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ASSESSMENT OF DOUBLE SKIN FACADE FOR ENERGY EFFICIENCY IN HIGH-RISE OFFICE BUILDING, ABUJA.

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ABSTRACT
The cooling need of office buildings for adequate work efficiency and comfort in hot humid climates like that of Abuja has led to an increase in building energy consumption. In other to achieve these needs a high amount of energy has been significantly placed on the energy grid system of the city and furthermore due to the unstable supply of electricity the users of the such buildings have alternatively resorted to the use of other sources of power which is generation through the burning of fossil fuels. This has contributed in turn contributed significantly in global warming and ozone layer depletion. Building envelopes have been proven to enhance in building sustainability substantially in the aspect of energy efficiency around the globe. This study is aimed at assessing the effect of double skin façade (DSF) cavity depth and external skin material on energy efficiency in the hot humid climate of Abuja. The study employed a mixed methodology with the use of case studies and computational simulations using the quasi-experimental approach. With the use of prototype DSF models and a purposively selected case study of a typical commercial office building reference base case models were generated and energy simulations performed using Energy Plus Design Builder to obtain annual cooling load data for varying base cases with and without a DSF solution. The most optimal DSF external skin material and cavity depth combination is the Amorphous silicon (a-Si) PV-DSF with a cavity depth of 300mm which had a significant reduction in the total energy consumption. Further application of these findings on the Churchgate Tower, Abuja base case reduced the total annual cooling loads of the building. This implies that adequate selection of DSF cavity depth and envelope material would increase energy savings thereby enhancing energy efficiency. This study therefore recommends the use of the photovoltaic double skin façade as it performed well in reducing cooling loads and also provides potentials for substantial energy generation especially in high-rise buildings.

KEYWORDS: Double-skin Façade, Envelope, Energy, Efficiency.

BACKGROUND TO STUDY

A double skin facade (DSF) consists of an internal skin of facade which is the normal facade, an air cavity and an additional external skin in which both layers are made of glass. This facades design work as a building envelope lending character to the building and also significant energy savings. The DSF plays a significant role as the thermal buffer zone between the external and internal building environment, and these performances offer building energy saving opportunities (Abdul-Wahab, 2019).

According to Ding, Hasemi, & Yamada (2005) DSF incorporates the passive strategies of natural ventilation, day lighting and solar heat gain into the fabric of a building which form the key components with respect to energy efficiency and comfort while having transparent facade of modern buildings for adequate day lighting. However, its implementation is accompanied by significant challenges in terms of adaptability to climatic conditions of different geographical areas. Study shows that the performance of a building envelope in the hot humid climate, an energy saving of as much as 31.4% and peak cooling load saving of 36.8% for high-rise apartments was recorded by implementing passive energy efficiency strategies (Abdul-Wahab, 2019).

The facade design should be such that it achieves goals that are critical and important to the particular context it is being built in and the main goal of a building facade in a temperate region as Nigeria should be to reduce the solar heat gain and give access to adequate day lighting. But unfortunately, this has not been the in facade design of contemporary buildings in countries like Nigeria which is situated in a very different context in terms of climatic conditions, all just been a mimicry of the western building facade in the use of curtain wall and completely glazed facades.. Leading to an increased demand in the building energy consumption. The need to meet this demand through the use of fossil fuel has greatly led to the climatic change and ozone layer depletion (Anderson, 2016) Notwithstanding, there is a solution and this research intends to have an assessment on double skin façade in other to improve energy efficiency in high-rise mixed-use buildings in the hot humid composite climate of Abuja.

LITERATURE REVIEW

DSF is termed as a pair of glass skin separated with air corridor that has main layer of glass usually insulating. There is an air space between the layer of glass which acts as insulation against wind, sound and temperature with shading devices often located between the two skins.

Many types of DSFs have been developed since the first double layer was used in the building envelope (Wigginton). It is helpful to agree on a consolidated classification of DSFs (Parkin 2004).

Furthermore, Saelens (2002) defined the multiple-skin facade as “an envelope construction, which consists of two transparent surfaces separated by a cavity,

which is used as an air channel." The extra skin offers improved thermal insulation.
The integration of Solar shading systems can be adopted with the cavity, protecting the building from excessive sun, or the used of photovoltaic glass can be needfully adopted. The Solar radiation absorbed by the shading systems will also be connected into the air volume in the cavity and conveced into a soucrce of energy for cooling or ventilated out of the building. The main types of DSF are four. These icludes the following; Buffer DSF system, Extract air DSF systems, Twin faced DSF system, Hybrid DSF systems.

