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Research on the Impact on Building Temperature and Ventilation by Outdoor Shading Devices in Hot-Humid Area: Through Measurement and Simulation on an Office Building in Guangzhou

Hankun Lin, Yiqiang Xiao, Qiaosheng Zhan

***Abstract*—**Shading devices (SDs) are widely used in buildings in the hot-humid climate areas for reducing cooling energy consumption for interior temperature, as the result of reducing the solar radiation directly. Contrasting the surface temperature of materials of SDs to the glass on the building façade could give more analysis for the shading effect. On the other side, SDs are much more used as the independence system on building façade in hot-humid area. This typical construction could have some impacts on building ventilation as well. This paper discusses the outdoor SDs' effects on the building thermal environment and ventilation, through a set of measurements on a 2-floors office building in Guangzhou, China, which install a dynamic aluminum SD-system around the façade on 2[nd]-floor. The measurements recorded the in/outdoor temperature, relative humidity, velocity, and the surface temperature of the aluminum panel and the glaze. After that, a CFD simulation was conducted for deeper discussion of ventilation. In conclusion, this paper reveals the temperature differences on the different material of the façade, and finds that the velocity of indoor environment could be reduced by the outdoor SDs.

***Keywords*—**Outdoor shading devices, hot-humid area, temperature, ventilation, measurement, CFD.

I. Introduction

SDs are widely used in various forms in building design, whose effects of lighting and thermal performance have been analyzed in some studies. Horizontal SDs, such as internal shading [1], venetian blinds [2], external roller shades [3], and overhangs [4] are usually chosen for application because of the benefit of easy vision and sunlight control. Depending on the different requirements of aesthetics, function, and climate character, SDs are also produced with different materials, sizes, and forms.

Double façade (DF) with SDs using in buildings in tropical climate have been studied and they demonstrated acceptable thermal comfort levels covering nearly 70% of the occupied hours, revealing that the SD system is one of the most influential factors of the DF on the thermal performance [5]. In maritime sub-tropical and temperate climates, it was found that external venetian blinds reduce life cycle energy demand by up to 25% [6]. Nedhal and Sharifah compared four shading systems in high-rise residential buildings in the tropics, including base case, vertical shading, horizontal shading and egg crate, and found that egg-crate shading has a significant impact on decreasing discomfort hours compared with other shading types [7].

Compared to the buildings with DF and SDs, many buildings in the tropical or sub-tropical climate area are only constructed with the external SDs to shade the windows. In this study, one office building in Guangzhou was chosen to estimate the SDs' effects of building thermal performance and indoor ventilation.

Guangzhou lies in southern China (23°08′N, 113°16′E), whose average high temperature (Temp) is 32.3 °C and average relative humidity (RH) is 83% in summer [8] (Fig. 1). It belongs to the humid subtropical climate according to the Köppen climate classification [9]). Responding to high temperature in summer, shading on both roof and façade, improving the natural ventilation in a building, are two of the importance strategies in building design, which could reduce the solar radiation, improve the human comfort, and cut down the energy of cooling system [10], [11].

On the methods, this study measured the building climate data at first step, and simulated with computational fluid dynamics (CFD) to take more discussions about the indoor velocity. Numerous studies have been reviewed before in order to underline the importance of simulation modeling for SDs in buildings [12], CFD is also one of the typical methods on analyzing building ventilation and thermal performance.

II. Experimental Investigation

A. Test Office Building Introduction

On the 1st floor, there is a doorway facing north, an atrium hall in the middle, a meeting room on the west and an equipment room on the east. On the 2nd floor, there is an office room on the east, a showroom on the west, and a small garden on the south. The office building is steel structure. Façade system consists of double-glaze glass and aluminum shading panels. On the east façade, there is a living wall (Fig. 4). The building information about the test office is shown in Table I.

On the façade of the 2nd floor, the aluminum SDs were installed horizontally around the building. Besides, the external SDs could be rotated to 90° by the electrical control system. Each of the aluminum shading panels is 250 mm width and 30

Hankun Lin is with the South China University of Technology, C406 Wushan Technological Plaza, Wushan Road, Tianhe District, Guangzhou, 51000China (phone: 86-13535449893; e-mail: hklam@foxmail.com).

Yiqiang Xiaoand Qiaosheng Zhanare with the South China University of Technology, C406 Wushan Technological Plaza, Wushan Road, Tianhe District, Guangzhou, 51000China.

mm thickness, empty inside with the construction of a rotating system. The vertical distance of each panel is 300 mm, and the horizontal distance to the wall is 400 mm. The construction of the building façade and roof is collected on Fig. 7 and Table II.

