Thermal Characteristics and Energy Performance of Double Skin Façade System in the Hot Summer and Cold Winter Zone

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ABSTRACT

Double skin façade (DSF) system is used in high-rise buildings increasingly in the hot summer and cold winter zone in China, due to its advantages in sound proof, aesthetic appearance and energy efficiency. This paper demonstrated a method of obtaining the thermal characteristics of the double skin façade system using computational fluid dynamics (CFD) techniques, and evaluated the energy performance of the DSF system. Based on the CFD simulation results using climatic data of Hangzhou city, a linear relation between the room heat gain and two other variables, the solar radiation and the temperature difference between the room and the ambient, can be confirmed. This linear relation shows two important characteristics of the DSF system: solar heat gain coefficient (SHGC) and effective heat transfer coefficient or U value. Effects of four DSF parameters were analyzed that included the glazing properties, the cavity width, the vent opening size, and the cavity height. The results show that the cavity width and the cavity height appear to have little effect on the thermal performance. Increasing the vent opening can improve the thermal performance up to a certain extent. Using the linear relations, the total cooling load can be easily evaluated as demonstrated. Such capability can be of great help during the DSF design and optimization process.

KEYWORDS

Double skin façade, Thermal characteristics, Linear relation, Room heat gain, Energy evaluation

INTRODUCTION

Double skin façade (DSF) system is a building façade usually consisting of double glazing and a single glass pane. It is increasingly used in high-rise buildings in the hot summer and cold winter zone in China, due to its advantages in sound proof, aesthetic appearance and the potential in energy saving. Because of improved structural features, double skin façades are claimed to be energy efficient by providing better

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thermal insulation and having air ventilation taking away extra unwanted heat during the cooling season (Balocco 2001, Tanaka et al. 2009). To further reduce the solar radiation, blinds can be placed inside the cavity of DSF，or low-e coating can be used. But blinds in the cavity increase maintenance, while low-e coated glasses do not last long enough. Therefore, thermal performance of DSF needs to be explored further and to adapt to the local environment. Although the DSF has several variations in structures, the “externally breathing” DSF type are widely used in the hot summer and cold winter zone, such as Shanghai and Hangzhou (Pan and Zhang 2008).

Much has been discussed on the DSF’s thermal performance (Zhou and Chen 2010, Jiru 2008). Traditionally, the ventilation scheme which prevents temperature built-up in the cavity, is thought to be the key feature that makes the DSF superior to the single skin façade (Tanaka et al. 2009, Xu and Ojima 2008). But He et al. (2011) think that the role of ventilation’s contribution to energy saving may have been exaggerated and argue that an open cavity may not be cost-effective considering the added maintenance. On the other hand, whether DSFs are energy efficient and cost effective, is a much debated topic, due to two reasons: lack of supporting experimental data and lack of understanding on the climate dependence of the DSF performance. Clearly, annual energy should be considered in the evaluation of the DSF. Recently, He et al. (2012) found that the energy flow through the DSF can be expressed as a simple linear relation of the environmental parameters, which, if confirmed, would greatly simplify the calculation of building energy simulation with DSF systems.

The paper was a continuation of our early work (He at al., 2012). More cases were analyzed to confirm the relationship. Further, we analyzed the effects of four parameters on the DSF performance: the cavity width, the cavity height, glazing properties, and the vent size. Finally, we demonstrated how the building energy could be calculated based on this relation using the climate data of Hangzhou, Zhejiang Province.

METHODS

CFD Simulation

Heat transfer in DSF takes all the three general forms: radiation, convection and conduction. The computational fluid dynamics (CFD) techniques are widely used in studying the thermal characteristics of DSF systems (Balocco 2001, Høseggen et al. 2008).

The detailed CFD simulation method used in this paper can be found in He et al. (2011). Here, only a brief description was presented. Convective and conductive heat flows were solved by CFD while the solar radiation was calculated separately. Solar absorption was represented by heat sources within the glass panes. The room gained heat from the solar radiation in two ways: direct transmission and heat convection from the glass after the glass absorbed the solar radiation. The commercial software PHOENICS was used and the RNG k-ε turbulence model was chosen.

Energy Evaluation

To calculate the annual cooling load of the DSF, we used the Hangzhou's typical meteorological year data developed by a research team from Tsinghua University. The data were exported from the DeST software developed by the team (DeST 2011). The hourly heat gain was calculated based on the hourly meteorological data and then summed up for the total cooling load in summer as show in Equation (1):

$$Q = \sum_{m}\left(\sum_{n} Q_{heat}\right) \quad (1)$$

where Q is the total cooling load, m, the day number from June to August, n, the hour number from 8:00 am to 17:00 pm each day, Q_{heat} , the room heat gain in each hour.