Buffer DSF System:
These predate the invention of insulating glass, which was made to keep light entering the buildings while enhancing the soundproofing and insulating capabilities of the wall system.
They use two layers of single glazing separated by a distance of 250 mm to 900 mm, sealed, and allowing fresh air into the building through a controlled method, such as a HVAC system or box type window that penetrates the overall double skin with shading devices built into the cavity. An illustration of a buffer DSF system can be seen in the image below.

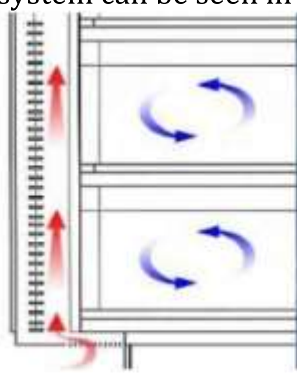

Fig.1: Buffer DSF
Source: Boake UW

Figs. 3 & 4: Business promotion centre Germany
Source: www.fosterandpartner.com

Extract Air DSF System:
In order to make the air space between the two layers of glazing a part of the HVAC system, second layer of glazing was a double-galzed çade adeed to the interior of main fa (thermopane units). While the outer layer of insulating glass minimizes heat-transmission gain, the heated used air between the glazed layers is extracted through the cavity with the aid of fans, tempering the inner layer of glazing and the fresh air is provided by HVAC, eliminating natural ventilation. Additionally, shading devices can be mounted on the cavity, with air spaces ranging from 150mm to 900mm between the layers of glass. This system is typically used in locations with high noise levels or those where natural ventilation is not possible.

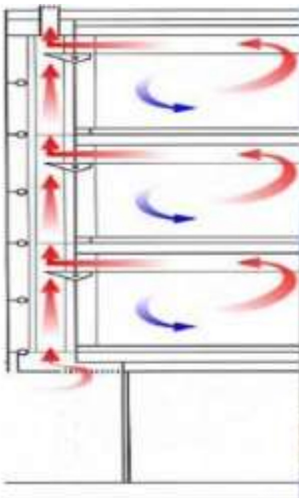

Fig. 5: Extract Air DSF **Figs. 6 & 7: Bürogebäude Felbermayr, Salzburg, Austria.** *Source: T Boake UW* *Source: www.architecten.at*

Twin Face DSF System:

Within a single glass building skin, this consists of a conventional curtain or thermal mass wall system. The outer glass could be laminated, insulating, or safety glass. Shading tools might be present. This system needs an interior space for cleaning activities. In contrast to the buffer and extract air DSF system, the twin faced DSF has an opening for allowing natural ventilation. The internal skin serves as insulation to reduce heat gain, whereas the external skin serves as a shading device to protect the contents of the air cavity. This system is mostly used and highly effective in hot climate where the main aim is to increase in heat transmission loss, reduction of noise and natural ventilation. This method can be applied in a box window system, corridor system or even a multi storey system.

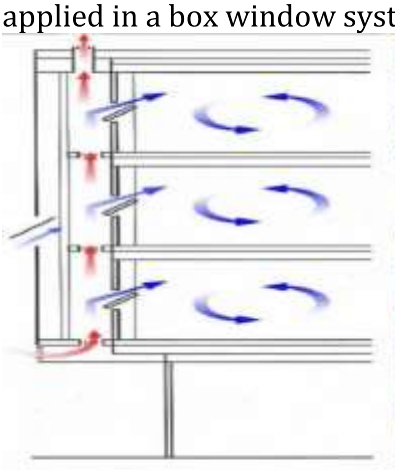

Fig. 8: Twin Face DSF **Figs. 9: Daimler Benz (Debis) Building, Berlin**

Source: T Boake UW *Source: www.coltinfo.net* *Source: www.rpbw.com*

Hybrid DSF System:

Hybrid DSF system is the combination of any two the above mentioned DSF systems used in a situation where any among them does not accommodate to the building system involved. The buildings may use a layer of screens or nonglazed materials on either the inside or outside of the primary environmental barrier. The Jiao center in New Caledonia by Renzo Piano may be used to as an example of hybrid DSF system.

