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Integration of Double Skin Facade with HVAC Systems: The State of the Art on Building Energy Efficiency

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Abstract: **The nature of heating, ventilation and air conditioning (HVAC) systems of a building, its facade and the system controlling them plays a great role and affects the natural ventilation of the building envelope.**
It was reported that about 10–60% of energy consumed by a building is caused by HVAC systems Depending on the building type.
However, the Double Skin Facade in now widely known to be a means of conserving the wasted energy through design of intelligent buildings.
The main aim of this paper is to outline the different systems of the Double Skin Façade systems, examine their characteristics and functions, their advantages and disadvantages and finally the Integration with HVAC System. It will also present recent researches carried out by different authors in relation to the subject. Furthermore, relevant software used for simulation of the Double Skin Facade–HVAC systems Integration and the building envelope in general will be outlined. There is a need for practicing Architects and other related engineers to in-cooperate it in their designs from the design stage since it is a complex subject that needs a careful understanding according to the different individual climatic factors. Finally, it was concluded that building efficiency can be achieved through integration by reducing building's energy consumption.

Keywords: **Building Envelope, Double Skin Facade, HVAC System, Modelling, Natural Ventilation, Thermal Comfort and Simulation**

I. INTRODUCTION

The emerging trend in Architecture for the use of Facade in our building designs, has disposed an impelling force in finding new methods to enhance the energy performance of buildings.

The outdoor climate of our conventional buildings are now considered as a problem that can discomfort the inhabitants of which its effects must be controlled through heating, ventilation and air conditioning.

Zero energy building has attracted a lot of attention internationally in order to reduce energy consumption in buildings, save cost of services bills and as well saving the environment. This is now seen as the target for future building designs (Lynch 2015)

It was also discovered that people spend averagely 90% of their lives indoors of which the HVAC system consumes a higher percentage (Hensen & Clark, 2014).

HVAC system is now pushing designers to apply new solutions to the building ventilation system as a continuous bid to cut the energy consumptions. Nowadays the design of office buildings are increasingly done in full or part glazing of Double Skin Facade.

Now the question is, "is integration of the Double Skin Facade with the HVAC systems possible? Can they work together and at the same time minimise energy consumption?"

Researchers have studied a lot regarding the use of Double Skin Facade and HVAC systems but however lacks the integration of both (Stec & van Paasen 2004). Example of such include the following articles. An Integration of services in buildings through Design approach (Fouchal, Hassan, & Loveday 2013), Marija Hensen & Wetter (2010), Co-simulation for performance prediction of integrated building and HVAC systems in order to analyse the characteristics solution using a two-body system. Stec and Paaseen (2005) studied the Optimisation of an HVAC system with a Double Skin Facade.

Poirazis (2006) in one of his papers, conducted a literature review of multiple skin facades and recommended some new research topics and in another one Poirazis (2008) analysed single and double skin glazed office buildings for Scandinavian climatic conditions.

More also, Kragh et al (2002) studied on advanced facades and HVAC systems, a Preliminary results of full-scale Monitoring by providing Twelve full-scale test rooms which were used to monitor different configurations of facades and environmental systems.

Alibaba and Ozdeniz (2011) also studied on the thermal comfort of multiple-skin facades in warm climate Offices. The author conducted a parametric study on warm climate by testing a building set up at Eastern Mediterranean University. This research was aimed at guiding the architects and other designers on implementation of the concept at their design stage.

Never the less, Stec & Paassen (2004) wrote a paper titled symbiosis of the double skin facade with the HVAC system. They tested several buildings using different components, comparing the double skin and single skin façade and letter discussed the impact of the natural or mechanical night cooling.

Maio and Paassen (2004) studied in one of their papers, an Integration of HVAC systems with Double Skin Facades in buildings.

However these Research seems insufficient due to the fact that it is difficult to apply practically as the author have not yet seen or heard so far of any building in the world that has the Integration of the HVAC systems with Double Skin Facade. Thus a need to further research into the subject.

Therefore this paper will review recent studies and or researches in regards to the subject in order to encourage designers to come up with easier ways for implementation.

II. LITREATURE REVIEW

A. Double Skin Façade:

Double skin facade paved its way in the early 1990s with its history and practical implementation not particularly established but however it is popularly used in developed countries which regulates performance of their buildings (Ahmed et al, 2016). Choi and Kwak (2012) maintained that very few counties have standard guides on how to design and access its performance, thus a barrier for its implementation.

Arons (2000) defined Double Skin Facade as that which consists of two distinct planar elements that allows the air in the internal part of a building or the exterior to go through the system (cited by Poirazis, 2006).

The concept behind the Double Skin Facade is that of an ordinary Facade, which has another external glass skin with an air cavity in between.

Klein (2013) further explained the system as that which consists of two skins placed with air flowing within the intermediate cavity where by the outer skins are single glazing while the inner are insulated with other possible constellation.

