Comparison of the Energy Performance of a Building with Double Skin Façade and Green Wall

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ABSTRACT: Double Skin Façade system and Green Wall system are two façade techniques that have the potential to improve indoor thermal performance and reduce the energy consumption of a building. Studies have been done in both areas, but no research has been conducted comparing the performance of Double Skin Façade and Green Wall, even though both façade techniques have been applied (mostly) in commercial buildings for years. This study compared the performance of a simple designed office building implementing Double Skin Façade and Green Wall respectively, based on simulation results carried out using the EnergyPlus simulation program. The comparison focuses on the temperature, cooling, heating, lighting, and total energy consumption of the building by implementing each façade technique on four sides during a summer design week and a winter design week as well as the whole year. The results show that the building with Green Wall is potentially able to reduce more energy consumption and has better thermal performance than the building with Double Skin Façade under most conditions.

Conference theme: Buildings and energy
Keywords: Double Skin Façade, Green Wall, Multi-storey Building, Simulation

INTRODUCTION

Building energy consumption can be reduced through improved design solutions in the early stage when the decisions on the building design are being made. Even applying only some of the conventional energy efficiency technologies, including shading, low-e glazing window, insulation, and daylighting controls can decrease building energy use significantly – up to over 40% (Joshua, 2010).

Double Skin Façade (DSF) and Green Wall (GW) systems are more advanced energy-saving techniques compared to the conventional techniques. They can be considered special “insulation systems” for building façade, and GW systems also have the function of providing external shading. Therefore, implementing DSF or GW for one or more of building façades would potentially reduce heat transfer and energy consumption and improve indoor comfort to a certain extent in a building, particularly in multi-storey buildings.

Many studies have been conducted on DSF and GW (Gratia & De Herde, 2004, 2007; Pérez et al., 2011; Stec et al., 2005; Hashemi et al., 2010; Hamza, 2008; Shewoka & Magdy, 2011; Francis & Lorimer, 2011; Wong et al. 2009, 2010; Cheng, 2010) DSF has the potential to reduce both cooling and heating load (Hashemi, 2010). The stack effect and greenhouse effect in the DSF cavity are the basic features that can significantly influence a building energy performance. On the other hand, GW is found to reduce and limit the fluctuation of the surface temperature of building walls, reduce illuminance and has cooling effect on the indoor space (Pérez et al., 2011). In addition, GW, as a technique for urban ecology, has the potential to reduce the urban heat island effect as well (Francis & Lorimer, 2011) (Wong & Yu, 2005).

Although both of the façade techniques have been applied or are about to be applied in Adelaide (e.g. SA Water House, Tower 8, etc.), no study has been conducted to compare these two techniques implemented in buildings in Adelaide to achieve the best outcome. Finding a better strategy is important in achieving a low-energy building design. The research reported in this paper investigates these two strategies, Double Skin Façade and Green Wall, and compares their impact on building thermal performance and energy consumption through a building performance simulation.

1. METHODOLOGY

The energy consumption and indoor temperature of the base building, the building with Double Skin Façade (DSF) and the building with Green Wall (GW), applied respectively on each side of the building walls, were compared for a whole year, during a summer design week and during a winter design week.

Building performance simulation software – EnergyPlus (Design Builder interface) – is used to model and simulate the building. All simulations are based on Adelaide weather data. Adelaide is a city in the southern hemisphere that has a dry and hot summer and a cool and wet winter.
1.1. Base Building Design
A 30 m by 30 m, 8-floor base building covered with 80 percent double glazing was designed. Each level of the building is 3.5m high. The north, east, west and south zones are separated by virtual partitions purely to sub-divide the space for different HVAC provision, daylighting, and solar overheating studies (and no corresponding wall in the actual building) (Fig.1). The central zone, 10m x 10m, has neither an HVAC system nor ventilation, and no simulation results for this area will be presented in this study. Thus, it is isolated from the other zones by standard internal partitions. Table 1 and Table 2 present the base building properties and operation.