Working phenomenon of Double Skin Facade

The temperature difference between the outside air and cavity air created by the solar intensity reaching the DSF has been identified as one of the most important elements in generating ventilation for the indoor space. It is the main natural stimuli of the thermal and airflow behaviour of the DSF as studied by Kim *et al.* (2009), Gratia and De Herde (2007). The phenomenon of thermal chimney on the DSF occurs due to the density difference between the warmer air inside the cavity and the cooler outside air. The air inside the cavity is warmed up by the solar radiation and exhausted to outside from the top of the cavity.

The fresh air drawn through the inlet between the external and internal envelope, passes through the cavity right into the required space of use and the heated air is then discharged through the outlet into the external environment. Thus, the effective use of the DSF can enhance energy for cooling purposes by stack effect driven by the heat from the users of the building.

Control Strategy of DSF installation in buildings

A crucial point when integrating Double Skin Façade systems in buildings is to define a control strategy that allows the use of solar gains during the heating period and provides acceptable thermal comfort conditions during the whole year. The risk of the offices becoming extremely cold during the harmattan is high when the design of the Double Skin Façade is not coupled properly with the strategy of the HVAC system. According to Stec *et al.,* (2003) this system allows the outside conditions influence the indoor climate. As the authors describe, "Efficient control system needs to be applied to manage rapidly changing outside conditions. A successful application can only be achieved when the contributions of all the devices can be synchronized by an integral control system". According to the authors, "The control system of the "Passive climate system" of the building should be done according to the following principles:

1. In order to save energy, the control system must take the maximum advantage from the outside conditions before switches over to the air conditioning system (Poirazis, 2006).

2. All the control system must be focused on the realization of the comfort with the lowest energy consumption.
3. During the unoccupied period the control system is focused only on the energy saving, while during the occupied period must be focused on the comfort as well.

The control system has three tasks to fulfill with the use of the passive and active components.
These tasks are following:

a. keep the right level of the temperature inside the building
b. supply sufficient amount of the ventilation air to the building
c. ensure the right amount of light inside the building".

Table 1. 1a*:* Summary of Related methodologies from similar studies

Title/ Author	Objectives	Method	Instruments of Data collection
Exploring building envelope design for energy efficiency in the design of a net-zero energy housing estate, Kano state, Nigeria. (Dansarai, 2018)	To determine the annual energy demand and energy performance of residential buildings in hot dry climate of northern Nigeria.	Energy audit	Checklist
	To evaluate the effectiveness of various design strategies of the building envelope for each case study building to determine the most effectual in achieving energy efficiency	Computer simulations	Design Builder
	To compare electricity consumption data from case studies to the expected annual energy demand by the proposed net zero energy models.	Case study and Computer simulations	Checklist, Design builder
	To validate the computer software's and user's ability to simulate PCMs in buildings	Comparative validation	Two different versions of Energy Plus

Assessing the thermal performance of phase change materials in	To investigate electricity consumption within office buildings in Nigeria	Literature review and Energy Audit	Literature review and Energy Audit
composite hot humid/hot dry climates: ***An examination of office buildings in Abuja Nigeria.*** **(Batagarawa, 2013)**			
	To evaluate the potential effect of incorporating PCMs in the building fabric on thermal comfort and energy consumption	Computational simulations	Energy Plus V6 and V7 and Design builder V3
Double skin facades and heat modulation in the design of hotel in hot dry climate, Kano. (Aliyu, 2017)	Identify appropriate cavity depth and DSF material for hot dry climate	Identify appropriate cavity depth and DSF material for hot dry climate	Literature, checklist, Ecotect
	To identify heat gains in existing hotel buildings in hot dry climate	Literature review, case study and computational	Literature, Ecotect
	To evaluate various types and configuration of Double skin façade	Literature review	Literature
	To evaluate the extent to which DSF can improve heat modulation in hot dry climate	Computational simulation	Ecotect
Assessing the viability of double skin glass facade for enhancing thermal	To identify the optimum window types used in tropical wet and dry	Literature review and visual survey	Literature, Checklist
comfort in the design of four-star hotel Kaduna, Nigeria. (Abdul-Wahab, 2019)	climate.		
	To investigate the effect of DSGF glazing material in lowering solar heat gain in the context of Nigeria	Computational simulation	Design Builder