Heiselberg et al.(2001) maintained that, it act as an element that responds to climate with both natural and mechanical ventilation (hybrid) concept which has the possibility of changing the concept of the airflow just as to the climatic and weather conditions.

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It is a pair of glass skin which is separated by an air corridor with a width ranging from 20cm and above which can be applied to stretch all over the building or just a portion of it (Uuttu 2001).

Claessens and DeHerte cited by Poirazis (2006) further explained that the space between the second skin and the original facade serves as a buffer zone which insulates the building which may also be heated by the sun according to the orientation of the sun. The heated air on the south can be used to heat up spaces in winter. Therefore, there is a need to be vented in as much as possible to refrain from overheating during the summer.

According to De Gracia *et al*. (2013), the wind in the surrounding and its pressure difference serve as the main factor that encourage the movement of air in the building with double skin facade.

B. Classification of Double Skin Facades:

Double Skin Facade have several classifications by different Authors, some of which are according to the type of air flow in the cavity, destination, origin and construction type.

Uuttu, (2001) classified it as the following:

- Building-high double-skin facade
- Box Double-Skin Facades
- Storey-High Double-Skin Facades
- Shaft Facades

Oesterle et al. (2001), classified the Double Skin Facades based on the Architectural forms and ventilation function as outlined below:

1. Box window: this has openings inwards for easy supply of fresh air with divided cavity between room which helps to reduce the spread of sound and smell in the room.

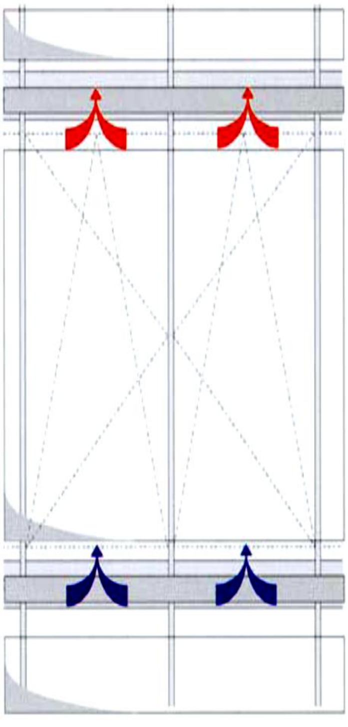

FIG.1 elevation of a box window double skin facade (Oesterle et al, 2001)

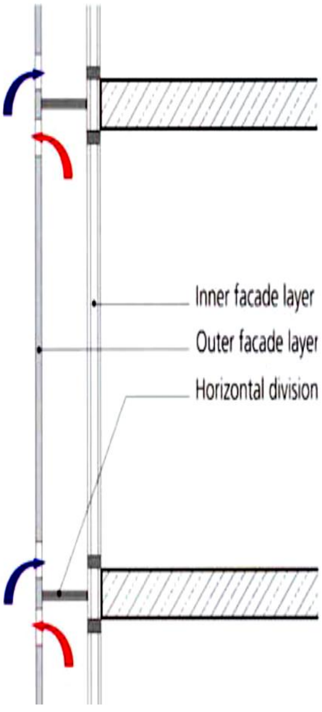

FIG.2 section of a box window double skin facade (Oesterle et al, 2001)

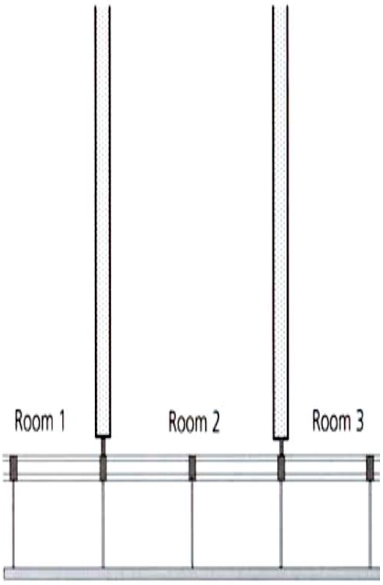

FIG.3 floor plan of a box window double skin façade (Oesterle et al, 2001)