![Fig. 1 Base building block layout](image1)

**Table 1 Building properties**

<table>
<thead>
<tr>
<th>Building Properties</th>
<th>U-Value (W/m²-K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>External Wall</td>
<td>0.735</td>
</tr>
<tr>
<td>Internal Wall</td>
<td>2.193</td>
</tr>
<tr>
<td>Roof</td>
<td>0.349</td>
</tr>
<tr>
<td>Ground Floor</td>
<td>1.094</td>
</tr>
<tr>
<td>Intermediate Floor</td>
<td>2.564</td>
</tr>
<tr>
<td>Double Glazing</td>
<td>3.159</td>
</tr>
<tr>
<td>DSF External Single Glazing</td>
<td>5.778</td>
</tr>
<tr>
<td>DSF Cavity Single Glazing</td>
<td>5.894</td>
</tr>
</tbody>
</table>

**Table 2 Building operation detail**

<table>
<thead>
<tr>
<th>HVAC system type: Dual duct VAV</th>
<th>Heating</th>
<th>Gas-fired condensing boiler</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setpoint temperature</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Cooling</td>
<td>DOE-2 centrifugal/5.50COP</td>
<td></td>
</tr>
<tr>
<td>Setpoint temperature</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Fresh Air supply rates</td>
<td>10 l/s-person</td>
<td></td>
</tr>
<tr>
<td>Mechanical ventilation</td>
<td>Return air temperature</td>
<td></td>
</tr>
<tr>
<td>Humidity</td>
<td>10%-90%</td>
<td></td>
</tr>
<tr>
<td>Infiltration</td>
<td>0.7 ac/h</td>
<td></td>
</tr>
</tbody>
</table>

**Lighting**

- General lighting: 5W/m²-100 lux
- Radiant fraction 0.37
- Task lighting: 33.3 W/m²
- Daylighting: 70% coverage

**Office Equipment**

- Thermal gain: 11.77W/m²
- Radiant fraction: 0.2

![Fig. 2 Base building with Double Skin Façade](image2)

![Fig. 3 DSF opens in summer months and night ventilation](image3)

![Fig. 4 DSF is shut during the day-time of other months](image4)
1.2 Double Skin Façade and Green Wall Design

DSF and GW are implemented 1 metre away from each façade of the base building one at a time. The exterior skin of DSF is 100% glazing. Two controllable vents with a height of 0.5m are installed on the top and bottom of DSF. The DSF cavity is separated on each level by a grill, which is simulated as eight controllable internal windows with a width of approx. 0.125m. The DSF opening and vents (Fig. 2-4) allow natural ventilation in the summer months (December to February) and night-time ventilation during the other months. During the other times of the year, they can be shut tightly.

The building energy consumption is simulated with the HVAC system off. The indoor temperature is the average indoor radiant temperature.

Thus there are three scenarios to simulate in this study: base building, base building with Double Skin Façade, and base building with Green Wall (0.1m thickness). Furthermore, the simulation results are compared from four sides (north, west, east and south respectively), to find the optimal energy performance solution for each side.

1.3 Simulation Design

Double Skin Façade and Green Wall are applied on base building.

The building energy consumption is simulated with the HVAC system operating while the indoor temperature is simulated with the HVAC system off. The indoor temperature is the average value of the indoor air temperature and the indoor radiant temperature.

It was very time-consuming to do the whole-year simulation for all of the scenarios due to the long duration of simulation process; therefore, each case was simulated to predict only the breakdown energy consumption and use in the most typical weeks (summer design week: Feb 10 – Feb 16; winter design week: Jun 22 – Jun 28) of the year. In addition, the temperature performance in the design weeks and an annual building simulation were also examined.

2. RESULTS AND DISCUSSION

2.1 Temperature

**North**

![Fig. 8 Temperature of N-level 1 in summer design week](image)

![Fig. 9 Temperature of N-level 4 in summer design week](image)
Fig. 30 Temperature of S-level 4 in winter design week Fig. 31 Temperature of S-level 8 in winter design week

Fig. 8-31 demonstrates the impact of DSF and GW on the temperature of the building zones if the building is provided with only natural ventilation. Generally, in summer, the temperature in the base building increases when the building level is higher. The building with DSF has a quite similar temperature as the base building in the lower levels. Hot air rises in the DSF cavity due to the stack effect, so the temperature increases more in the building with DSF than in the base building on the higher floors. On the other hand, the GW is more helpful in reducing indoor temperature. The building with GW always has a lower temperature than the base building, and the indoor temperature of the building with GW increases more slowly when the level goes up. However, the indoor temperature is too high for occupants even in the building with GW. Thus, an air-conditioning system is still required for the building during the summer.