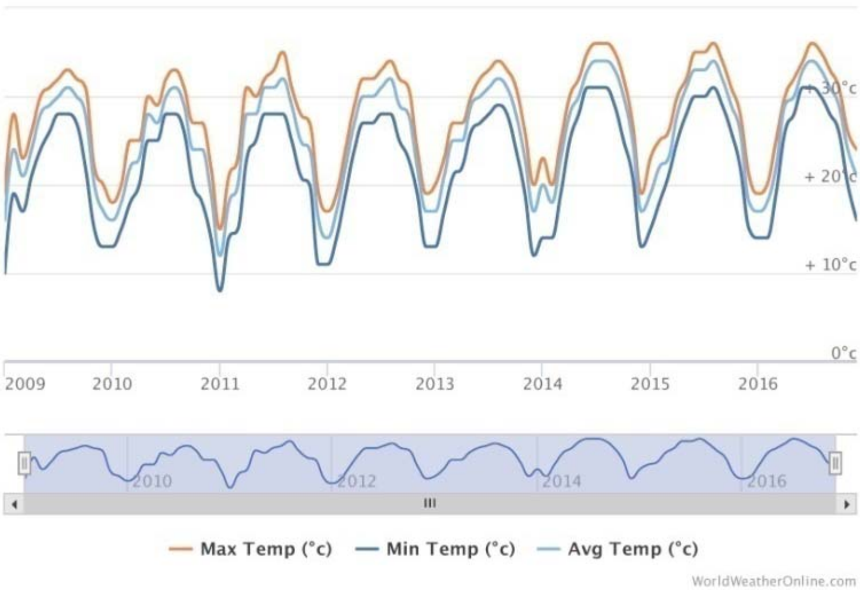


Fig. 1 Max Temp, Min Temp and Avg. Temp of Guangzhou (2009-2017) [13]

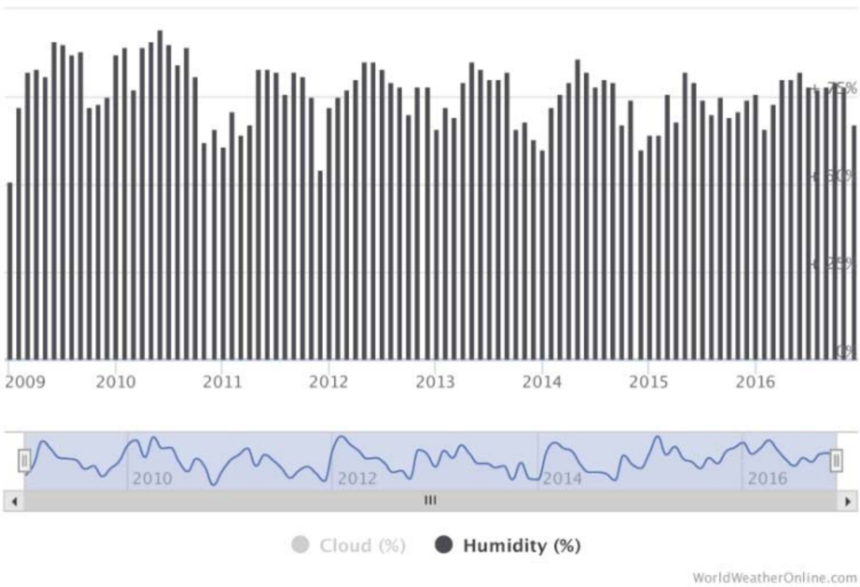


Fig. 2 Avg. Humidity of Guangzhou (2009-2017)[13]

TABLE I
TEST OFFICE BUILDING INFORMATION

Building information	Data
Floor area	732 m^2
Height	7.5 m
1st floor	4 m
2nd floor	3.5 m
Orientation	South

Fig. 3 The entrance of the test office building (north view)

TABLE II
EXTERNAL WALL AND ROOF CONSTRUCTION LAYERS

External wall	12 mm fireproofing plasterboard Moisture paper 12mm plasterboard Lightweight steel structure (With 90 mm rock-wool thermal insulation) 6 mm cement fibrolite board 30 mm rock-wool thermal insulation Waterproof membrane Metal support assemblies 3 mm aluminum board
Roof	100 mm reinforce concrete roof on profiled steel sheet 20 mm cement mortar 40 mm plastic extruding polystyrene warming plate 3 mm polyester reinforcement waterproof coil 30 mm C30 fine aggregate concrete 160 mm ceramist concrete 10 mm mortar 20 mm cement mortar

