# Effect of Double Skin Facade Air Cavity and Orientation on Energy Efficiency in Hot-Dry Clime Buildings

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**Abstract**

*Institutional buildings are very important facilities that contribute to the development of every nation. Previous studies indicated that energy efficiency is the key challenge in hot dry climate buildings. This is due to the nature of building form, orientation and the risk of exposing building envelope to solar radiation, which attracts consumption of energy in tropical climate. This study aims at employing double skin facade to reduce the level of energy consumption for cooling in hot-dry climate buildings. The study examined energy performance of double skin facade with respect to effect of different horizontal distances in air cavity and orientation. Experimental study was conducted through Ecotect simulation software to study energy performance of double skin facade in hot dry clime using weather data of the same climate region. The study established that 900mm double skin facade air cavity depth reduced cooling energy by 31% in hot-dry climate and designing double skin facade on south orientation in hot-dry climate reduced cooling energy consumption by 4%.*

**Keywords:** Double skin facade, Air cavity, Orientation, Hot-dry climate, Energy efficiency

## INTRODUCTION

In Nigeria, energy consumption in buildings is continuously increasing, as the ecological zones of Nigeria have been experiencing a temperature increase per decade (Oladipo, 2011). Consequently cooling loads in the institutional buildings of Nigeria account for 40% of energy consumption (Batagarawa, Hamza, & Dudek , 2011). Most of the energy consumed by buildings is for provision of heating/cooling and air-conditioning which attracts the need to drive alternative means of achieving occupants'/users' comfort in building and energy saving (Milan, Tomas, & Roman, 2014).Therefore, it can be concluded that climate has a strong influence on the large amount of energy consumed for cooling loads in hot dry climate buildings. Cooling a space in an institutional building is necessary, and the best way to achieve that in Nigeria is through private power generation (Adenikinju, 2005). Chou & Chiou (2007) asserted that solar radiation has a pronounced influence on buildings in hot dry climate, more than 30% of cooling load in buildings are caused by the solar radiation passing through envelope walls and windows. Previous researchers have suggested that the risk of exposing buildings to solar radiation attracts high level of energy consumption for cooling the envelope in tropical climate (Rahmani, Zin , & Parisa , 2012). However, buildings are also affected by some design perimeter such as; building form, orientation and urban patterns, which are parameters affecting occupants' comfort and energy conservation in building (Leylian, Amirkhani, Bemanian, & Abedi, 2010). Murphy & Charles

(2010) asserted that lowering electricity consumption for powering air conditioning systems especially in institutional buildings where cooling is needed for users' comfort will significantly enhance energy saving in such facility.

According to Amed, Abdel-Rahman, Ali, & Suzuki (2016) double skin facade is one of the best architectural strategy that manages the interactions between outdoor and indoor spaces. Related studies determined effect of double skin facade on energy consumption in different climatic regions, whereas little or no study was conducted in hot dry climate on the effect of double skin facade and its design parameters on buildings' energy consumption.

**Double Skin Facade Concept**

The term double skin facade can be defined as an integration of two conventional single skin facade which are separated by air cavity, the second layer is largely dominated by glazing. Each of these layers are commonly referred to as a skin, hence the origin of the widely used term ''Double Skin Facade'' (Atef , 2017). The air cavity (either naturally or mechanically ventilated) is used for evacuating the radiated heat absorbed by the facade elements. The outer glazed skin can be single or double glazing units with a distance from 0.2m to 2m from the inner skin. Sometimes, for radiation protection, solar shading devices are placed inside the cavity (Parra et al, 2015). The double skin facade could have made a very good architectural tool which when properly designed base on climate would effetely reduce energy consumption due to cooling in buildings. Double skin facade is categorised in to; Box window, shaft, corridor and multi-story double skin facade.

**Air cavity**

Torres et al. (2007) investigated on DSF cavity dimensions for saving energy on mediterranean climate, city of Barcelona in particular. The study employed experimental assessment method (simulation) using TAS software. Parameters tested on an office building base case are DSF cavity depth (400mm, 600mm, 800mm and 1000mm). Which predicted that DSF saves more energy on annual cooling load in the climate when designed with thinner cavity and large exterior openings in the case of multi-storey facade.