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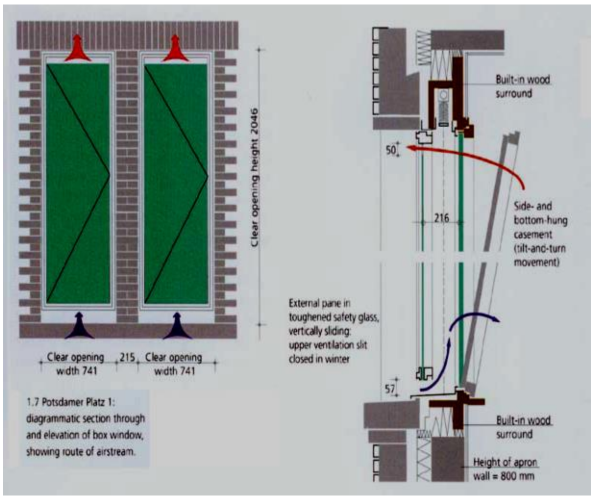
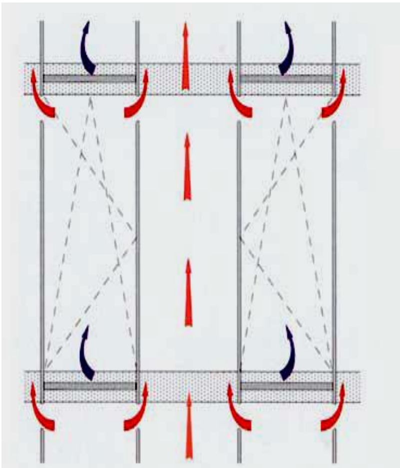
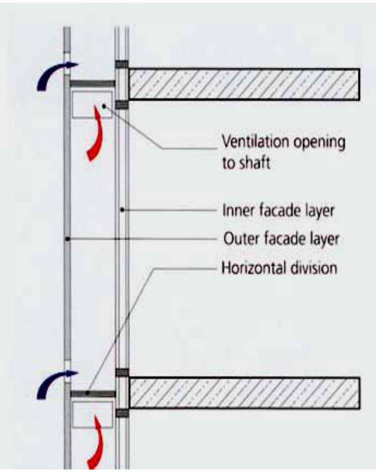


FIG. 4 a section through and an elevation of a box window (Oesterle et al, 2001)

Fig.5 a box window at Berlin Postdermer Platz building (Oesterle et al, 2001)

2. **Shaft Box Facade:** This form however requires less openings on the outer skin in order to reduce noise from the street. It consist of a special form of box window which goes up vertically over many floor to produce stack effect.





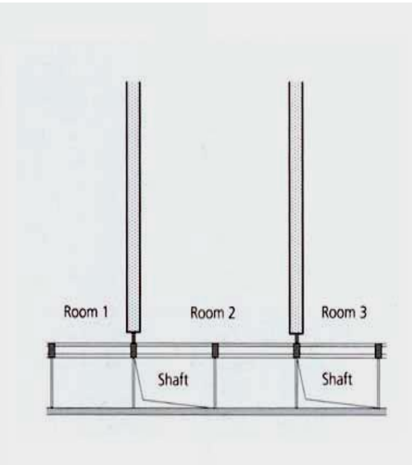


FIG. 6 elevation of a shaft box façade (Oesterle et al, 2001)

FIG. 7 section through a shaft box facade (Oesterle et al, 2001)

FIG. 8 floor plan of a shaft box facade (Oesterle et al, 2001)

FIG.9 Exterior view of Arag Tower shaft, facade, Dusseldorf (Oesterle et al, 2001)

FIG.10 Interior View of Arag Tower shaft facade, Dusseldorf (Oesterle et al, 2001)

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3. Corridor Facade: in this type of facade, the floors are divided and closed horizontally along the corridor. However the division only occurs when there is a need for acoustics, fire protection, or ventilation. It has its openings mechanically ventilated.

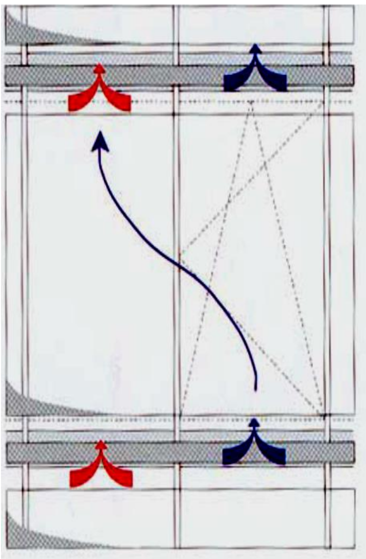

FIG.11 elevation of a corridor façade (Oesterle et al, 2001)

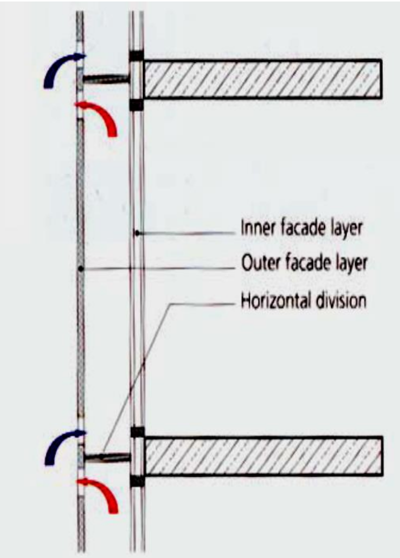

FIG.12 section through a corridor facade (Oesterle et al, 2001)