	To calculate the best cavity width that will enhance thermal comfort in tropical wet and dry climate of Nigeria	Computational simulation	Design Builder
An evaluation of architectural forms for improving energy efficiency in shopping mall design, Abuja. (Ngague, 2017)	To investigate the level at which the factors that determines the choice of building forms to achieve energy efficiency was considered in existing shopping mall	Case studies	Checklist, Camera
	To evaluate the effects of building forms on annual cooling, heating load and illumination level.	Computer simulation	Ecotect
Assessing the Role of Double Skin Facade in Improving the Thermal Comfort Condition of Microfinance Bank; Ahmadu Bello University, Zaria;	To identify the various types of DSF systems available	Literature Review	Literature
Nigeria (Abubakar and Ibrahim, 2019)			
	To identify the various types of DSF systems that can be employed in hot-dry climate	Literature Review	Literature

Source: Author's literature review, 2023

THE RESEARCH METHOD

The study employed a mixed methodology. A descriptive and quasi-experimental approach of a research design was employed by the use of case studies and computational simulations. A descriptive research design for the objective to determine and identify energy consumption patterns for cooling in high rise buildings and energy audits was be conducted on individual case models chosen for the study. With the use of prototype DSF models and a purposive selected case study of a typical commercial office building reference, base case models were generated and energy simulations performed using Energy Plus Design Builder to obtain annual cooling load data for varying base cases with and without a DSF solution.

Sampling Method

The purposive sampling method was adopted for this study in selecting cases. Factors that necessitated this were geographical location, type of climate, building Typology and the availability of energy consumption data.

Data Collection

A preliminary site visit was conducted following a pre notification of scheduled visits; primary and secondary was obtained for analysis. A reference building model of the cases studied was developed and the energy consumption of the base case models was determined from both primary and secondary data obtained. Energy audits, visual surveys and observation was conducted with the aid of a guided tour round the site, taking note of cooling appliances and their power rating.

Methods of Data Collection

The research being evaluative and quasi-experimental in nature, this study employed a visual survey and assessment method (with physical measurements and documentation) and energy audit to obtain data. System design parameters and constraints was duly examined.

FINDINGS AND DISCUSSIONS

During the entire construction process, pertinent information regarding theçade double skin fa

This parameter has a direct impact on both the general design and construction process. These fundamental and basic criteria include the following: Type and design of the façade; Type of façade structural design -Present cavity geometry Different shading, glazing, and lighting devices are used. Materials for panned and shading devices are chosen. Positioning of shading devices is based on cavity type and building HVAC.

The above-mentioned factors and thorough analysis of the Double-skin facade system's performance result in good technical knowledge and handling of the system during the design construction, and post-construction stages.

Additionally, the engineer will analyze all of the aforementioned data in accordance with the aforementioned parameters.

As a result, this will produce the primary goals that have been set, which are crucial for the design and construction of a double skin façade. Energy use during the construction stage (typically 10 to 20% of the total energy use) and during the occupation stage (typically 80 to 90% of the total energy use) are also factors to take into account. Indoor climate considerations also include thermal and visual comfort, air quality, and acoustical concerns. Last but not least, the building's façade's environmental impact during construction, afterward, and during occupancy, as well as the cost of the investment, operation, and maintenance.

To achieve a comprehensive approach and for professionals to be more accurate in their design process predictions that will prevent unpleasant flaws and issues that will increase the construction or operational costs of the Double-skin facade, design constraints should include measures taken at an early stage of the decision-making process.

These include:

- Climate (sunlight, air temperature, etc.)
- The building's location and obstructions (such as latitude, the amount of local daylight available, the atmosphere, exterior obstructions, ground reflectance, etc.).
- The building's use (operational hours, occupant duties, etc.).
- Rules governing construction and design.

Summary of Findings from Prototype DSF Simulations

For the 300mm cavity depth test a maximum cooling load reduction of 22% by the pv DSF and 21.8% by the3/6mm dble low e glass air both on the east orientation and a minimum of 7.6% by the 6mm single clear glass.

