounding environment. Contrast with this, the GF could change the hydrothermal performance of the surrounding area as the results of the evapotranspiration of plants, reducing the heat reflection to the building facade and the environment [20]. Thus, the GF is much friendlier to the building environment and could be even considered as one of methods to optimize the function and performance of the SDs. In this research, the effects of the GF could be tested and analysed through the measurements in situ.
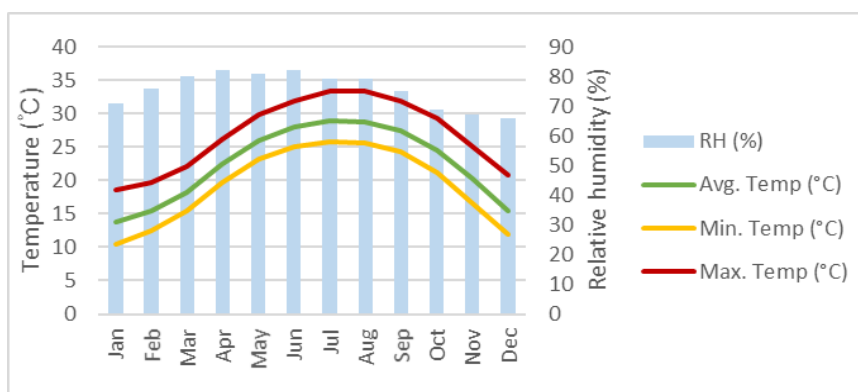

Figure 2. Climate data of Guangzhou, China (1986-2015) [18]

2.Research methodology

2.1. Object of the measurement

This research selected a high-rise residential project (Ave. height of 54m) in Guangzhou, China. With the architectural concept of vertical gardens, the project is designed with serials of public balconies, planting with shrubs and trees. Besides, climber plants are designed to cover the bare walls of the building façade. In the investigation before the measurement, the climber plants on the east and south façade facing to the external environment grew better than which were shaded by the buildings. Thus, three external GFs were chosen to measure, two of them face to the east (A&B) and one faces to the south (C) [Figure 3].

The construction of the GFs is the additional component of the building. Vertical and horizontal aluminium pipes (Φ=20mm, horizontal distance=200mm, distance to the bare wall=800mm) are set to support and guide the plants to grow up. Soil containers are designed to 800mm width and 800mm depth, setting at every 2 floors. Irrigation systems are set to auto control, providing water twice per day. Water store tanks are set on the roof of the buildings, connecting to the water supply system of the buildings. Climber plants are combined with Qiusqualis indicia and Lonicera japonica. The project is finished in 2013, thus the plants on the GFs have grown for 4 years till 2017.
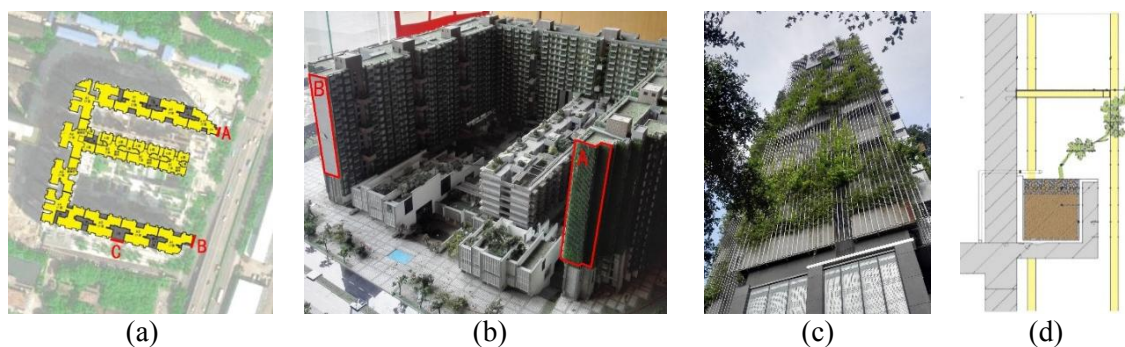

| (a) | (b) | (c) | (d) |

Figure 3. Project photos (a. Site-plan with the test GF A, B and C; b. Model of the project; c. Photo of the GF B; d. Construction detail of the GF)

2.2. Tools and methods of the measurement

In order to evaluate the shading effect of GFs and the influences on the environment, the measurement is divided into two parts. One is about the air Temp and RH behind the shading area of the GF, one is about the surface Temp change of the building façade.