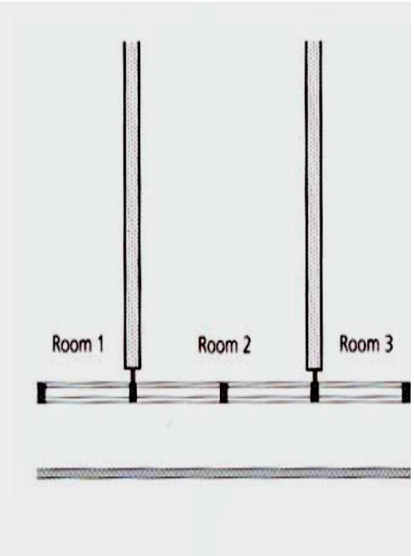

FIG.13 floor plan of a corridor facade (Oesterle et al, 2001)

4. Multi Storey Façade:

This type of facade does not necessarily need openings on the external skin in the sense that it takes in air from the bottom and release it at the top while the space in between the two skin is vertically and horizontally adjoined

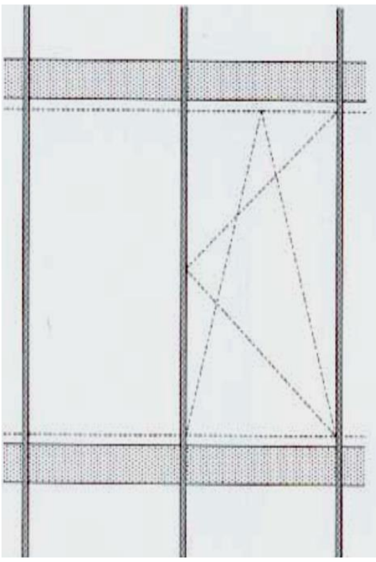

FIG.14 elevation of a multi storey facade (Oesterle et al, 2001)

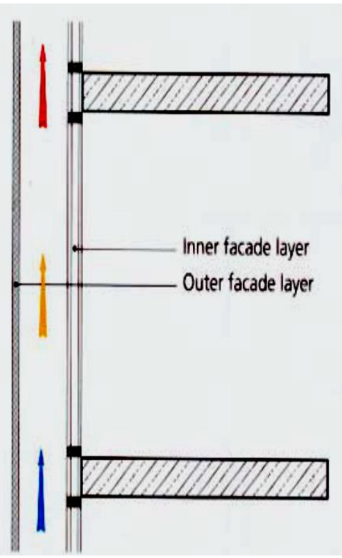

FIG.15 section through a multi storey facade (Oesterle et al, 2001)

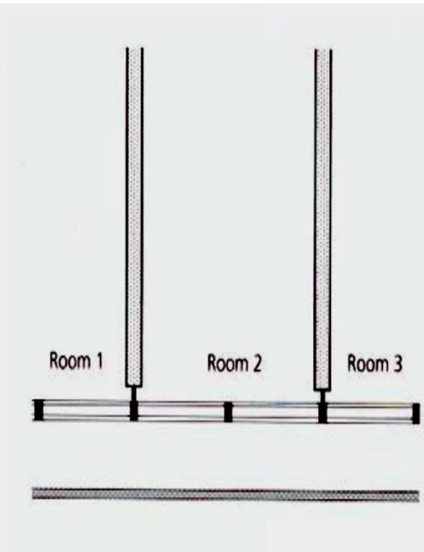

FIG.16 floor plan of a multi storey facade (Oesterle et al, 2001)

Furthermore Lang and Hertzog (2000) classified the double skin facade into four, namely: the buffer, extract air, twin face and hybrid (cited by Pollard & Beatty 2008).

Buffer Double Skin Façade: produces a buffer in between the internal and external part of a building whereas the cavity serves as an insulation in such a way that the heat gained in the cavity can be evacuated in summer by the stack effect. Example is show in Fig. 17-19 below.

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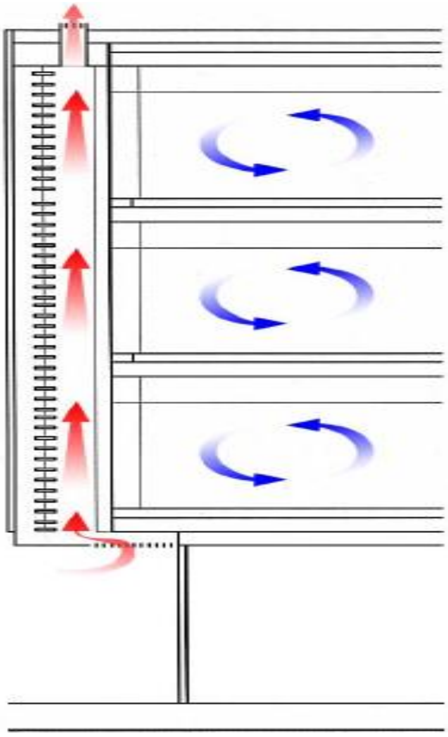

Fig. 17 Buffer DSF
(Polard & Beatty, 2008)

Figs. 18 & 19: Business Promotion Centre Germany
(Polard & Beatty, 2008)

Extract Air Double Skin Façade makes use of the heat trapped between the internal and external cavities for re use in the HVAC system where by the cavity serves as the exhaust of the returning air.