In winter, DSF traps warm air inside the cavity and keeps the building warm. The temperatures of the zones of the building with DSF are slightly higher than those of the base building. Moreover, when the level is higher, the temperature difference between the building with DSF and the base building becomes bigger. On the other hand, due to the shading of GW, the heat gain decreases and the indoor temperatures of the zones of the building with GW are lower than those of the base building. In addition, the fluctuation of the temperature of the building with GW is less on the west, east, and north façade because GW intercepts and absorbs some solar heat gain while the buffering effect of GW keeps the zone temperature fluctuating less in the winter.

3.2 Energy Consumption in Summer and Winter Design Weeks

Table 3 Energy performance in design weeks

<table>
<thead>
<tr>
<th></th>
<th>North</th>
<th></th>
<th>WEST</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DSF</td>
<td>GW</td>
<td>DSF</td>
<td>GW</td>
</tr>
<tr>
<td>Cooling Load Reduction</td>
<td>8.8%</td>
<td>19.6%</td>
<td>21.6%</td>
<td>40.0%</td>
</tr>
<tr>
<td>Heating Load Reduction</td>
<td>8.0%</td>
<td>-11.2%*</td>
<td>42.0%</td>
<td>62.0%</td>
</tr>
<tr>
<td>Lighting Load Increase(Summer)</td>
<td>3.7%</td>
<td>5.5%</td>
<td>4.7%</td>
<td>5.9%</td>
</tr>
<tr>
<td>Lighting Load Increase(Winter)</td>
<td>4.9%</td>
<td>5.7%</td>
<td>4.9%</td>
<td>7.0%</td>
</tr>
<tr>
<td>Total Energy Consumption Reduction</td>
<td>3.7%</td>
<td>9.0%</td>
<td>14.7%</td>
<td>27.2%</td>
</tr>
</tbody>
</table>

Table 3 and Figure 32 show the energy reduction percentage for the summer and winter design weeks. They indicate that, first, applying a second façade on different sides of the building walls can significantly reduce the total energy consumption of the west, east and north zones. Second, the building with GW is able to reduce more total energy consumption of the west, east and north zones than the building with DSF.

The results also illustrate that GW works the most efficiently on the west façade of the building compared with the performance of GW applied on other sides. This is due to the fact that direct solar radiation comes from the western direction in the afternoon with higher intensity than earlier in the day. GW applied to the west façade will reduce the heat gain of the west zones rather than any other zones, thereby reducing the cooling load significantly. Since the cooling load takes a great proportion of the total energy consumption, when the cooling load is reduced, the total energy consumption is consequently reduced. On the other hand, DSF works the most efficiently on the east side of the building wall compare with the performance of DSF applied on other sides. This is due to the fact that the eastern DSF receives direct solar radiation only in the morning when the sunlight is not quite strong and the heat inside the cavity is removed by the stack effect. At other times of the day, the north and west DSF receive much more heat gain and requires more cooling load than the east DSF, so DSF performs the best when applied to the east wall.
GW can provide more reduction of total energy consumption than DSF (north, west, and east zones) or lead to a smaller increase in total energy consumption than DSF (south zone). This is basically due to the fact that the building with GW reduces the cooling load more than the building with DSF. Meanwhile, applying GW reduces the heating load more in the east and west zones than applying DSF, and increases less heating load of south zones, although the heating load takes the smallest and most inconspicuous proportion of the building’s total energy consumption.

According to the simulation results, buildings with GW are able to reduce the cooling and heating load more than buildings with DSF under most conditions. GW protects the building from a great deal of heat gain through its evapotranspiration and the shading of plants during the summer, and it protects the building against heat loss through its insulation effect during the winter. However, the shading from GW also reduces building heat gain during the winter, thereby increasing the heating load. On the other hand, the DSF reduces the building cooling load through its stack effect in the cavity during the summer and reduces the building heating load through its greenhouse effect in the cavity during the winter. It seems that the shading and insulation effect of GW affect the building more significantly than the stack effect and greenhouse effect of DSF. One of the important factors that may lead to this result is the resistance of the DSF and GW materials. Plant layers have a higher R-value than the single glazed windows, so if one is considering DSF and GW as insulation, GW is the better insulation material.