For the measurement A, two HOBO loggers [Table 1] were set unmovable behind the GF with the distance of 400mm to the GF, one on the east façade and the other one on the south facade. The measure points were chosen at the places fully shading by leaves and whose foliage layers thicknesses were over 200mm. Besides, one logger was set on the roof of the building as a contrast point of the external environment. During the measurement, the HOBO loggers were set in solar radiation shields in order to avoid the interference of the direct solar radiation and rains. The measurement lasted for 6 days (2/08/2017-08/08/2017) with the test frequency of 5min.

For the measurement B, the thermal imagers [Table 1] were invited to record the thermal images of three building facades (GF A and GF B on the east and GF C on the south). The measure points were set in front of the building facades with the distance of 50m. The measurement was lasted for 10h in the daytime (08/08/2017) and the test frequency is 30min. Before the measurement, the environmental Temp and the material emissivity (μ value) were set as default values (Temp=20℃, μ=0.95). After the recording, the thermal images were input to the software FLIR QuickReport to reset the background

parameters (the environmental Temp and RH), which have been recorded on the same day by the HOBO logger. Because the thermal images are composed of pixels of the Temp data, thus they could be counted and analysed in the statics software in further (Figure 4). Besides, the thermal images could be also analysed directly using the data points of the climber plants and the bare wall (Figure 11, a2, b2, c2).

Table 1. Range and Accuracy of the instruments

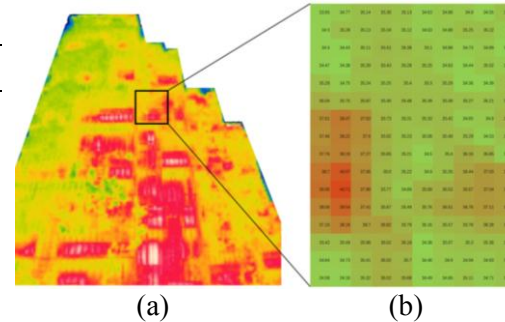| Instrument	Accuracy	Test frequency
HOBO data logger (U23 Pro v2)	Temp: ±0.21 °C (from 0 to 50 °C) RH: ±2.5% (from 10% to 90% RH)	5 min
FLIR B50 thermal imager	Temp: ±2% or 2 °C	30 min

(a)   (b)

Figure 4. Diagram of pixels analysis of the thermal images (a. Thermal image; b. Thermal image data input to the Excel file for value statics)

3.Results and discussion

3.1. Results of measurement A- Shading effect analysis

Firstly, the Temp and RH data recorded by the HOBO loggers were compared to which recorded by an official weather station setting at about 5km away from the test project.

Figure **5** and

Figure **6** show that two data sources had the same variation trend in 6 days of the measurement. Temp of 08/02/2017 to 08/04/2017 is lower because of the continuous rain. The average of the difference of Temp is 0.9℃, with the average error percentage of 3.3%. And the average of the difference of RH is 4.3%, with the average error percentage of 5.5%. The comparison verifies the credibility of the measurement.
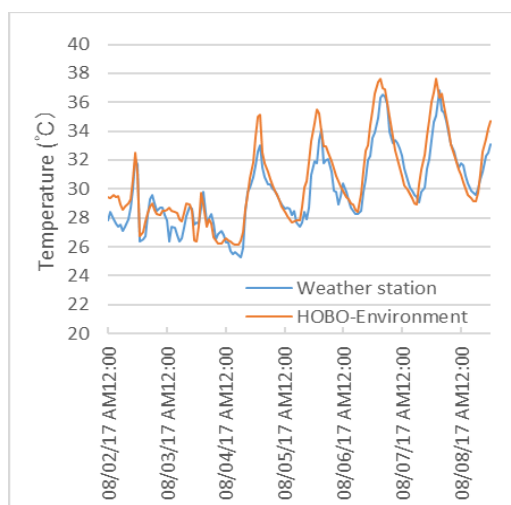

Figure 5. Environmental air Temp data comparison (08/02/2017 AM12:00-08/08/2017 PM04:00)
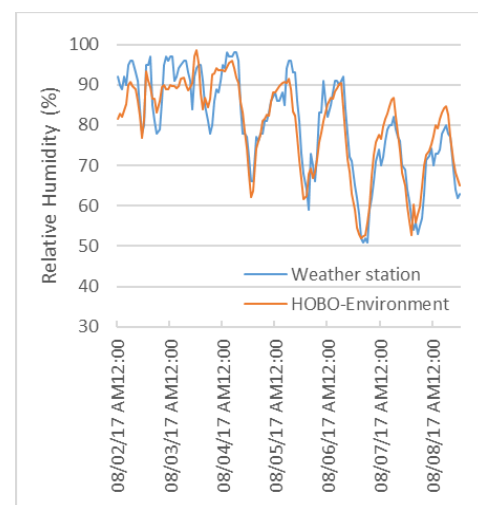
Figure 6. Environmental air RH data comparison (08/02/2017 AM12:00-08/08/2017 PM04:00)