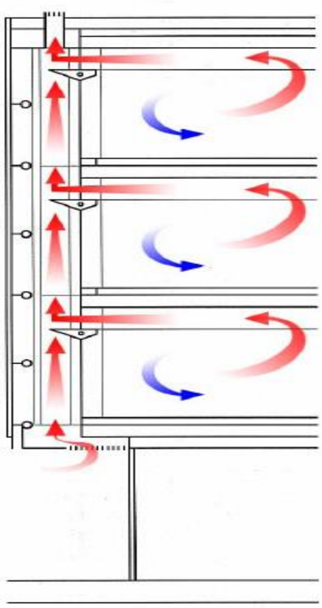

Fig. 20: Extract Air DSF
(Polard & Beatty, 2008)

Figs. 21 & 22: Bürogebäude Felbermayr, Salzburg, Austria
(Polard & Beatty, 2008)

Twin Face Double Skin Façade: this type contains both interior and exterior operable windows which can allow natural ventilation to circulate within both the cavity and interior of the building.

In this type of façade, the internal skin has doubled glazing while the external is single glazed

This type of façade is mostly used in location where less heating is required. (Polard & Beatty, 2008)

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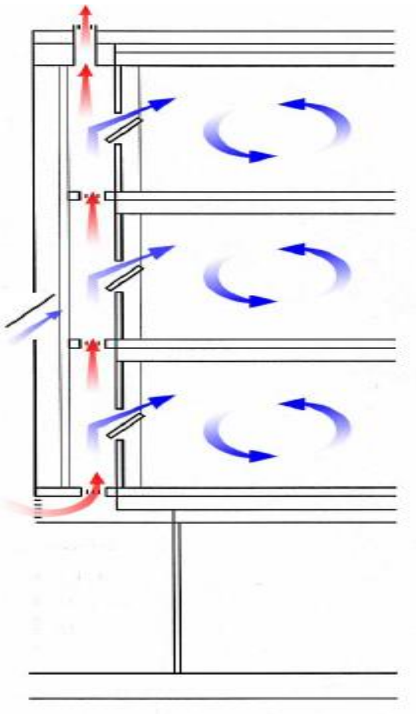

Fig. 23: Twin Face DSF (Polard & Beatty, 2008)

Figs. 24 & 25: Daimler Benz (Debis) Building, Berlin (Polard & Beatty, 2008)

Hybrid Double Skin Façade: combines the principles of, or variation of three other types of the double skin façade mention above. Example is shown in the in fig. 26& 27 below where by ceramic rod were used to reduce glare and heat from the sun as well as allowing natural lightening to penetrate into the building. The aim of this design was reduce the amount of energy consumed by the HVAC and lightening systems.

Fig. 26: New York Times Building (Polard & Beatty, 2008)

Fig 27: Detail of ceramic shading elements (Polard & Beatty, 2008)

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III. ADVANTAGES AND DISADVANTAGES OF A DOUBLE SKIN FACADE SYSTEM

a. Advantages:

The main Advantage of the Double Skin Facade is its ability to save energy and allow enough light into the interior spaces of a building and also reducing the use of the HVAC system.

In regards to this subject, a number of authors have outlined their views.

Author and Pollard (2000) mentioned the following as some of the Advantages:

- Reduction in heating demand
- Reduction in energy consumption
- Solar gain Control
- Reduced environmental impacts

Van Paassen & Stec (2006) also outlined the following:

- Improved thermal insulation
- Improved sound attenuation
- Lower solar energy transmission
- Preheating the ventilating air
- Night cooling
- Reduced capacity and energy consumption of the HVAC system
- Psychological impact of transparent facades on the inhabitants
- Architectural aesthetic aspect

b. Disadvantages:

- Higher costs
- More complicated control systems
- Higher gross area of the building
- Reduced daylight transmission
- unclear limit of fire protection
- Maintenance and operational cost (Oesterle et al, 2001)

IV. HEATING, VENTILATION AND AIR CONDITIONING (HVAC) SYSTEMS

The concept of the heating, ventilation and air conditioning (HVAC) system is a technology of environmental comfort which has the function of thermal comfort, acceptable air quality, reasonable installation, operational and maintenance cost.

These systems are known for provision of ventilation and maintained air pressure where by their control systems and installations are integrated into a single or more HVAC systems.

Their installation also varies depending on the use and type of the building and its requirement for heating, ventilation and air conditioning in that environment.

The controls systems makes it possible to monitor and control the usage of the HVAC systems effectively (Gupta et al 2011).