For the 600mm cavity depth test a maximum cooling load reduction of 15.1% and a minimum of 4.0%.

The 900mm cavity depth test revealed a maximum cooling load reduction of 15.5% and a minimum of 4.1%.

The 1200mm cavity depth test revealed a maximum cooling load reduction of 15.5% and a minimum of 4.1.

For the 1500mm cavity test a maximum cooling load reduction of 15.7% and a minimum of 4.2%.

For all simulations the east orientation and pv-dsf recorded the maximum cooling load reduction.

As illustrated in figure 4.33 below, the general cooling load patterns for the cavity depth and materials test revealed lower cooling loads for 300mm cavity depth a seemingly constant cooling load pattern for 600mm,900mm and 1200mm cavity depths while a sudden drop in that of 1500mm was noticed. This is illustrated with a line in the chart in figure 1.

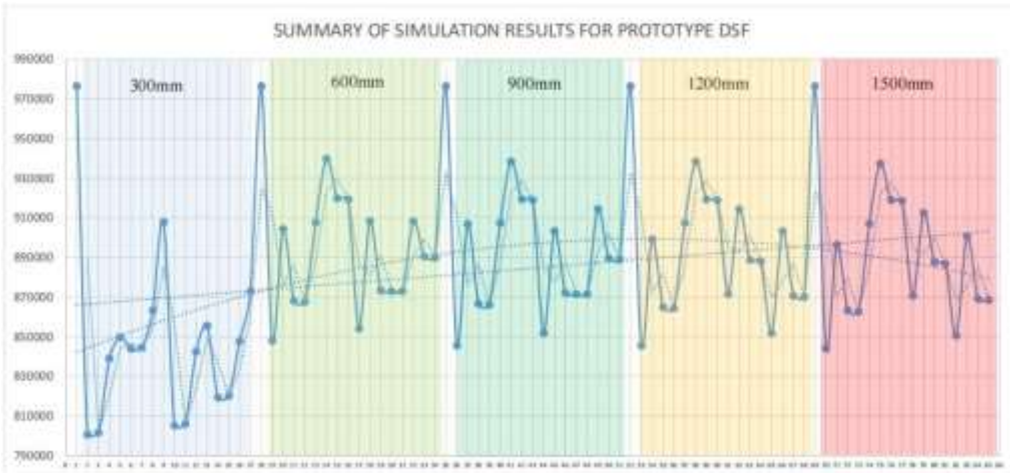

Figure 1: Chart showing summary of result from simulation
Source: Author (2023)

RECOMMENDATION AND CONCLUSION

According to my research, twin faced DSFs are more dependable, particularly in hot climates, because they permit natural ventilation because they have operable windows, which is preferable but requires more technical construction, and extract air DSFs are more complicated mechanically. Additionally, the double skin façade system has both positive benefits and negative drawbacks.

These benefits include lowering the demand for heating, supplying views, solar heat gain regulation, thermal insulation, Increased security, provision for natural ventilation, increases building lifespan, improves occupant comfort, future-proofs the structure, and provides emergency egress and acoustic protection. It also acts as a pollution barrier.

The initial cost of construction and space consumption are then its main drawbacks. In order to innovate and advance technological understanding, knowledge, and technical know-how of the use of the DSF in various building types and in various zones globally, more in-depth research on DSF should be conducted on various climatic conditions and zones.

In conclusion, it is crucial that all of the project's participating professionals (Architects, HVAC designers, users, etc) get together and establish the project's main priorities after establishing the basic and fundamental goal for the design and construction of the DSF system. When the project is finished, doing this will produce effective and ideal results.

in order to build a high-rise that is energy efficient. These recommendations are based on this study.

1. The study tested double skin façade models (DSF) for two different climates, and the results support the idea that a double skin façade should be implemented according to the local climate. So before integrating a DSF into a building, the necessary tests should be run.

2. The photovoltaic double skin façade is suggested for use as it performed well in reducing cooling loads and offers potentials for significant energy generation, particularly in high-rise buildings.
3. Before specifications are made in designs, adequate cavity depth and material tests for DSF should be conducted.
4. To decrease cooling loads and improve energy efficiency, this study suggests using double skin façades in high-rise buildings.
5. Prior to approval by the appropriate bodies, the performance tests of buildings should be made a requirement as part of the planning stage of design.

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