(a)

(b)

Fig. 4 (a) SDs close on the west façade; (b) SDs open on the west façade

Fig. 5 1st Floor plan

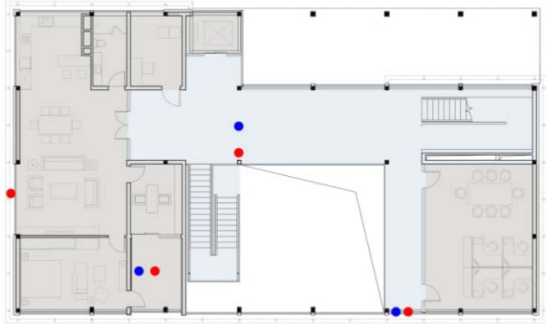


Fig. 6 2nd Floor plan (Red: HOBO data loggers; Blue: HD 32.3 Instrument)

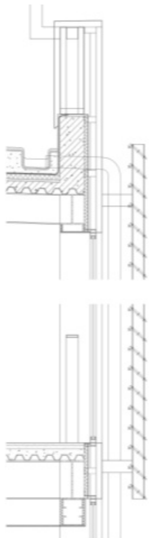


Fig. 7 Section details of the façade with SD on 2nd floor

(a) (b)

Fig. 8 Measurement tools and places (a) HOBO data loggers behind the SD, (b) HD 32.3 Instrument beside the window on 2nd floor

B. Experiment Setup

In order to measure the Temp, RH and wind velocity of the test building, types of tools were used in the experiment (Table III). Five HOBO data loggers were set up, two of them behind the SDs of south and west façade, one in the small garden, one beside the atrium, and one on the roof (see the red dots on Fig.

6). HD 32.3 Instrument was set up at the same places with the HOBO data loggers (see the blue dots on Fig. 6).

The Flir E4 thermal imager was held by hand in order to take the thermal images of different parts of the façade, such as the surface Temp of SDs, double-glaze glass with or without shading, aluminum panels, and the living wall.

The measurement was tested on 19th Sep.2016, on which the average Temp of daytime is still higher than 30 °C. The HVAC of the office building was on at 14:00-15:30. During the measurement, two of windows on southern and western façade of the 2nd floor and the door on northern facade of the 1st floor were opened. The shading panels were kept the angle of 0°.

TABLE III
RANGE AND ACCURACY OF EXPERIMENT TOOLS

Experiment tools	Range	Accuracy	Test frequency
HOBO data logger (U23 Pro v2)	Temp: -40 to 70 °C RH: 0-100% RH;	Temp: ±0.21 °C from 0 to 50 °C RH: ±2.5% from 10% to 90% RH	60 Sec
HD 32.3 Instrument (WBGT-PMV-PPD)	Velocity: 0.1-5 m/s; Temp: -5 to 50 °C RH: 0-90% RH	Velocity: ±0.2 m/s Temp: 1/3 DIN RH: 1/3 DIN	60 Sec
Flir E4 thermal imager	Temp: -20 to 250 °C	Temp: ±2% or 2 °C	60 Min