**Orientation**

Atef (2017), carry out a study that analysed DSF effect on thermal comfort and energy consumption in office buildings in three different cities; Alexanda, Cairo and Aswan city. This study employed simulation via IETSVE simulation tool as method of assessing effect of DSF base on four orientations (North, East, South and West) in office building in those cities. Result of the worst case scinario predicted reduction of 11% cooling loads in Alexanda, 14% cooling loads in Cairo and 35% cooling loads in Aswan city. It has been concluded that DSF performs best when oriented towards north and south with horizontal shading devices and 300mm width window openings in the cavity.

## METHODOLOGY

The study was conducted via experimental control of the surroundings. An in-depth analysis using computer simulation was adopted to identify the level of energy consumption in hot dry climate buildings and to help in identifying optimum DSF air cavity and orientation in the climate. Ecotech simulation engine was used to simulate different air cavity sizes of DSF on the hottest day (6th of April) in hot dry climate using weather data of Katsina. A base case was selected from in an existing building within the hot dry region of Katsina and modeled using Revit 2017. Figure 1 show the base case in the modelling environment. The base case is produced as a duplicate of an existing conference hall located in Katsina, Katsina state. The base case was simulated through which hourly air temperature was obtained for the hottest day.

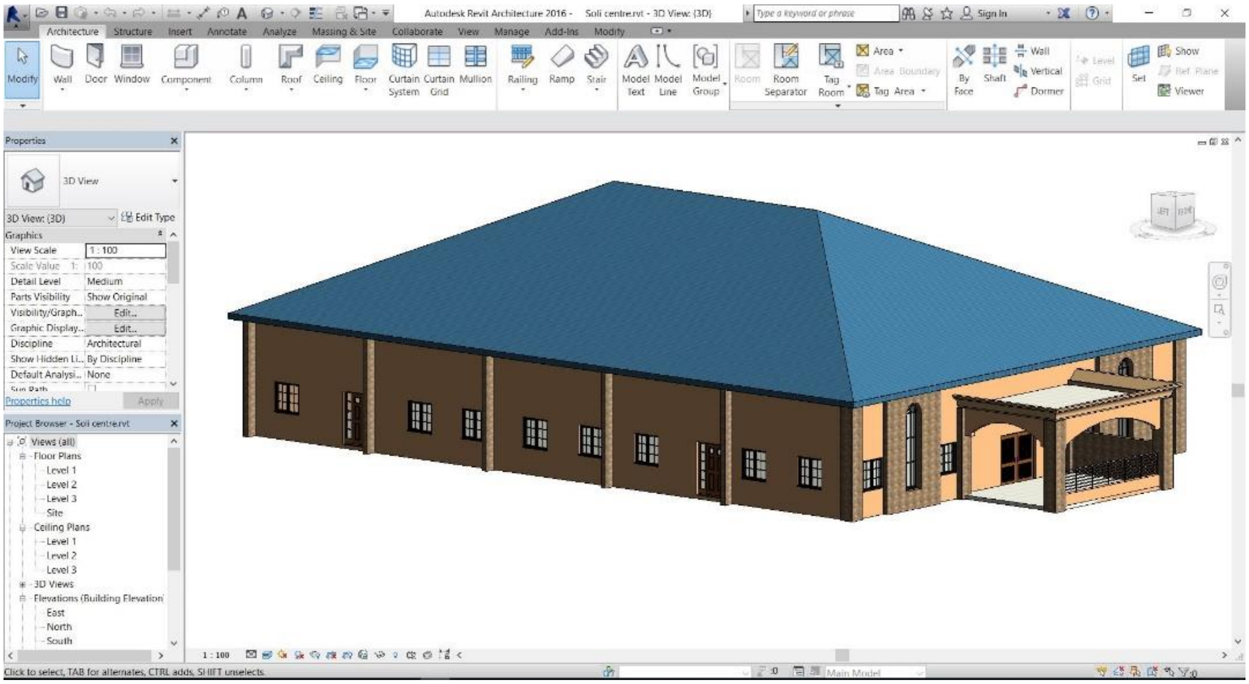

Figure 1: Base case

**Dependent and Independent variables**

The dependent and independent variables investigated in the study are presented in figure 2.