Secondly, the Temp and RH data of three HOBO loggers are compared.
Figure **7** and
Figure **9** show the data variation of the Temp and the RH of the measure days.
Figure **8** and
Figure **10** show the Temp and the RH differences between the outdoor environment and the shading area behind the GFs. The results could be divided into two groups to discuss because of the obvious differences between the rainy days (8/2/2017 to 8/3/2017) and the sunny days (8/4/2017 to 8/8/2017). The extreme values and wave ranges are lower in the rainy days than the sunny days.

From 8/2/2017 to 8/3/2017, the Ave. Temp is 28.3℃(E-east) and 28.0℃(S-south), comparing to the outdoor environment of 28.4℃. And the Ave. RH is 77.3%(E), 88.8%(S) and 88.6%(Environment). Thus, the Ave. difference values between the outdoor environment and the shading area are not so obvious. However,

Figure **8** shows that even in the rainy days, the Temp of the shading area of the east and the south GF are still lower than the outdoor environment about 0-2℃ in most time of the day. From 8/4/2017 to 8/8/2017, the Ave. Temp is 31.0℃(E), 30.9℃(S) and 31.6℃(Environment). And the Ave. RH is 73.5%(E), 76.7%(S) and 75.4%(Environment). Compare to the rainy days, the differences of Ave. Temp in sunny days are clearer with 0.6℃(E) and 0.7℃(S). Table 2 shows that the difference values between the shading area and the environment are about 0-2.5℃ in most time of the day, and the maximum is up to 3.2℃(E) and 3.8℃(S) at noon. However, the differences of the RH are still similar in both the rainy and sunny days, mostly in the range of 0-5%.

Furthermore, analysis of the data of daytime (06:00-18:00) and night time (18:00-06:00) is given in Table 3, revealing that the differences of the Temp are higher in the daytime than in the night time. The Ave. Temp differences are up to 1℃(E) and 1.2℃(S) in the daytime, but only 0.0℃(E) and 0.1℃ (S) in the night time. However, the Ave. RH differences are less obvious, which are only 0.8%(E) and -2.8%(S) in the daytime, while 3.3%(E) and 0.9%(S) in the night time.

Results reveal that as the GF is not a closed system, the air Temp and RH of the shading area and the outdoor environment have the same variant trend. The GFs presented a better shading effect in the daytime in the sunny days. There is nearly no difference of the Temp in the night time. Besides, the difference of RH between the shading area and the outdoor environment is not so obvious as the Temp, whenever in the rainy days or the sunny days. With the contrast of the maximum of the Temp, the shading effect of the GF is presented clearly.

Table 2. Ave. and Max. value of Temp and RH

Date typology	East	South	Environment
Ave. Temp (℃)	30.2	30.0	30.7
Ave. Temp of 8/2/2017-8/3/2017 (℃)	28.3	28.0	28.4
Ave. Temp of 8/4/2017-8/8/2017 (℃)	31.0	30.9	31.6
Max. Temp difference compare to environment (℃)	3.2	3.8	-
Ave. RH (%)	77.3	80.3	79.4
Ave. RH of 8/2/2017-8/3/2017 (%)	86.2	88.8	88.6
Ave. RH of 8/4/2017-8/8/2017 (%)	73.5	76.7	75.4
Max. RH difference compare to environment (%)	6.7	9.9	-

Table 3. Ave. value of Temp and RH (divide into daytime and nighttime)