The DSF Windows

For comparison purposes, the DSF model in our earlier work (He et al. 2012) was designated as model 1 (Fig.1(a)). Two more DSF window models (3.3m×0.436m) were constructed (Fig. 1(b) and Table1).

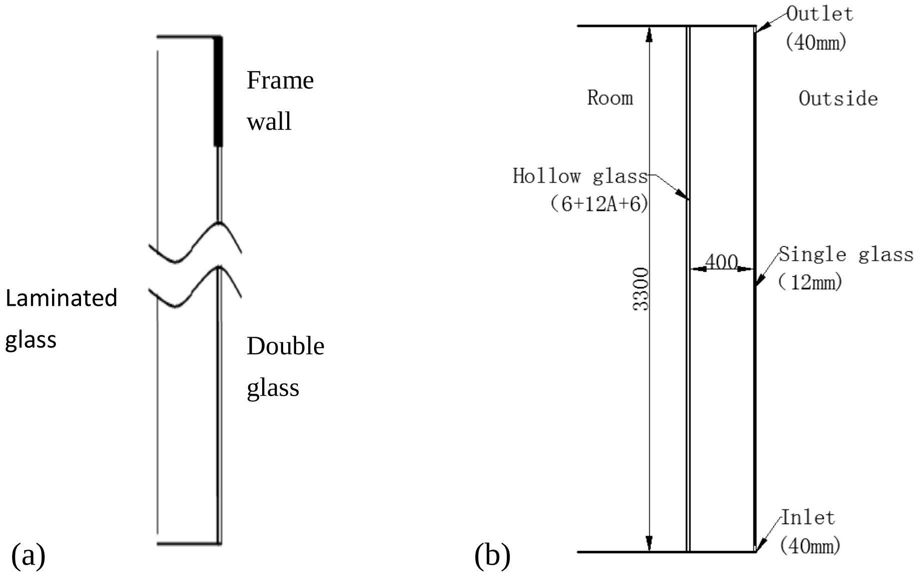

***Figure 1**. Sketch of the DSF window. (a) A sketch of model 1, and (b) A sketch of model 2 and model 3.*

In Model 1, the room side skin contained a frame wall at the top, which was modeled as an insulation wall with a U value of 0.8 W/(m^2 K). Model 2 and Model 3 contained no frames. In theory, Model 1 used glazing with the highest performance (higher SHGC and lower U value). Model 2 used glazing with the lowest performance (lower SHGC and higher U value). The performance of glazing used in Model 3 was somewhere between Model 1 and Model 2.

Simulated Cases

CFD simulations were performed using one typical summer day's climatic data in Hangzhou (Table 2). For each hour, a steady state condition was assumed in computing the energy flow during that hour.

Table 1. *Optical and thermal properties of the DSF windows*

Model	Properties	Single pane	Double glazing
1	Transmittance	τ_{11}= 0.54	τ_{12}= 0.54
	Reflectance	β_{11}=0.06	β_{12}=0.23
	U value (summer)	5.4 W/(m^2 K)	1.8 W/(m^2 K)
2	Transmittance	τ_{21}= 0.67	τ_{22}= 0.66
	Reflectance	β_{21}=0.07	β_{22}=0.12
	U value (summer)	4.98 W/(m^2 K)	2.84 W/(m^2 K)
3	Transmittance	τ_{31}= 0.57	τ_{32}= 0.52
	Reflectance	β_{32}=0.08	β_{33}=0.13
	U value (summer)	3.6 W/(m^2 K)	1.8 W/(m^2 K)

Table 2. *Meteorological data for simulation*

Time	Solar radiation (W/m^2)	ambient temperature
6	219	29.2
7	366	30.1
8	435	31.0
9	431	32.3
10	370	33.6
11	268	34.5
12	143	34.8
13	138	34.3
14	127	33.5
15	109	32.5
16	84	31.5
17	53	30.6
18	18	29.7
19	0	29.2

Table 3. *Details of the construction variables*

Construction variables	Values				
Cavity widths	200mm	400mm	600mm		
Opening sizes	0mm	5mm	40mm	100mm	200mm
Story heights	3.3m	6.6m			

Model 3 was chosen as a basis to study the influences of three DSF parameters on the thermal characteristics: the cavity width, the opening size, and the cavity height, as shown in Table 3. To emphasize the role of solar radiation, comparisons were done based on climatic data at 8 a.m. when maximum irradiance occurred.

RESULTS

The amounts of room heat gain by convection, heat loss from the outer pane, and heat loss through cavity ventilation were all read from the CFD simulation results. The room heat gain is the sum of the transmitted solar heat and the heat transferred from inner pane by convection.

Heat gain relationship with ambient temperature and solar irradiance

Through the regression method and the criterion of least sum of squares, fitting formulas (Eq.2 and Eq.3) were obtained that expressed the hourly room heat gain as a linear function of the solar irradiance and the temperature difference between the room and the ambient.