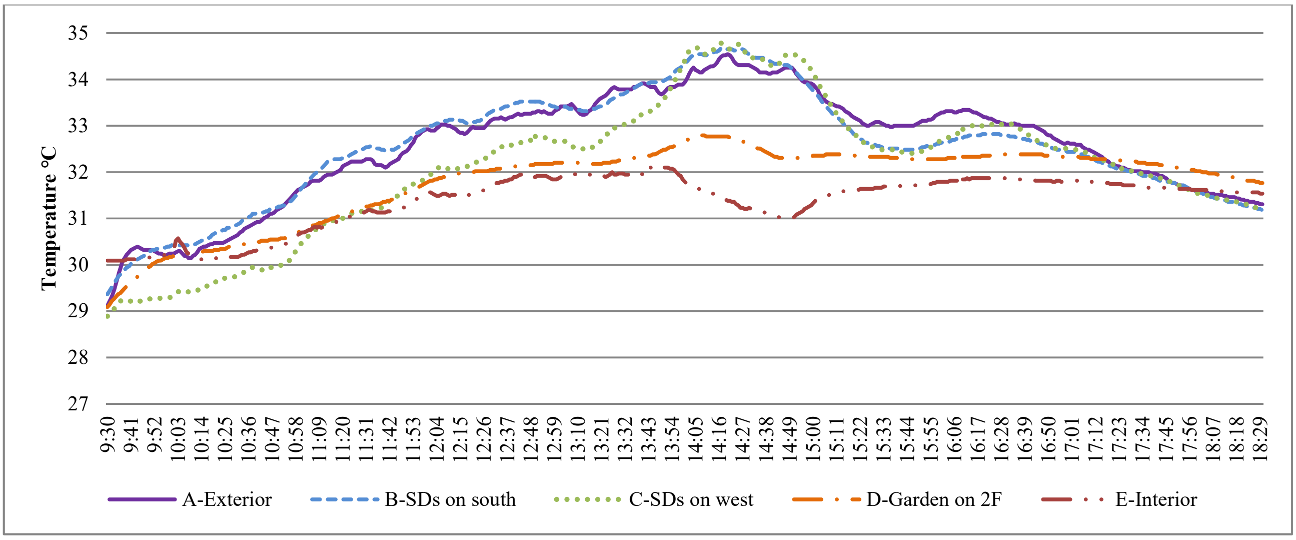


Fig. 1 Temp data (9:30-18:30, 19th Sep.2016)

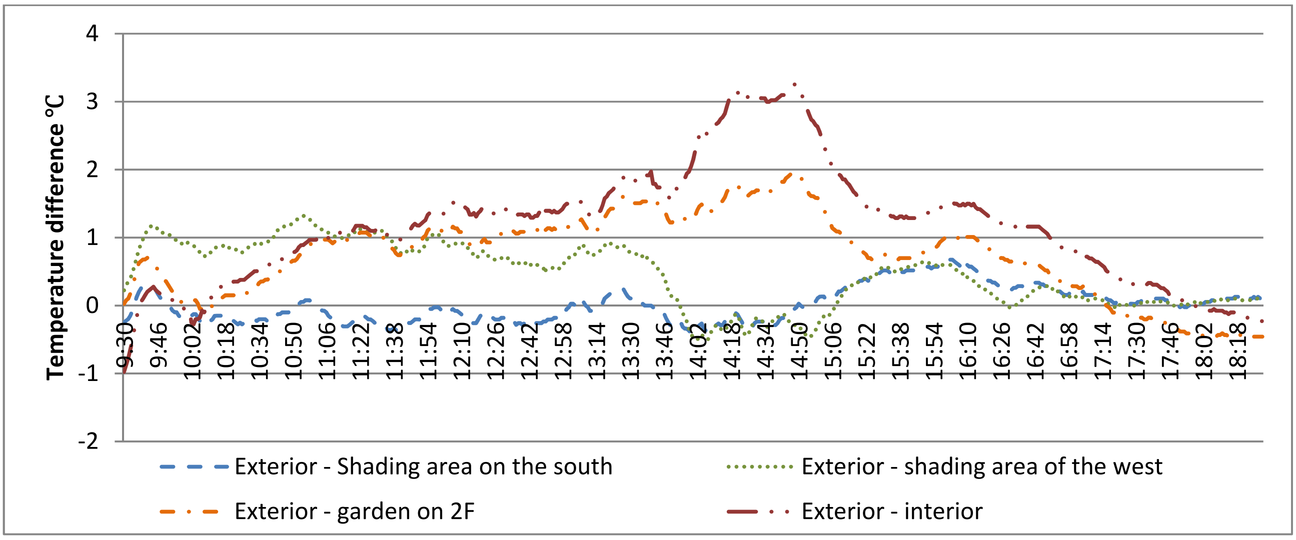


Fig. 2 Temp comparison of exterior and other measure points (9:30-18:30, 19th Sep.2016)