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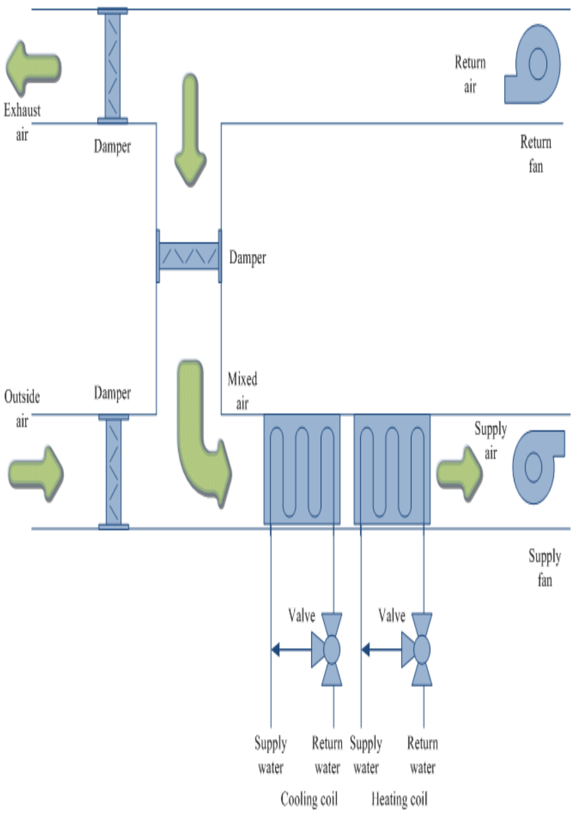
The choice of the HVAC system determines the performance of the building envelop which has a great impact in terms of the capacity needed and the type of applications that can meet up the requirement (Kragh et al 2002).

According to Zaheeruddin (2006), the energy consumed by a building through the HVAC system is over 60% with the possibility of even increasing in the future if not carefully controlled. Thus the need for a comfortable environment for the inhabitants. Furthermore, Stec & Paassen (2004) noted that the HVAC system is pushing designers to apply new solutions for the ventilation systems due to continuous demand to cut their energy consumption. They further highlighted multiple skin façade, natural ventilation, night cooling, effective use of ground, solar and wind energy as other issues that are gaining attention due to their ability to save energy.

Stec et al. (2003) further maintained that HVAC system can be used in three ways namely:

- Full HVAC: involves the highest energy use but has a choice of the control system usage, mechanically or naturally ventilated.
- Limited HVAC: uses the facade to support the HVAC as a pre-heater, pre-cooler etc.
- No HVAC: use no HVAC but the double skin facade which reduces the energy use.



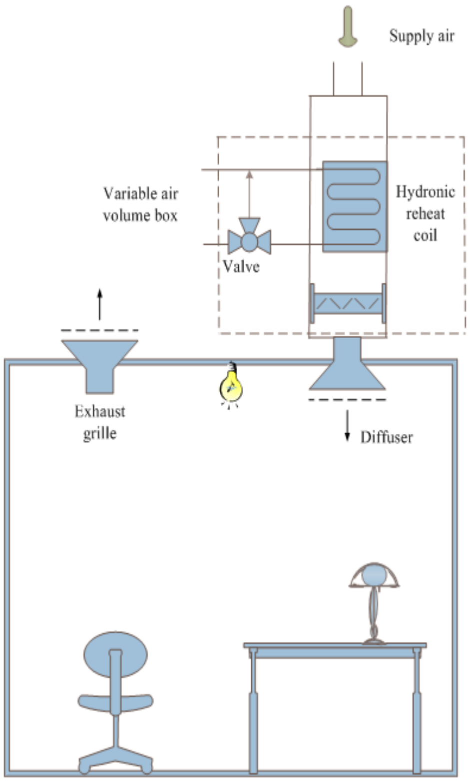


FIG. 17 Schematic diagram of a typical single-room variable-air-volume box (Zaheeruddin 2006)

FIG. 18 Schematic diagram of a typical air handling unit system (Zaheeruddin 2006)

According to Marija et al (2010), HVAC systems are responsible for 10–60% of the total building energy consumption Depending on the building type.

V. INTEGRATION OF DOUBLE SKIN FACADE AND HVAC SYSTEMS

The concept behind the Integration lies on the attempt to stop or reduce the use of the HVAC systems in ventilating the interior spaces of our buildings. Therefore integrating the Double Skin Facade with the HVAC system is aimed at improving thermal comfort by utilising the heat from the sun and the wind in order to reduce the energy consumption of the building.

The need to reduce the energy consumption of our buildings worldwide has being the state of the Art in the construction industry, thus necessitating in depth research in to the subject.

Maio and Paassen (2000) presented a paper on the above subject, briefly explaining the concept of the double skin facade and also the effects of air temperature in the buildings, the outdoor climate, the need for thermal comfort and the need to reduce energy consumption. They studied a system of a Double Skin Facade coupled to a west oriented four storey building simulating the external environment and the facade using Simulink simulation code.

They ascertained that a cooler air is endowed in the second and first floor while the highest floor experienced an averagely higher air indoor temperature as a result of the warm air present in the cavity.