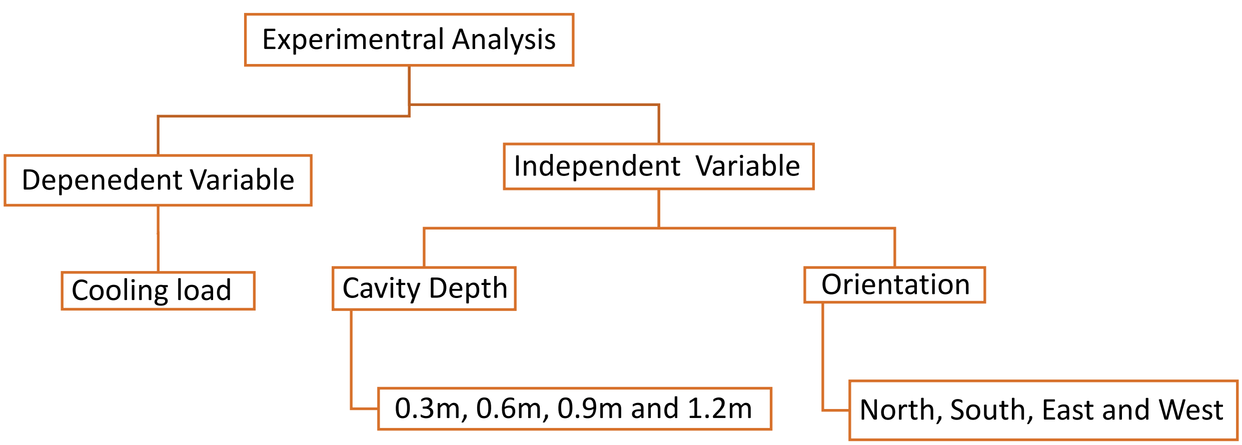


Figure 2: Dependent and independent variables

**The building**

The model is a conference hall (institutional building) with 380 capacity. DSF cavity is naturally ventilated 24 hours during the whole year through a shaft façade, partitioned at a certain distance.

The air flows diagonally, entering through bottom opening and exiting by top opening on the DSF exterior skin.

**Simulation**

Ecotect software was adopted was for the simulations using hourly conditions according to local climate data (weather data of Katsina), the simulations describe cooling loads consumption in all the involved scenarios. Ecotect software also takes into account internal loads like equipment, and people's load in the building. The simulation software is provided with climatic data and predefined internal loads, plus the construction materials with their thermal properties. Energy demand for mechanical conditioning of the building is obtained from a balance between internal and external loads, construction materials and heat exchange between the building and the external environment. All these parameters will determine the necessary energy to keep the system working properly. The study concentrated on performance of the building by means of its energy demand for cooling loads and effects of the applied parameters in reference to reduction of energy consumption.

The base case was simulated after which different DSF configurations where incorporated and cooling loads obtained for each simulated scenario. Comparative analysis was conducted for the different cases to determine the extent to which cooling load reduction was obtained. Selection of the conference hall (base case) was based on the following criteria.

a) Single skin glazed façade exposed to the outdoor climate.
b) Large scale conference building located within hot dry region of Nigeria.
c) Located in a fast growing commercial area of the selected location

A typical cross section across the DSF model adopted for this study is shown in figure 3. D is horizontal distance in the air cavity between internal and external skin and W stands for the external skin material configuration. Both variables were modified and simulated using the same boundary conditions.

