ISSN No:-2456-2165

The Effects of Smart Facade on Office Buildings

Abdulrahman Hasan Alsalim
Architect at Istanbul Okan University, Institute of Sciences and Architecture, Istanbul, Turkey
Prof: Kerem Ercoskun

Abstract:- Technology is the ultimate component for more sustainable buildings and better quality of life. Technology also changes our lifestyle and habits. Retrofitting of old buildings transform the spaces we live in; from a simple mixture from various construction materials to sophisticated high- performance machines thanks to the development and advancement in technology. One of the research domains for retrofitting is the building envelope and building facades as a subset of it. Increasing awareness towards energy conservation and reducing carbon emissions requires finding appropriate technological solutions in terms of facades which is a mediator for the ecological among external and. This energy conservation performance of the building can be drastically improved by contemporary façade technologies. Various design strategies are available for better façade performance which includes developments in the field of smart materials, better thermal insulation, power generation, vertical gardens and green infrastructure, selecting optimum mixture of solid and void areas, dynamic shading elements, biomimetic design approaches, light shelves, etc. The impact of the external environment is reduced by using static and mobile systems with great savings for energy expenses as well, A façade is providing appropriate natural ventilation, shading, and openings in hot locations. Meanwhile, It also allows the sun to shine as brightly as possible in colder climates. This adjustment ensures a perfect environment; The term "intelligent" facades refers to facades that change their aesthetic appearance.

Three elements can be used to classify the comprehensive performances of intelligent façade device, energy consumption, visual comfort, and thermally comfort are the three key system utilities.

Each of these utilities is defined as a function of the system's can be observed situation while adhering to a set of extra control variable requirements, The summation of these three utilities evaluated by user preferences is then used to create the cost function.

The restricted nonlinear optimization problem arises when the cost function is minimized. The system's dynamics are highly nonlinear, and there are extra constraints on the control variables, Analytically solving this optimal control problem is tough. On the contrary, daylighting is frequently used to save electricity and may also improve visibility, The primary benefits of daylighting are untouchable the use of natural light in construction is influenced by a number of variables. These variables ae summarized in aesthetics, psychological response, health, energy and cost.

In this research the detailing principles and the identification measures for smart facades a well as their main effects on office buildings, with reference to previous case studies and past projects located mainly in Saudi Arabia are elaborated.

Keywords:- *Smart façade, Smart materials, Saving energy, Technology solution.*

I. INTRODUCTION

A. Problem Statement

Technology has affected buildings and may be affected as presently as they're obtainable. If today's buildings are no longer as they are accustomed to be, being an easy mixture of various building materials solely, but rather became superior machines developed with the event and progress of technology, then sensible buildings with high potential have emerged by desegregation advanced technology into the building's details and parts, and in line with the wants of the times. And the sensible facades emerged and joined with the foremost necessary elements of the sensible building as a result of the primary defensive barrier. It performs the foremost performance that it fully was designed to boot and provide multiple services, the quality facade at intervals of historically made buildings cannot perform in terms of being facades that square measure effectively awake to the encircling setting and through a swish and uninterrupted manner. It fulfills many needs of rationalizing energy consumption associated with making an applicable, snug, and distinct setting for its occupants, with associate degree aesthetic performance throughout operation. Several branches of knowledge studies have treated sensible facades in buildings with multiple and various style aspects in terms of their formations, techniques, and materials adopted in them. As well as a result of the character of the performances and responses that they accomplish per totally different biological representations, and these studies highlighted the restricted information and theoretical and sensible presentation of the chances, development, or replacement of existing interfaces, to boot as restricted Arab and native application.

The presence of windows allows inhabitants to benefit from natural light, a sense of openness, direct lighting, visual touch with the surface, The use of daylighting rather than electrical lighting is modified by windows, which provide occupants with a nice outside reading experience. However, Glazing has the potential to generate a variety of issues: Due of its high U-value, it experiences considerable unwanted heat gain during the cooling season and heat loss during the winter. Glare is caused by an overly brightened window surface. This could be a major source of dissatisfaction among residents Furthermore, uneven thermal radiation caused by cold or hot window surfaces can cause thermal discomfort. To reduce the risks associated with window systems, Throughout the 1970s, double skin façades and air flow window systems were developed at various times. In summer and winter, they usually have opening louvers and ventilation holes that compel completely distinct air flow regimes through the glass boxed in chamber. The current disadvantage of double skin façades and air flow windows is that they require proper dynamic management to achieve the results that had performed. several investigation have recognized that solely associate degree optimum management of the louvre angle and air flow regime allows, these devices will primarily serve as active energy savers and indoor temperature controllers. However, associate degree with sufficient resolution for this moveable optimization downside should date not been developed.