Model 2 $$Q_{heat} = 0.56Q_{sun} + 1.128\Delta t \tag{2}$$

Model 3 $$Q_{heat} = 0.425Q_{sun} + 1.161\Delta t \tag{3}$$

Where Q_{heat} and Q_{sun} is the room heat gain and the solar irradiance, respectively. Δt is the temperature difference between the room and the ambient.

The correlation coefficient between the room heat gain calculated by the fitting formulae and that from the CFD simulation is close to 1 (Figure 2) indicating that the linear formulate can effectively replace the CFD simulations in computing the room heat gain.

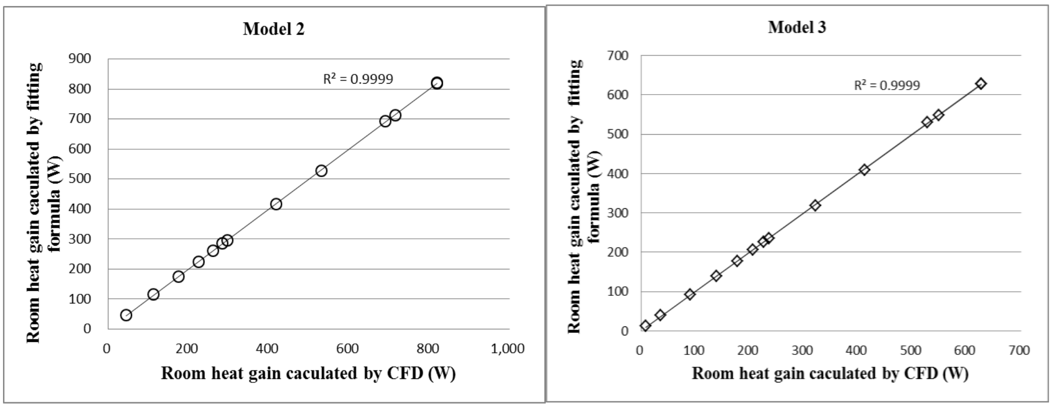

Figure 2. *CFD simulation results compared with the linear model. Hollow points represent the value of the room heat gain, while lines represent the line y=x.*

Parameter Analyses

The influence of the cavity width is shown in Figure 3(a). Changing the cavity widths from 200mm to 600mm reduced the room heat gain slightly indicating an insignificant influence. However, 400mm width of cavity had advantages over 200mm width to some extent. No changes were found when 400mm vs. 600mm.

The influence of the opening size is shown in Figure 3(b). The room heat gain reached the maximum when the cavity was closed. Increasing the vent size to 40mm reduced the room heat gain by 6.4%. But further increasing the vent opening appeared to have little effects on the value.

The influence of the cavity height is shown in Figure 3(c). In terms of total room heat gain per unit of façade area, the results were same for the two cases simulated, indicating the cavity height may not be a significant factor influencing the energy characteristics of the DSF.