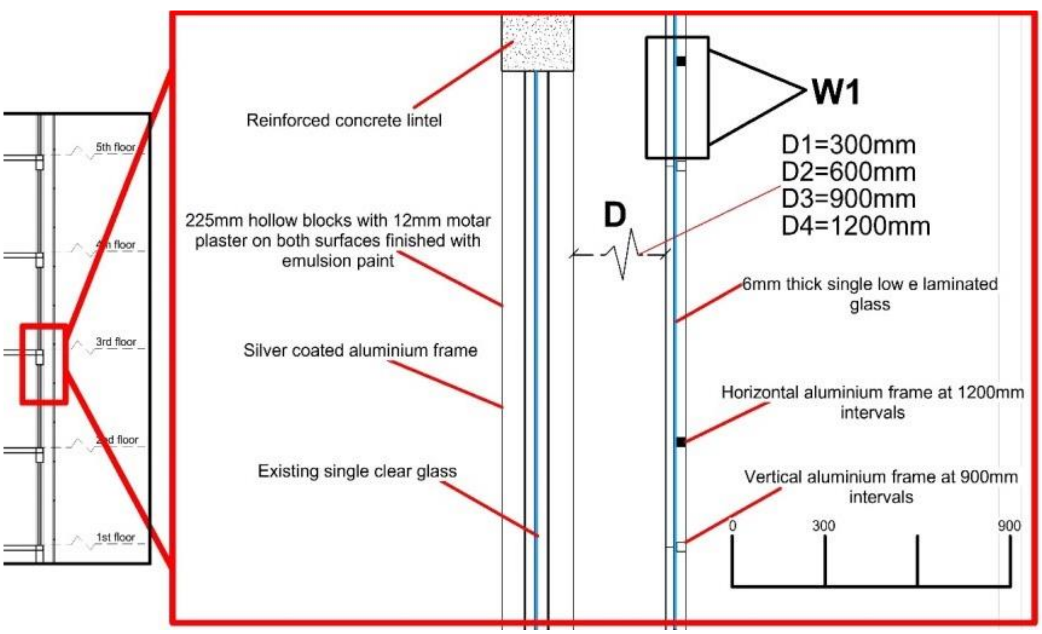


Figure 3: Cross section of DSF model

For the first scenario, the simulation adapted four different cavity depths (0.3, 0.6, 0.9 and 1.2m) represented by D1, D2, D3 and D4 respectively with a fully glazed external envelope made of 6mm thick low emissivity (Low E) coating. The DSF model was incorporated to the base case through the south façade for all simulated cavity depths. The simulation sequence started with cavity depths simulation, the simulations were conducted varying facade's cavity width (D1, D2, D3 and D4).

Table 1: Building materials properties

| simulation input data | | | |
|---|---|---|---|
| Working schedule | 8am to 8 pm | Ground floors U-value | 0.27W/m$^2$C |
| Artificial lighting thermal load | 15 W/m$^2$ | Exterior walls U-value | 0.5W/m$^2$C |
| occupancy latent gain | 4.2W/m$^2$ | Exterior walls solar absorption | 0.51 W/m$^2$ |
| Air leakage | 0.05 – 0.1ACH | Exterior walls reflectivity | 0.55 W/m$^2$ |
| Floor height | 4.5m | Roof u-value | 0.25W/m$^2$C |
| Exterior glazing width | 3.9mm | Roof solar absorption | 1 W/m$^2$ |
| Exterior glazing U-value | 5.73 W/m$^2$C | roof solar reflectivity | 0.57 W/m$^2$ |
| Exterior glazing solar absorption | 0.56W/m$^2$ | Cavity partition elements U-value | 6W/m$^2$C |
| Exterior glazing reflectivity | 0.73 W/m$^2$ | Windows frame conductivity | 0.14W/m$^2$C |

## RESULTS AND DISCUSSION

Number of simulations were carried out on the base case model with different cavity depths, result shows cooling load with and without DSF model. Cooling load reduction for all simulated cases were obtained at best using envelope material configuration state above.

Table 2: Reference case monthly cooling load with different sizes of air cavity.

| Cooling loads (kwh) | | | | |
|---|---|---|---|---|
| Months | D1 | D2 | D3 | D4 |
| Jan | 2659.498 | 1913.881 | 1662.455 | 1769.447 |
| Feb | 3480.412 | 3309.029 | 2872.479 | 3076.758 |
| Mar | 5277.824 | 440.355 | 4967.854 | 5254.214 |
| Apr | 8388.732 | 7053.976 | 6468.004 | 6862.807 |
| May | 8437.141 | 7198.137 | 6577.117 | 7002.124 |
| Jun | 7988.771 | 6853.911 | 6273.413 | 6665.312 |
| Jul | 5163.335 | 5427.617 | 4921.582 | 5239.135 |
| Aug | 3069.989 | 4161.403 | 3782.998 | 3986.212 |
| Sep | 4294.582 | 4772.958 | 4377.241 | 4598.37 |
| Oct | 5852.966 | 6084.679 | 5521.117 | 5893.907 |
| Nov | 4306.266 | 4313.046 | 3924.799 | 4111.898 |
| Dec | 2438.131 | 1745.213 | 1409.508 | 1592.055 |
| Total | **61357.645** | **58274.203** | **52758.566** | **56052.234** |
| Floor Area | **814.834 m2** | | | |

**Effect of DSF air cavity depths on base case model**

Different depths of DSF air cavity were applied on the base case with 5% external opening on the DSF. Simulations of all the selected DSF air cavities were carried out along north orientation. Table 2 shows effect of DSF cavity depth applied on the base case; the table stated monthly cooling loads and total annual cooling loads as generated from the simulations.