Associate degree residents will use a standard browser to reach the sensible controller and select a pre-defined model. (energy consumption model, natural ventilation comfort model, thermal insulation comfort model, standard model, and nighttime mode are all examples of energy-saving modes.) or set a most well-liked mode (user-override mode) by adjusting the screen's preference sliders.

Fig 1:- Smart façade system installed in the College of Architecture building, Georgia Institute of Technology

B. Objectives of Study

In some emerging locations, there is a high degree of energy use, resulting in significant ecological difficulties like within the geographic region It has the second-highest intensity of energy use within the world (World Energy Council, 2012). Many of the energy use is accounted for by fossil fuels produced by construction within the region, which causes considerable amounts of greenhouse emission (GHG) emissions, and, indeed, buildings account for pretty much 40% of ultimate energy consumption and related GHG emissions in most countries. However, in Saudi Arabia (where the study was initially geared toward) things are even worse, this number goes much higher and reaches almost 80% of the overall energy consumption. Moreover, during the amount of 1971-2004, residential buildings in geographic area accounted for the second largest regional producer of CO2 emissions. the first objective of this study is to look at the effect of smart façade systems on office buildings. Smart materials are classified according to their susceptibility to change, as color-changing materials and bond-changing materials, as can be classified depending on their abilities to transform the energy to the intelligent material that brings daylight, also having the features those can transform the energy to the smart materials for electrical dynamic and the eventually the smart materials which featuring by energy consumption can be transformed as well.

II. RESEARCH METHODOLOGY

The following will be the main points of discussion in this paper; to study the effects of smart facades on office buildings:

- Simulation of thermal
- Modeling in daylight
- Optimal control functional
- Comparison investigating
- Case study of previous smart facades in Riyadh

➢ *Study Delimitation*

- **Scientific delimitation**: The investigation is aiming on explaining the effects of smart facades on office buildings.
- **Human delimitation**: this study carried on by an architect who works on the smart façade systems.
- **Place delimitation**: this study is conducted in the geographical scope of the Kingdom of Saudi Arabia, KSA
- **Time delimitation**: the academic year 2021/2022

III. COMPONENTS OF SMART FAÇADE

The review of components of smart façade was undertaken in order to first identify what facades are, and then to present investigations carried out on the daylighting and thermal modeling of smart facade systems and related systems. Also, several comparative investigations comparing different window systems have been reviewed.

An assessment of double-skinned systems and airflow window systems, which are basic characteristics of intelligent facade systems, will be discussed. Since the 1950s, researchers have studied daylight propagation mechanisms via complicated glazing systems in three ways: numerically, experimentally, and theoretically. A review of the components on daylight modeling relevant to smart façade systems is also covered. Finally, comparison investigating carried out on window device and daylight designs are approaching in scope of smart facades in the hot region of Saudi Arabia.

❖ *Introduction*

Facades are defined as the visual interfaces between the outside and the inside of a building. A building's façade can not only provide a visual experience but can also display the style of architectural work that has been done. It can also serve to create a suitable environment and provide protection from external factors.

Let us start by defining smart facades. A façade is smart, according to (Archdaily.com), when it adjusts to changing environmental conditions and transforms easily.

the change is occurring as resulting of the its active or passive components that are not active respond to changing conditions. An intelligent façade is able to be reacted at changing on the exterior as well as the interior of the structure.

This transformation's characteristics include three important elements:

- Achieving a balance of maximum natural light.
- Protection against harmful radiation.
- Maintain control over ventilation and thermal heat.

A façade provides ideal ventilation, shade, and openings in hot regions. At the same time, it lets sunlight enter freely in cold regions. This change preserves atmospheric balance; some façades also modify their aesthetic looks, therefore the moniker "smart" façades.

A case study showed that when thermal heat is balanced, that is, when our body temperature is in balance with the heat we lose, our bodies function more effectively. Smart façades should respond to local environmental factors. Then, the architecture should incorporate structures that match those factors.

According to studies, the ratio of heat loss to structures is 15% through the floors, 25% through the roof, 25% through windows, and 35% via the walls. The architecture, on the other hand, regulates the rate at which heat is dissipated. This is accomplished by the materials used and the complexity of the structure's architecture.

Mineral wool, ceramics, polyurethane, and polystyrene are some of the materials that have been suggested. These materials have a significant vacuum, which implies that the air in the gaps makes it difficult for heat to transmit.

Second, building materials with significant thermal inertia may retain heat while also releasing it back into the outdoors.

With all that in mind, let us look at the four areas that might gain or lose heat: windows, roofs, floors, and walls. Let us start with the floor. The insulation reduces heat transfer between the floor and the premises; the type of material employed that used has a big impact on the temperature. of the structure. The walls come next. In addition to the previously listed elements, plaster is a chosen insulator; the thickness and coating affect the temperature of the room.