The energy consumption for lighting is the second-largest in the total energy consumption. Applying both DSF and GW impacts the indoor daylighting and lighting load increases. Generally, more lighting load is required by the building with GW than the building with DSF, and a greater lighting load is required in the winter than in the summer.

Although the DSF used in the simulations is a transparent glazing type and a small amount of daylighting can be intercepted, the grills inside the DSF cavity can block a large amount of daylighting and shade the building. On the other hand, GW shades the building more completely, and much more daylighting is intercepted by the plants and the concrete container for the growth media of GW. This is why building with a second façade needs a greater lighting load than the base building and the building with GW needs a greater lighting load than the building with DSF. In addition, the sky is cloudier in the winter in Adelaide.

### 2.3 Annual Total Energy Consumption

Fig. 32 Energy consumption of north, west, east and south zones during summer and the winter

<table>
<thead>
<tr>
<th>Zone</th>
<th>Heating</th>
<th>Cooling</th>
<th>Lighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>West</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>East</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

GW reduces the cooling load more than DSF (south zone) or lead to a smaller increase in total energy consumption than DSF (south zone). This is basically due to the fact that the building with GW reduces the cooling load more than the building with DSF. Meanwhile, applying GW reduces the heating load more in the east and west zones than applying DSF, and increases less heating load of south zones, although the heating load takes the smallest and most inconspicuous proportion of the building’s total energy consumption.

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Fig. 33 Annual total energy consumption of north, west and east zones

Applying a second façade could efficiently reduce the building total energy consumption of the summer design week and the winter design week. This does not necessarily mean that the second façade has the potential to reduce the total energy consumption for the whole year, or that GW works more efficiently for building than DSF based on annual energy consumption. If the increased lighting load is larger than the decreased cooling load over the year, applying the second façade will be useless. Therefore, another series of simulations was run to compare the annual energy consumption of the base building, the building with DSF and the building with GW (0.1m). Since the previous

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**Fig. 32** Energy consumption of north, west, east and south zones during summer and the winter

**Fig. 33** Annual total energy consumption of north, west and east zones
results show that the south zone demands less energy without a second façade, the annual energy simulation focuses only on the north, west, and east zones.

From the standpoint of annual energy analysis (Fig. 33), applying a second façade to the north, west and east of building façade can reduce the total energy consumption for the whole year. Furthermore, the energy performance of the building with GW is better than the energy performance of the building with DSF on the north, west and east façades, respectively.

3. CONCLUSION

This study has compared the energy performance of a simple designed office building implementing DSF and GW respectively, based on simulation results carried out using the EnergyPlus simulation program. The analysis focuses on a comparison of the indoor temperature; cooling, heating and lighting load; and total energy consumption of the building with the two façade systems on four sides (one at a time) during a summer design week, during a winter design week, and over a year.

The results show that both DSF and GW have the potential to reduce building energy consumption, and the building with GW is able to reduce total energy consumption more and has better thermal performance than the building with DSF under most conditions. In general, the building with GW requires less energy on cooling and heating compared with the building with DSF. On the contrary, the building with DSF uses less energy for lighting than the building with GW. However, the south façade is an exception. Neither DSF nor GW reduces the south zone’s total energy consumption. Thus, DSF and GW are not suggested for installation on the south façade.

In addition, another impact of DSF and GW was discovered from the two-week simulation results. If only natural ventilation is provided for the building, the temperature of the building with DSF is generally higher than the temperature of the base building. The temperature of the building with GW is generally lower than the temperature of the base building.

The results from this study are for a proposed building in the Adelaide area only and may not be representative of applying the same techniques on buildings with different thermal properties and layouts, with different designs of DSF or GW, or even in other climate zones. Different buildings should be considered individually to achieve the best façade solutions through proper building performance simulation.

Future studies should be conducted and may include: (1) verifying the comparison of the performance of DSF and GW using measurements rather than based only on simulations; (2) expanding the focus of the comparison by looking at the life cycle analysis, which includes energy consumption and, installation and maintenance cost by applying DSF and GW; (3) studying the occupants’ perception of applying DSF and GW; and (4) comparing the impact on the urban environment by applying DSF and GW (to mitigate urban heat island effect).

REFERENCE

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