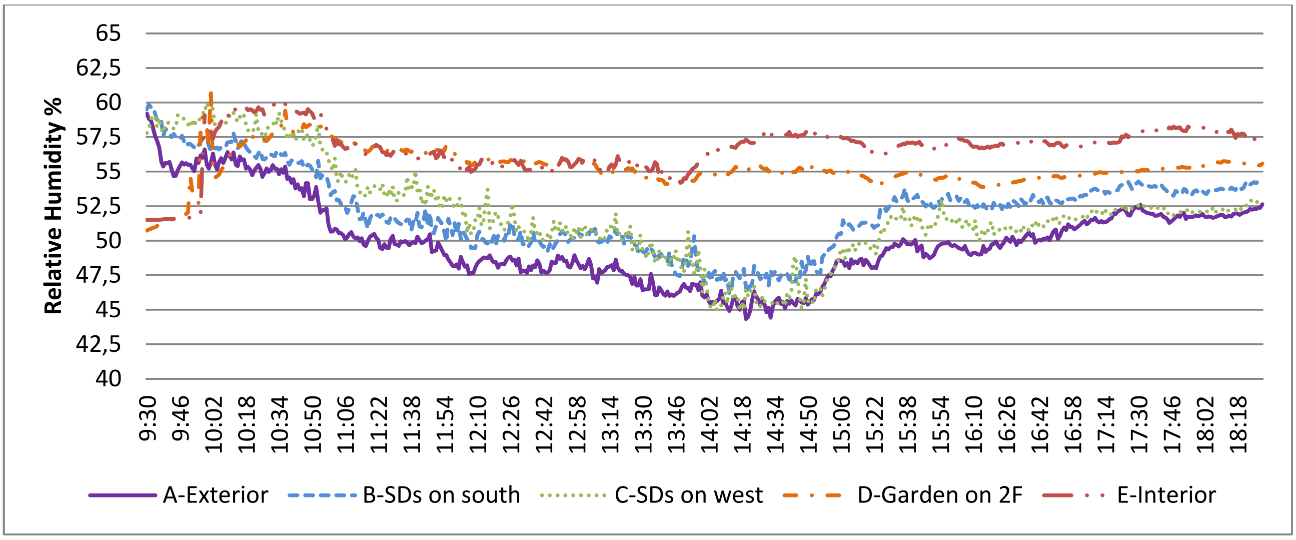


Fig. 3 RH data (9:30-18:30, 19th Sep.2016)

III. Measurement Results and Analysis

A. Temp, RH and Wind Velocity of Interior Space

Fig. 9 provides the Temp variation of the day time. The Temp of southern façade and outdoor space was close in the morning. But the Temp of the shading area decreased faster in the afternoon. And the Temp of the west façade was lower than the outdoor space and the south façade. Fig. 10 also compares the differences of Temp of exterior and other measure points. It shows that the Temp of the shading area on the south side and the exterior area was close. On the west side, the Temp is lower than the exterior most of the day time; the difference was about 1 ℃. At 14:00-15:00, the Temp of both the shading areas were a bit higher than the exterior, which was the result of the outdoor air flow reduction, the higher sun angle at noon, and the reduction of shading effect with no enclose panel at the top of SDs. This result reflected that the effects of shading are better on the west side. On the other side, the Temp of the small garden on the 2nd floor was lower than the shading area, with less fluctuation. The interior Temp was lowest, with the cooling effect of air condition on 14:00-15:30.

Fig. 12 compared the maximum, minimum and average Temp of the roof, the south and west façade, the small garden and the interior of the building. In this comparison, the Temp of the shading area and outdoor area was nearly the same. The maximum Temp was 34.5 ℃, the minimum was 29.2 ℃, and the average was 32.5 ℃. On the contrary, the maximum Temp of the interior was 31.8 ℃, the minimum was 29.1 ℃, and the average was 31.8 ℃. Thus, the Temp of the interior was reduced by 0.1-2.7 ℃. This result is close to the measurement by [14]. Besides, the Temp of the small garden on the 2nd floor was also lower than the outdoor area. The maximum was 32.8 ℃, the minimum was 29.0 ℃, and the average was 31.9 ℃.

Fig. 11 shows that the RH of the interior was stable in the daytime. On the other side, the RH of the shading area on the south and west was higher than which of the outdoor area. This result revealed the shading effect of SDs, which reduced the solar radiation and air flow on the building façade.

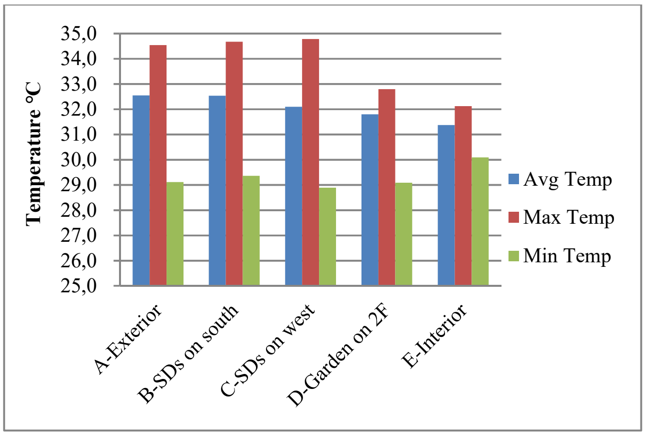


Fig. 12 Max, Min and Avg. Temp comparison (Time: 9:30-18:30)

Figs. 13 and 14 recorded the daytime wind velocity of in and out-door space. In general, the wind velocity on the morning is lower than the afternoon. The range of the outdoor area was 0-4 m/s, the average value is 2.2 m/s. The range of the small garden on the 2nd floor was 0-2 m/s; the average value was 0.6 m/s. The range of shading area behind the SDs was 0-0.7m/s; the average value was 0.3 m/s. Most of the interior velocity value was lower than 0.5 m/s, the average value was 0.2 m/s.