Thirdly, the roofing materials employed must be appropriate for the surrounding environment. Let us use tropical regions as an instance. Finishing must be done utilizing light materials and brilliant colors. In colder climates, drab colors and thick slabs may be used to help preserve heat.

Finally, windows, the type of glass used can either allow or block solar radiation or natural light, influencing the surroundings; the same holds true for façades, as will be discussed later.

A. The Opaque Component (Building Shell)

In the modern world, where attaining sustainability is one of the key requirements for architecture, several building shell design ideas have been put out and investigated; Building shells that can adjust to the climate are one of the most promising ideas.

➢ Tinted Sage Glass
➢ PRIVA-LITE
➢ EGLAS
➢ Self-Cleaning Glass

B. The Transparent Components (Voids & Openings)

Fig 2:- Amorepacific Headquarters.

The highlighted walls are flexible innovations that can rapidly adapt to various climates. These walls are an excellent fit, considering the recent climatic change caused by global warming.

C. Vertical gardens, shades, double facades

Rapid population growth and urbanization alter city characteristics, turning them into concrete jungles. Growing urbanization and population have certain negative effects and increased concrete structures and hard surfaces contribute to pollution in the air, noise, and water, lack of vegetation, increasing urban heat island, global warming etc. Indoor surroundings get increasingly uncomfortable as air temperature rises. A smart solution to address some of these issues and reduce resource depletion is to implement sustainable practices such as greenery systems and integrate these systems into buildings.

➢ *Materials and method*

This page provides an in-depth analysis of the definitions and classifications terms, categories, and advantages of vertical greenery installations. The investigation resources were compiled from a variety of sources, including publications, conference paper and thesis, To evaluate thermal performance and energy characteristic of vertical greenery systems 22 peer-reviewed papers were scanned from 2005 to 2014 to ensure the most updated data on vertical greenery systems.

➢ *Definitions and classifications of vertical greenery systems*

Vertical greenery systems are plants grown on vertical surfaces. This allows for the vertical growth of one or more types of flora on a surface, whether it be created naturally or artificially by humans within or outside the building. either connected to the building's wall or standing isolated in front of the wall, In a nutshell, vertical greenery systems grow various plant species on various types of vertical surfaces, To describe these systems, several names and jargon were utilized. proposes several terminology for these systems, but the term "vertical greenery system" is inclusive and widely used. Systems for vertical greenery can be classified in a variety of ways. One such approach bases classification on plant species, building techniques, and growing mediums. It categorized vertical greenery systems into the following four groups: tree-against-wall type; wall-climbing type; hanging-down type and module type. Tree-against-wall type actually do not contain vertical greenery installations, but definitely it will be same performance. In Wall-climbing type they are typical in historical architecture, Plants can immediately cover wall surfaces or climb up trellises. Wall climbing is simple to use. However, it takes time to completely cover facade surfaces in vegetation. Long-pedicel plants on balconies or the ceilings of buildings produce hanging-down types. his sort falls somewhere between a green facade and a green roof, In a short period of time, all of the building facades will be green thanks to the use of hanging-down type on each level. Additionally, by adding a variety of plants, the façade will be vibrant and appealing. The final method, module type, is a novel approach. The position of the growing material affects the type of vertical greenery systems in all classifications. The growing medium is where plant roots obtain nutrients. Growing medium may remain on the ground while all vertical surfaces are covered with plants that grow vertically. It is referred to as a "green facade" and is typical of traditional architecture. In addition, growth media can stand vertically in front of vertical surfaces. It is called living wall, and it is modern technique. Substrates support growth media in carriers while standing vertically in living walls, Living walls can consequently support a wider variety of plants. Panel systems are typical for living walls. Panel systems are pre-planted panels that are attached to the structures. Feel systems are connected to the waterproof walls that connect the structures and consist of felt pockets filled with plants. Plants are potted in containers and trained to climb trellises in container systems. There are different names for green facades and living walls: Green vertical system, support system and façade greening are frequent terminology for vertical gardens and green facades. carrier system and bio-wall are typical names for living walls, highlights a contrast between the language used for vertical greenery systems. Based on where greenery and wall surfaces are located, Hunter divides green facades into two categories: direct green facades and double-skin green facades. Self-clinging climbers are attached to the vertical surfaces of direct green facades, whereas engineered support structures let plants grow vertically in double-skin green facades. The subcategory can be expanded to include living wall systems.

As a result, it may be claimed that the basic categorization encompassing all other categories is the dichotomy of vertical greenery systems to green facades and living walls.