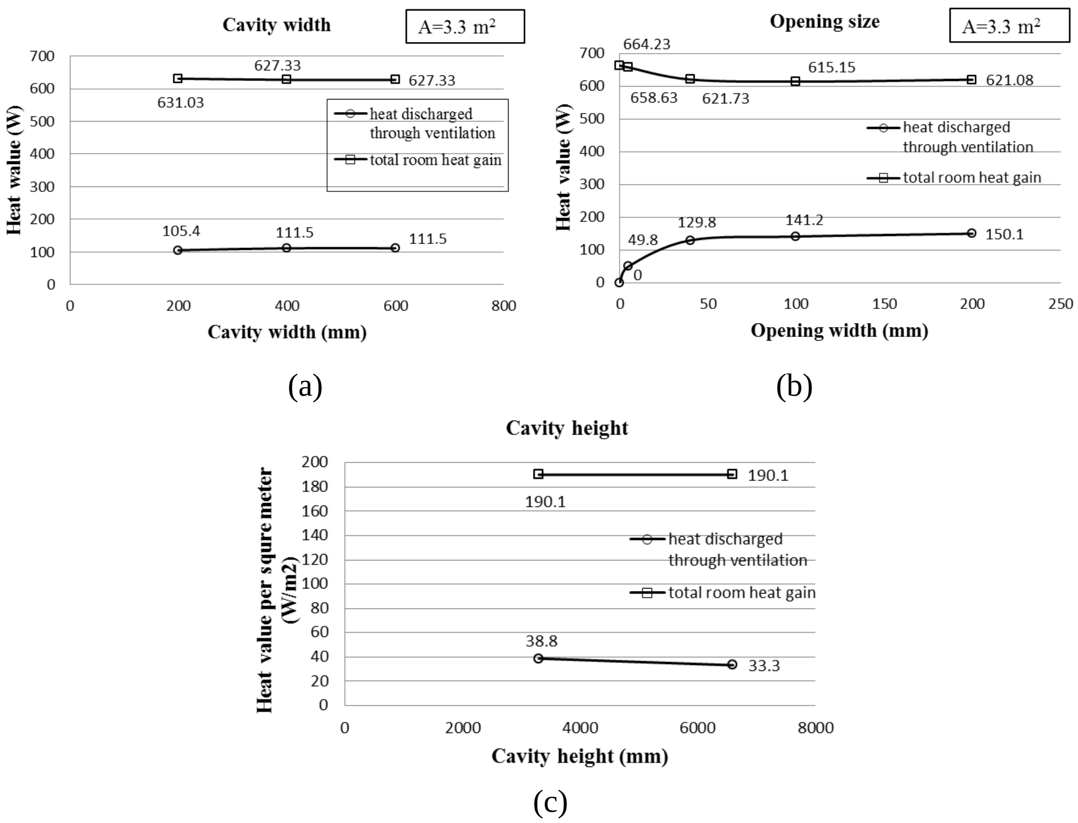

Figure 3. *Influences of three parameters on thermal performance of the DSF.*

Energy Evaluation

Only the energy performance of Model 1 was evaluated using the linear relation developed earlier (He et al., 2012). Eq. (4) is for DSF model while Eq. (5) is for the single skin model that comprised only the double glazing and the frame wall in Figure 1(a).

$$Q_{heat} = 0.224Q_{sun} + 1.209\Delta t \quad (4)$$

$$Q_{heat} = 0.270Q_{sun} + 1.650\Delta t \quad (5)$$

For comparison purposes, the cooling load was calculated for both the DSF and the single skin façade. The results were shown in table 4. Compared with the single skin model, the annual energy saving during the cooling season for the DSF was about 7.12 to 13.46 kW h/m^2. The maximum energy saving occurred when the DSF was installed on the west side and the minimum energy saving occured when the DSF on the north side. Nevertheless, the saving rate in percentage was almost same for four sides.

Table 4. *The annual cooling loads through DSF in four orientations*

Orientations	East	South	West	North
Double skin façade (kWh/m^2)	42.16	40.51	63.73	32.86
Single skin façade (kWh/m^2)	51.19	49.20	77.19	39.98
Energy saving（kWh/m^2)	9.03	8.69	13.46	7.12
Energy saving in percentage,%	17.6	17.7	17.4	17.8

DISCUSSION

The strong linear relationship for all three DSF models indicates that the solar radiation and the temperature differences between the room and the ambient are sufficient to explain the room heat gain. The physical meaning of the coefficients is obvious. The coefficient of solar irradiance is the effective solar heat gain coefficient (SHGC) of the DSF system, and the coefficient of Δt is the effective heat transfer coefficient, or the effective U value. The effective solar heat gain coefficient is greater than the solar transmittance because of the "secondary transmission" (part of the solar radiation is transferred from the glass after it is absorbed by the glass). The effective heat transfer coefficient differs from the U value, which is usually measured without the presence of solar radiation. In fact, a heat flow between the room and the ambient may not exist in the presence of solar radiation even the temperature difference is significant. However, the temperature difference does affect "the secondary transmission", although in a minor magnitude. A comparison between the two terms on the right side of Eqs. (2) to (5) reveals that the radiation term is much greater than the heat transfer term in the presence of solar radiation.

The height and width of the cavity both affect the convection heat transfer inside the cavity. In the studied range, both parameters showed little impact on room heat gain, indicating the convection in the cavity might play a minor part in the DSF thermal performance. Although, the cavity width shows insignificant influence on the energy performance, other factors may need to be considered when it comes to decide the cavity width, e.g. maintenance, ventilation, installation of blinds, etc.

Increasing the vent opening initially improves the performance of the DSF up to a certain extent. But the improvement potential may not be significant as expected, only about 6% in the discussed cases.

DSF orientations affect DSFs' energy performance. Although the west wall and the east wall may receive similar solar irradiance, the west DSF has greater cooling load and greater energy saving. This could be due to the fact that higher ambient temperature concurs with the solar irradiance on the west wall in the afternoon. The ambient temperature increases the “secondary transmission”, resulting a higher cooling load on the west wall.

CONCLUSION AND IMPLICATIONS

This paper displayed a method to obtain the thermal characteristics of a DSF system by using the CFD simulation method. As results shown, linear relationships were found between the room heat gain and two environmental parameters: the solar radiation and the temperature difference between the room and the ambient. As demonstrated, this linear relation can easily be used to calculate the building energy through the DSF. In order to further valid the findings, experimental data are needed.

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