As the data showed, the shading area was an open space, which was not developed as a wind tube like the double facade. Shading panels reduced the wind velocity in this area. However, building space relationships and apertures on facades are also important for interior air flow improvement. The small garden is a semi-open space between the in and outdoor space, the wind velocity of which was higher than the shading area behind the SDs. Based on the wind velocity, Temp, and RH data, the small garden could be also considered as a heat buffer space of the in and outdoor space.

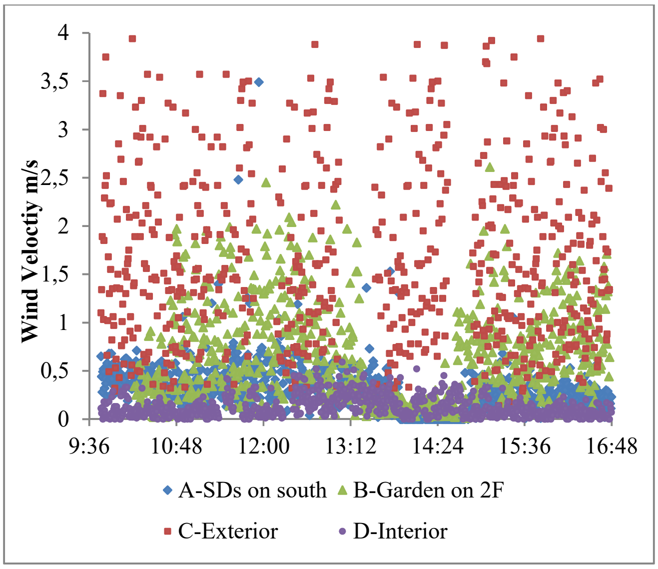


Fig. 13 Wind velocity data (Time: 9:30-18:30)

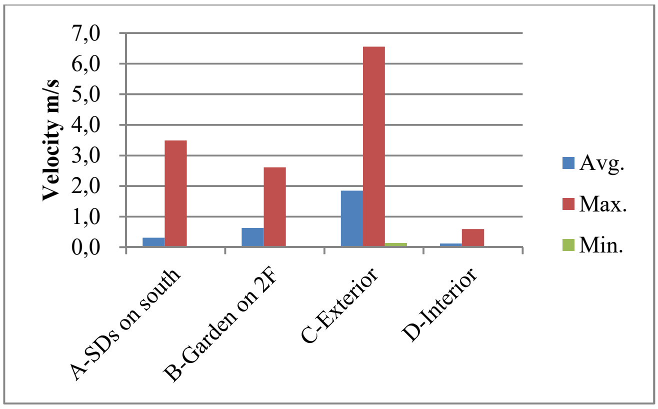


Fig. 14 Comparison of the wind velocity (Time: 9:30-18:30)

B. *Temp of the building façade material*

Besides of the measurement of the air Temp and RH, this observation also measured the surface Temp of the façade materials, such as glass and aluminum, which is with or without shading. Data on the different orientation are also another factor to compare.

Figs. 15 and 16 compare the Temp of different façade materials, reflecting that the Temp of aluminum shading panels on the west and south façade was higher than the double-glaze behind with 2.8 ℃ and 0.9 ℃. Furthermore, at the peak Temp the SDs on the west façade was close to 42 ℃, and 4 ℃ higher than the double-glaze. Besides, the average Temp of the double-glaze on the 1st floor (without SDs) on the south façade was 39.3 ℃, higher than which on 2nd floor 8.1%, and even higher than the SDs. Measured results show that the SDs reduced the solar radiation on building façade effetely.

Considered with the different specific heat capacity of the SDs (880 J/ kg·℃) and the glass (750 J/ kg·℃) of the façade, the efficiency of the Temp change of SDs is higher than the glass. As a result, the Temp of these materials nearly went down to the same level at 17:00.