Date typology	East	South	Environment

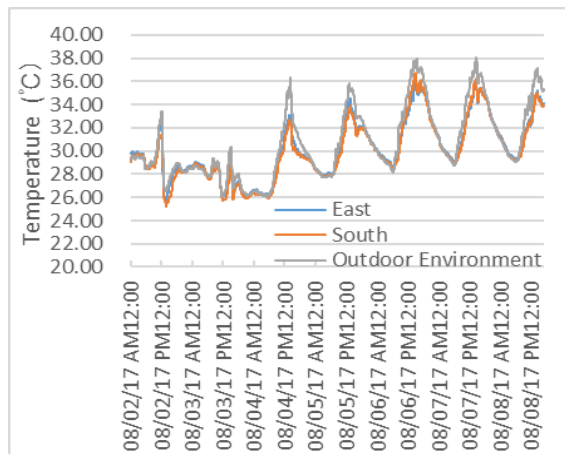|			
Ave. Temp of 06:00-18:00 (℃)	30.9	30.7	31.9
Ave. Temp of 18:00-06:00 (℃)	29.5	29.4	29.5
Ave. RH of 06:00-18:00 (%)	73.8	77.4	74.6
Ave. RH of 18:00-06:00 (%)	80.3	82.7	83.6

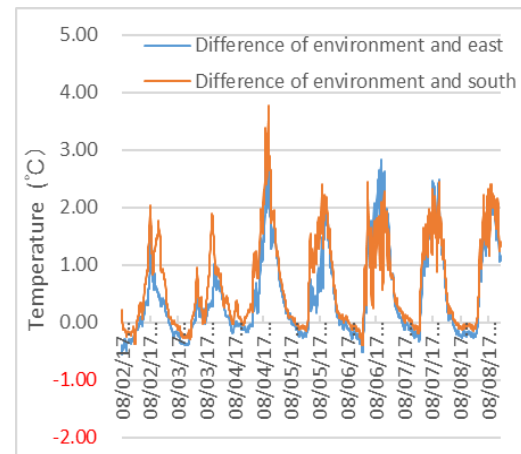**Figure 7.** Air Temp data of three HOBO loggers (08/02/2017 AM12:00-08/08/2017 PM04:00)

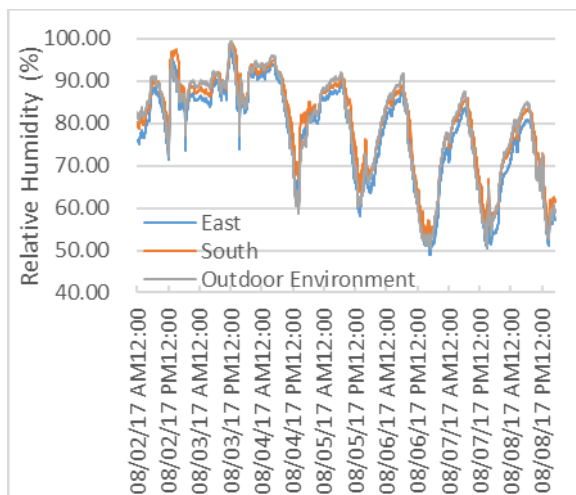**Figure 8.** Differences of the air Temp data of three HOBO loggers (08/02/2017 AM12:00-08/08/2017 PM04:00)

Figure 9. Air RH data of three HOBO loggers (08/02/2017 AM12:00-08/08/2017 PM04:00)
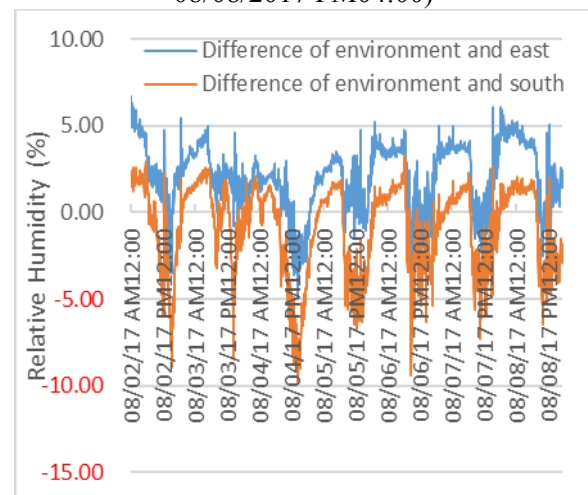

Figure 10. Difference of air RH data of three HOBO loggers (08/02/2017 AM12:00-08/08/2017 PM04:00)

3.2 Results of measurement B- Heat reflection performance analysis
Measurement B is focused on the surface Temp of the GF because the heat reflection of the building surface could influent on the surrounding environment. Two analyses are invited to evaluate the surface Temp, one is the statist of Temp pixels on the thermal image, one is the continuous measurement on the same points of the GF and the bare wall (Figure 11, a1-c1). Lastly, two results could be compared with each other.

On the first analysis, the thermal images should be dealt with to remove the data of the background sky. Firstly, the Temp values (<30℃), which released the Temp of the background but not the building façade, were excluded in the thermal images. Secondly, the values (≥30℃) were calculated with the interval of 1℃.