They finally concluded that the double skin façade can be used as a preheating device system with natural air supply which has some openings in its inner façade, as an exhaust fan or as a fresh preheated air supplier for a central air handling unit.

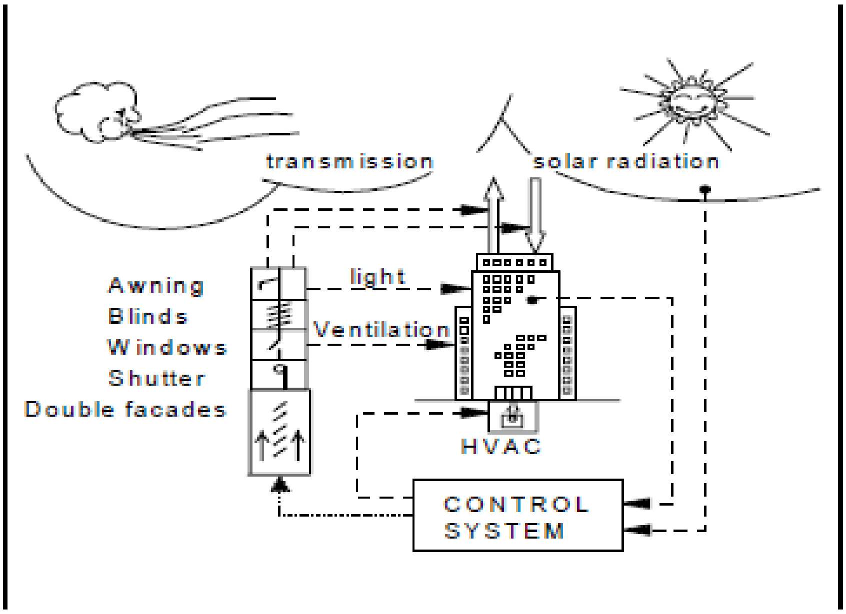


FIG. 19 a schematic building with an intelligent facade (Di maio and Van Paassen, 2000)

Another Research is that of Stec & Paassen (2004) titled "Symbiosis of the double skin facade with the HVAC system". They conveyed test using a test cell at TU Delft, real office building with Double Skin Façade, Laboratory test facility and a design program (VABI software) as options in order to validate their simulation using both Mat lab and Simulink simulation software. This options were shown in Figures below.

Fig. 20 Laboratory test facility (Stec & van Paassen (2004) **Fig. 21) test cell at TU Delft, building in Zwolle, NL (Stec & van Paassen (2004)** **Fig. 22 UNICA office (Stec & at TU Delft, Van Paassen (2004)**

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They compared the Double to the Single Skin Facades, external shading devices and with the climate wall. They developed a ventilation model which was able to calculate air flows through the cavity and inlets of the second skin according to the model's thermal output, the pressure generator, wind generator, the stack effect generator and the data from the simulator work space.

The ventilation model that the authors developed calculates the flows through the inlet and cavities of the second skin based on The outputs of the pressure generator, the wind generator, the stack effect generator, data of the weather acquired from the mat lab work space and the thermal model in whole. It was concluded that the structure with the Double Skin Facade may compete with the traditional buildings with external shading successfully in terms of thermal comfort.

They also found out that the choice of the building depend on both the Double Skin Facade and simplicity of HVAC system. Furthermore, the use of natural ventilation through operable windows and simple algorithms for weather predictions allows for reduction up to 70% of the energy consumption. It was concluded that smaller HVAC system installation may be used to compensate the cost of the façade as well as a reduction in the energy consumption which will in turn encourage the use of the double skin façade as viable solution

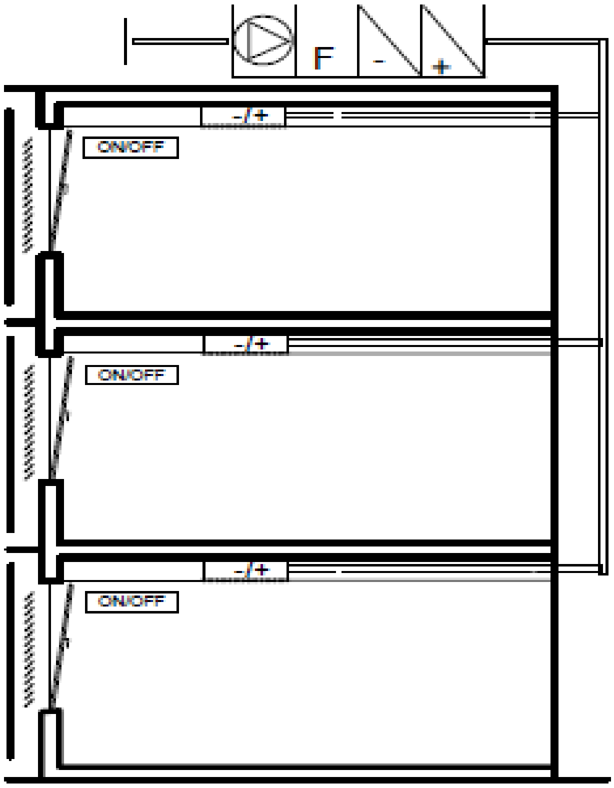

FIG. 23 *The* double skin facade as an exhaust ventilation duct of the building (Stec et al, 2006)

VI. MODELING AND SIMULATION

This subject has become the latest trend for architect, engineers and other designers as a result of the global need to reduce energy consumptions and dependence on fuel which contains polluting carbon deposits which causes a gradual damage to the ozone layer of the planet earth.