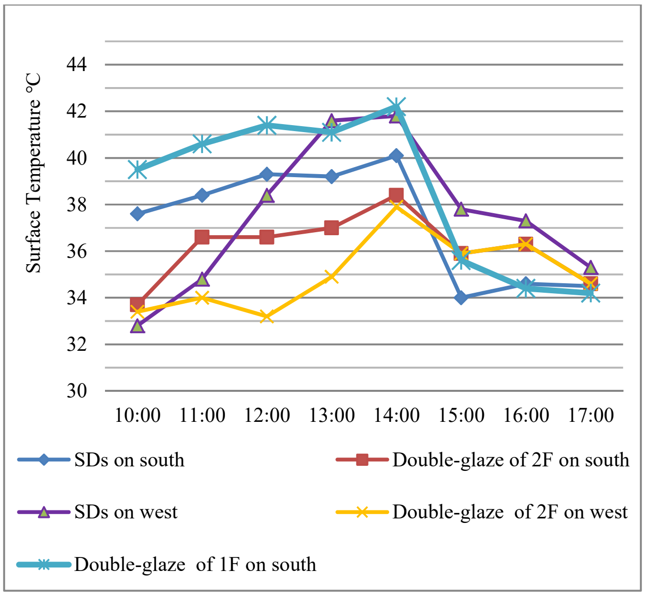


Fig. 15 Temp data of the building façade material (Time: 9:30-18:30)

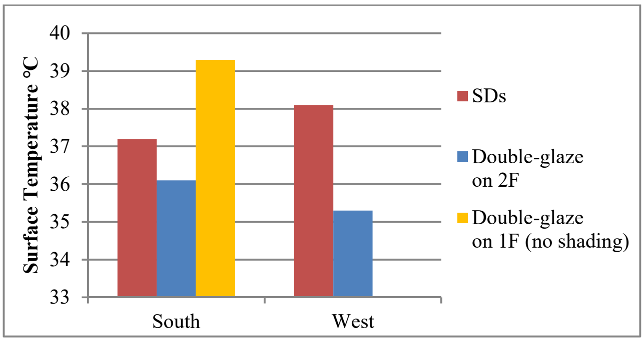
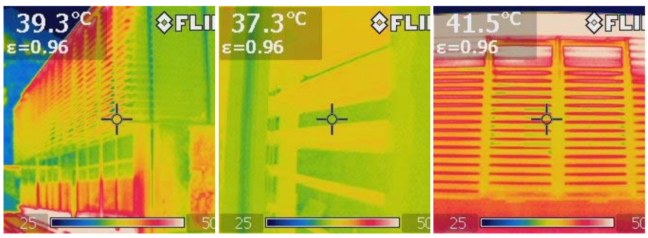


Fig. 16 Avg. Temp data of the building façade material (Time: 9:30-18:30)



(a) (b) (c)

Fig. 17 Thermal images of the building façade: (a) shading panels on south façade; (b) double-glaze shaded by panels; (c) shading panels on west facade)

IV. SIMULATION RESULTS AND ANALYSIS

The CFD simulations of ventilation with the software ANSYS Fluent were tested after the measurement. Two models, one with SDs on the façade of 2nd floor and the other one not, were compared under the same boundary situation (Table IV).

The result reflected that the SDs reduced the surface and the interior Temp of the building, but also reduced the wind velocity (Table V). The Temp of the double-glazing on south façade of Model 1 was lower 5.09 °C than the Model 2. But the difference of the Temp of the interior of two models is just 0.24 °C. The average velocity of the southern window and the northern window was reduced by 0.36 m/s and 0.25 m/s, but the wind velocity of the interior was equal.

TABLE IV
BOUNDARY SITUATION OF THE CFD MODEL

Model boundary size	80 x 90 x 36m (L x D x H)
Inlet velocity	1.5m/s
Ambiance Temp	32℃
Time & Date	14:00 19th Sep
Location	Guangzhou, China (23°08′N, 113°16′E)

Figs. 18 and 19 are the simulation images of the atrium in the office building, which reflect that the distribution of the wind and Temp is much more stable when the façade is covered with the SDs. Effects of the SDs are mainly presented around the windows. And it could also be seen clearly that the wind was disturbed around the SDs.