Figure **12** and

Figure **13** show the percentage variation of different Temp of the whole façade surface, revealing that the largest percentage of the Temp distribution is around 33℃-36℃.

On the other side, the foliage coverage ratio (FCR) of the GFs is calculated through the photo pixel colour filtrating in the software of Adobe Photoshop (Figure 11, d). As a result, the FCR of the GF is 37.5% (GF A), 54.4% (GF B) and 95.4%(GF C, without the bare wall behind). Combine with the distribution ratio of the Temp and FCR, the surface Temp of the GF could be read again in

Figure **12** and

Figure **13** with the value of 34℃-36℃ (GF A) and 33℃-36℃ (GF B).

On the second analysis, the Temp data of three points of the GF and the bare wall of each façade are recorded in the thermal image (Figure 11, a2, b2, c2).

Figure **14** and

Figure **15** show the point Temp variation and reveal that the surface Temp of the GFs is lower than which of the bare walls of 3-7℃. Table 4 presents the results of the Ave. Temp of the GF, the bare wall, and the whole façade. Results show that the surface Temp of the GF is lower than the bare wall, the Ave. difference is 4.6℃ (GF A) and 4.8℃ (GF B). Because the GF C is all covered with climber plants, thus there is no comparison to the bare wall. The Ave. Temp of the façade on GF C is the lowest in three test facades. In general, thanks to the GFs, the surface Temp of the whole façade is decreased about 3-4℃.

Both of two analyses reflect the Temp distribution on the building façade. Via the Ave. Temp comparison, they could be proved to each other at the end. The decreases of the façade Temp were recorded obviously. On the discussion of the micro-climate of the urban environment, the decrease of the surface Temp of the building could also reduce the heat reflection to the surrounding environment and provide a much friendlier public space.
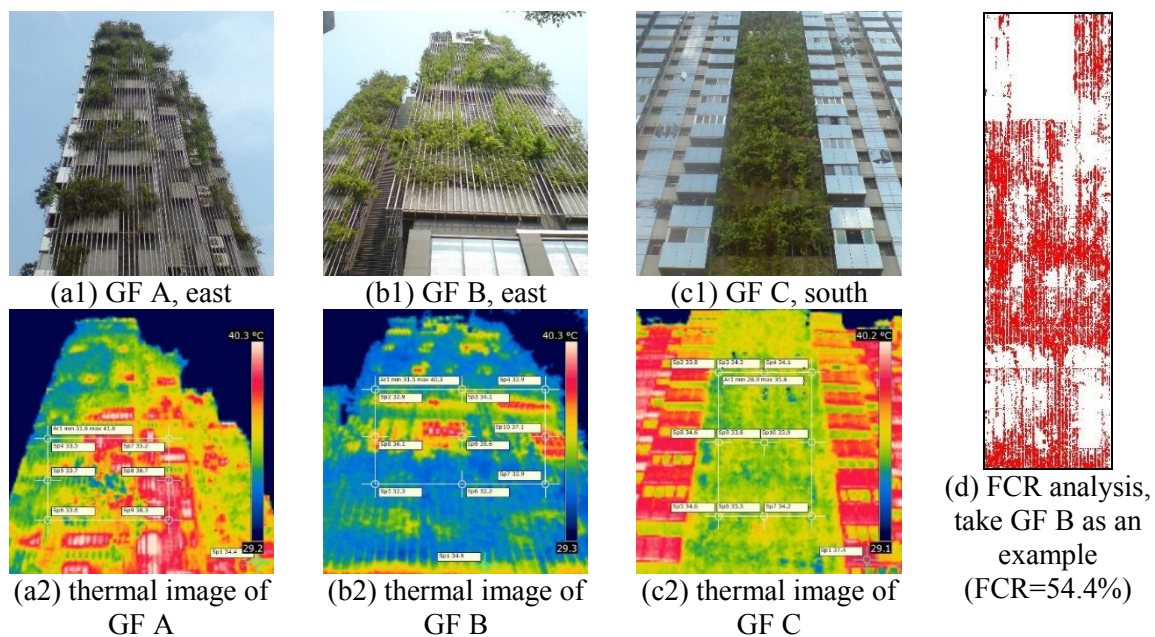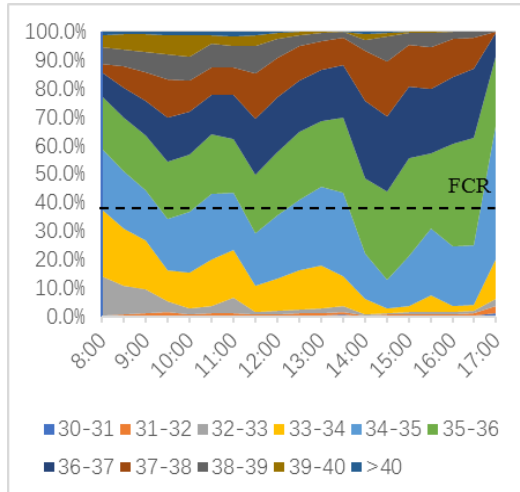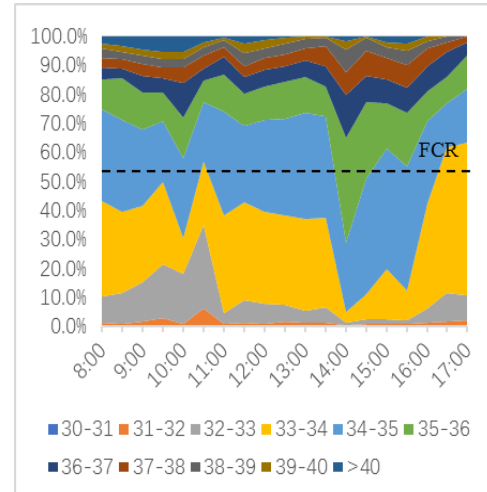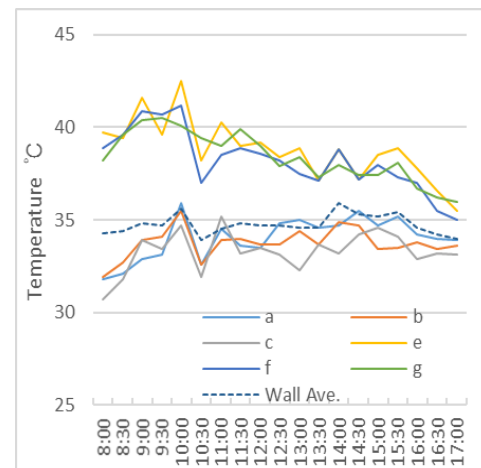