A number of modelling and simulation software have being used by different researcher in order to examine the efficiency of integrating the double skin facade with the ventilation or HVAC system.

Stec and Paassen 2004 conducted a simulation, testing and comparing the energy efficiency using UNICA Office in Zwolle, a Laboratory Test facility, a test cell at TU Delft and VABI design Software as shown in the figure 20, 21 and 22 above. Simulink simulation software and Mat lab were used to process the weather and building data to extract values of the temperature, solar radiation and wind conditions.

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Maio & van Paassen (2001) made use of the Alpha Generator subsystem inside the Double Facade model which used variables and other weather data to make the desired calculations. So also, Mat lab was used to store the air temperature from the rooms.

However most of the researcher prefer using the simulink simulation software in the sense that it allows a group of people carrying out different research to produce unique component which can be transferred and used by other groups simultaneously and successfully (Stec and Paassen, 2004).

Recently, Lynch (2015) conducted a study to find out how energy modelling affect the design process. He found out that, the energy simulation software was able to reach or surpass the 60%energy reduction and even 25% more coming closer.

This rest had given us the courage to start encouraging the present and upcoming architects to integrate the techniques in their buildings right from the design stage.

According to the American institute of architects' report, Sefaira is the most common used as a plugging for 3d modelling programs such as google sketchUp and Revit which recently added the feature in order to allow designers to see the impact of the energy on their architectural model (cited by Lynch, 2015). Other modelling tools include the Trace 700 (for HVAC systems), Vabi, eQuest, Trynsys (for solar design), Designer Builder, IESVE, IES Virtual Environment for Architects, Open Studio, Green Building Studio, and Graph iSOFT Eco Designer Star, and an extension for ArchiCAD (Lynch, 2015) and HVACSIM+, BLAST, TUTSIM, ESP-r and a DOE-2 (Hensen, 2014).

VII. FINDINGS AND DISCUSSIONS

In the cause of this paper, it was found that difficulties encountered in the process of the integration of the HVAC system with the double skin facade were limited to the control system of the individual facade. However, in the other way round the automated control system with manual over riding can allow the double skin facade to reduce energy wastage.

It was also understood that a successful application can be accomplished by making use of a single control system to integrate all the devices.

Furthermore, it was found that by reducing the mechanical ventilation, excessive expenses on the facade can be balanced. Optimising the HVAC system with the double skin facade can reduce both the energy consumption and obviously the initial cost.

The double skin facade was found to have the ability to strongly enhance the climate comfort in the interior spaces as well as minimising the rate of energy consumption without incurring additional cost to the total cost of investment. It also encourages the use of natural ventilation in different ways, therefore the reduction in the use of mechanical climate installations double skin facade. The double skin façade can also protects the building against weather conditions like the wind pressure and solar radiation. It can serve as a self-cooling systems as a pre heater to the building.

The high cost of the double skin facade is also able to be compensated by reducing the cost of installations of the indoor climate

Furthermore, it was also found that plant can be used as a shading device which reduces the increase in temperature in surface of the cavity.

VIII. CONCLUSION

The study was able to examine the different systems of double skin facade, their characteristics, advantages and disadvantages, the concept behind the double skin facade and its integration with the HVAC system concerning energy consumption and comfort which are the main aim of the study. Also recent researches done by different authors pertaining the subject were presented. It also highlights the various modelling and simulation software that can be used for testing the integration.

The fact that the double skin facade creates comfort in the indoor, it can be integrated as part of the HVAC system, as such demanding the need to revamp the design of both the double skin facade and the HVAC system in order to reduce the energy consumption.

The paper was able to show that building efficiency can be achieved through the integration of the Double Skin Facade with HVAC system by minimizing energy consumption of the building.

Finally, a smaller HVAC installation can be used to compensate the high cost of the double skin facade due to the reduction in energy consumption and thus will encourage the application in building construction.

By the integration, it can be said that the building is able to compete in both thermal and economic point of view, with the traditional building which has an external shading.

If Architects are able to build models from their designs using the modelling and simulation software, building efficiency will be ascertained and thus enhancing the beauty in their aesthetically appeasing structures.

Therefore, integrating the Double Skin Facade with HVAC system will if successfully implemented during the design stage reduce the reliance on mechanical systems for heating, ventilation and air conditioning as well as enhancing natural ventilation and comfort in our habitable spaces.

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