TABLE V
RESULTS OF THE CFD SIMULATION

	Model 1 (With SDs)	Model 2 (Without SDs)
Avg. velocity of interior (m/s)	0.55	0.55
Avg. velocity of the south window on 2F (m/s)	2.14	2.50
Avg. velocity of the north window on 2F (m/s)	1.47	1.72
Avg. Temp of interior (°C)	32.85	33.09
Avg. Temp of double-glaze on the south (°C)	29.43	34.52
Avg. Temp of double-glaze on the north (℃)	33.02	32.97

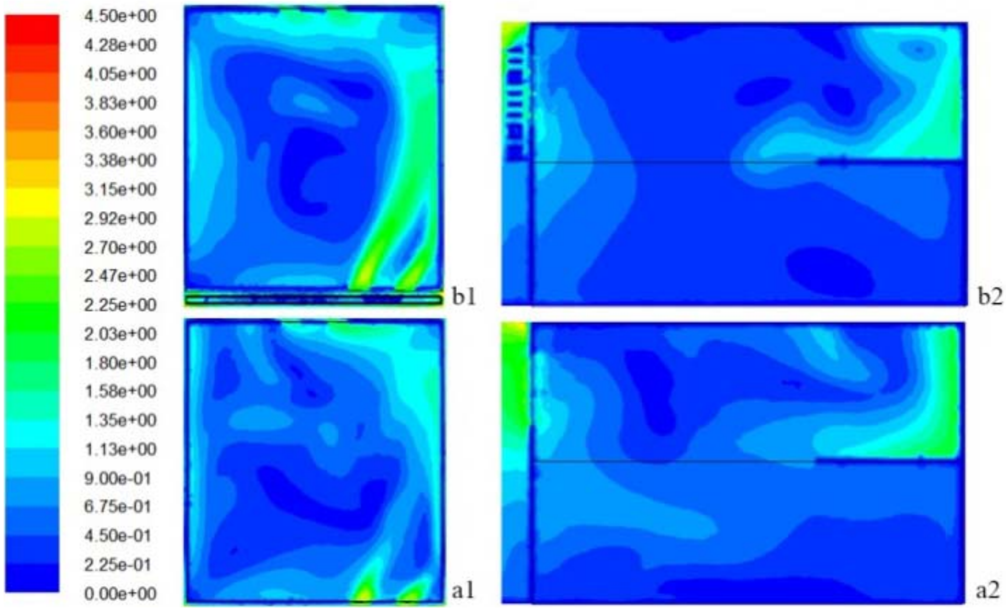


Fig. 18 Interior ventilation simulation result of the atrium (m/s): (a1) Distribution of velocity on 2nd floor, Floor plan, façade without SDs; (b1) Distribution of velocity on 2nd floor, Floor plan, façade with SDs; (a2) Distribution of velocity, Section, façade without SDs; (b2) Distribution of velocity, Section, façade with SDs)

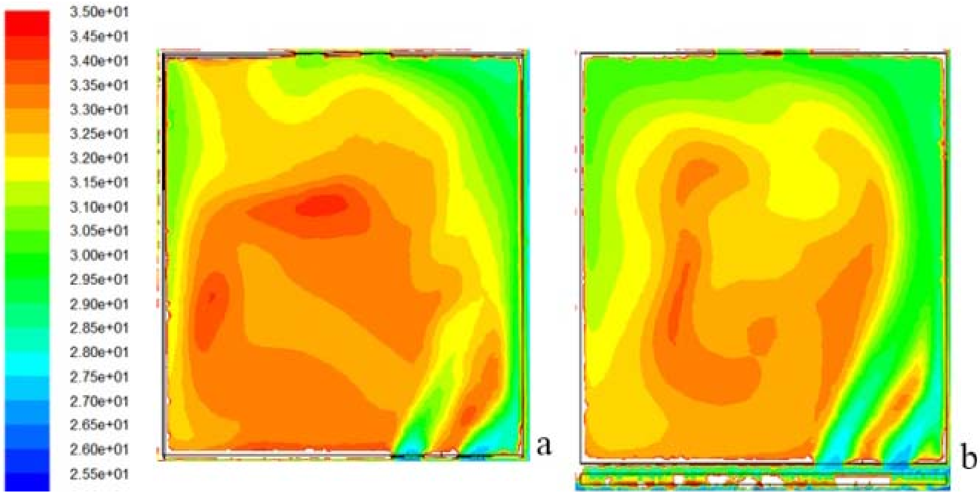


Fig. 19 Interior ventilation simulation result of the atrium (℃): (a) Distribution of Temp on 2nd floor, Floor plan, façade without SDs; (b) Distribution of Temp on 2nd floor, Floor plan, façade with SDs

V. Conclusion

Through measurement and simulation on typical summer day, this study discussed the effects of the external SDs on building micro climate. Both of the results reflected that, the external SDs could reduce the building Temp, and reduce the wind velocity. The human comfort value, which combines the analysis of Temp, RH, and velocity, could be analyzed in later researches. For the further study, more materials, organizations and scales of the SDs would be tested for the effects on building micro climate.

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