(a1) GF A, east   (b1) GF B, east   (c1) GF C, south

(a2) thermal image of GF A   (b2) thermal image of GF B   (c2) thermal image of GF C   (d) FCR analysis, take GF B as an example (FCR=54.4%)

Figure 11. Photos, thermal images and FCR analysis of the GFs

Table 4. FCR and Ave. surface Temp of the GFs

GFs	GF FCR (%)	GF Ave. Temp (℃)	Bare wall Ave. Temp (℃)	Whole façade Ave. Temp (℃)
GF A	37.5	34.1	38.7	35.8
GF B	54.4	33.7	38.5	34.7
GF C	95.4	33.5	-	33.5

Figure 12. Percentage of pixels of the facade Temp (East façade on GF A, 8/8/2017 8:00-17:00)

Figure 13. Percentage of pixels of the facade Temp (East façade on GF B, 8/8/2017 8:00-17:00)

Figure 14. Surface Temp of GF A (a-c: GF; d-e: the bare wall; Wall Ave.: the whole wall Ave. Temp; 8/8/2017 8:00-17:00)

Figure 15. Surface Temp of GF B (a-c: GF; d-e: the bare wall; Wall Ave.: the whole wall Ave. Temp; 8/8/2017 8:00-17:00)

4.Conclusion

Basing on the measurement in situ of the GFs, the shading effect and the decrease of the heat reflection are proved. The air Ave. Temp shading by the GFs in sunny days is reduced by 0.6℃(E)

and 0.7℃(S), and the Max. reduction is up to 3.2℃(E) and 3.8℃(S) at noon. On the other side, the surface Ave. Temp of the GFs is reduced 4.7℃ comparing to the bare wall, and the whole façade is decreased about 3-4℃ with the GFs, whose FCRs are 37.5-54.4%. Via the complete record of the project information, construction details, plant typologies, FCR, and the hydrothermal data, this research could be a valuable report for the research area of VGS and for GFs application in the hot humid climate area. Further studies will be focused on the GFs' influence on building energy consumption and the urban canyon. As the GF is a dynamic system that the plants are always growing, a continuous tracking of the variation is still necessary in future.

Acknowledgements

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