However, Table 3 shows annual cooling load per metre square in kilo watt hour (kwh) and maximum cooling load recorded from the simulation carried out with the selected air cavity sizes.

Table 3: Cooling load/m$^2$ and maximum cooling

| Air cavity | Annual cooling perm$^2$(kwh) | Max. Cooling (kw) | Date |
|---|---|---|---|
| D1 | 75.301 | 37.229 | 6$^{th}$ April |
| D2 | 71.517 | 35.577 | 6$^{th}$ April |
| D3 | 64.748 | 37.229 | 6$^{th}$ April |
| D4 | 68.79 | 37.229 | 6$^{th}$ April |

From the results presented in Table 2 above, D3 (0.9m) as DSF air cavity size tends to be more effective on the base case when it comes to optimizing cooling load. Whereas D1 air cavity proved vice versa with the least effect on similar model. However, base case simulation with D2 air cavity has the least maximum (max) cooling load; 35.577kw in the month of April which consumes highest amount of energy for cooling in a year. This is due to the fact that hot season is more pronounced in April whereby the solar radiation is at its peak with high temperature in hot dry climate.

**Effect of DSF orientation on the base case model**

Simulations of the base case modelled with DSF base on the four cardinal points (North, East, South and West) were conducted to determine the best orientation for DSF in hot dry climate region of Katsina. Table 4 shows effect of orientation on the base case DSF.

Table 4: Effect of the DSF orientation on reference case building envelope

| Cavity size | | DSF orientation | | | |
|---|---|---|---|---|---|
| | | North | East | West | South |
| D1 | ACL (kwh) | 61357.645 | 58319.098 | 59446.52 | 58014.844 |
| | ACL Perm$^2$(kwh) | 75.301 | 71.572 | 72.955 | 71.198 |
| D2 | ACL (kwh) | 58274.203 | 56247.238 | 57455.246 | 55133.812 |
| | ACL Perm$^2$(kwh) | 71.517 | 69.029 | 70.512 | 67.663 |
| D3 | ACL (kwh) | 52758.566 | 48789.898 | 51586.719 | 47840.977 |
| | ACL Perm$^2$(kwh) | 64.748 | 59.877 | 63.31 | 58.713 |
| D4 | ACL (kwh) | 56052.234 | 54388.922 | 55641.973 | 54117.941 |
| | ACL Perm$^2$(kwh) | 68.745 | 66.748 | 68.286 | 66.416 |

The result presented in Table 4 above, shows that annual cooling load (ACL) consumption has a slide difference in all the scenarios. The base case modelled with 900mm air cavity depth being it optimum size in the region, indicates that south orientation produced the highest energy saving with about 58014.844kwh. While North orientation has least effect on DSF with cooling energy consumption of 61357.64kwh. Therefore, these drive a conclusion that south orientation is the best with 4% energy saving compared to the worst case scenario (North) and is the appropriate orientation to Place DSF in hot dry climate.

Results from the simulation proved that by incorporating sufficiently designed Double Skin Facade (DSF) model on south facade to a single skin building in hot dry climate, cooling load reduction can be achieved to a reasonable extent depending on the external envelope material configuration.

Simulation result of the variables tested on the base case shows that; 0.9m (D1) air cavity depth and south orientation are the optimum variables for DSF in hot-dry climate. These optimum variables; DSF air cavity depth and orientation were able to reduced annual cooling energy consumption on the base case by 31% and 4% respectively.

## CONCLUSION

This study investigated the effect of cavity depth and orientation of a Double Skin Facade on cooling load in hot dry climate, specifically Katsina. This was undertaken to improve the application of DSF particularly in the hot dry region of Nigeria as most of the investigations regarding DSF were conducted in other climates. The result shows that DSF reduces cooling load which equally reduced dependency on mechanical cooling especially in hot dry climates where heat is dominant. The integration of DSF in hot dry climate of Katsina has shown great improvement in reducing internal heat gains thereby enhancing internal thermal environment for occupants. An energy reduction of up to 31% has been achieved by incorporating DSF on building envelope with adequate cavity depth in hot dry region thereby, leading to identifiable reduction in cooling loads and subsequently, reducing greenhouse gas emissions. Cooling load reduction through DSF is affected by many factors such as envelope material, orientation and cavity depths all of which should be taken into consideration at the onset of the design. However, further studies should be embarked on to investigate the effect of DSF cavity height and openings on air flow with regards to cooling load and heat gain.

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