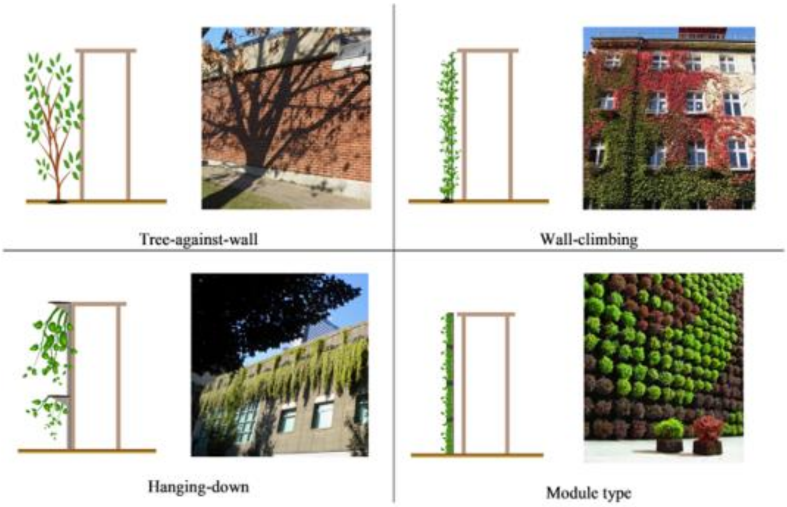

Fig 3:- Four groups of vertical greenery systems

The following table contains dichotomy of vertical greenery systems:

➢ *Green façade:*

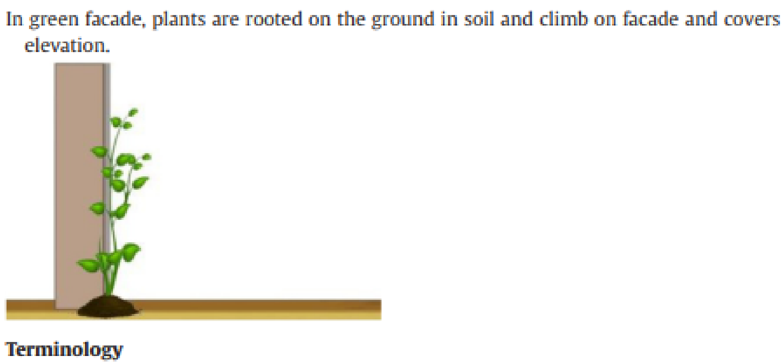

Fig 4:- Green façade

- Green façade/green wall
- Green vertical system
- Support system
- Façade greening

➢ *Living wall*

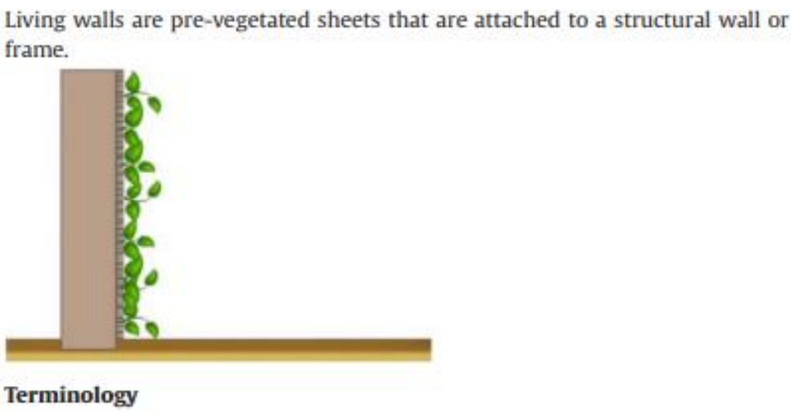

Fig 5 Living wall

- Living wall
- Vertical garden
- Carrier system
- Bio-wall

The installation's purpose, the climate, and the facilities must all be considered while choosing the correct type of vertical greenery system, green facade, or living wall, However, both of them have several advantages for the surrounding area, the structures, and the people who live there.

D. Simulation of thermal

The above mass and heat transfer phenomena controlling heat transfer mechanisms are investigated in order to outline the mechanism of smart façade systems:

- Solar radiation (direct, diffuse, and reflected)
- Surface-to-surface long-wave radiation
- Heat transfer via interior and exterior glazing and louvers.
- Air circulation via inlet/outlet cavities and grilles.

As previously mentioned, the problem's complexity must be recognized. The intelligent facade device is composed of an inner glazing, an outer glazing, air inlet and outflow louvers that can be controlled, and a spinning louver in the cavity that can be controlled where transient radiative, conductive, and convective heat transfer and turbulent air flows occur in an irregular three-dimensional geometry with boundary factors consisting of solar radiation, outside temperature, etc. Furthermore, appropriate optimal control actions (change of airflow regime or rotation of louver angle) should be identified while simulating the system's dynamics, the impacts whose ramifications are dynamic combined with the highly nonlinear moveable of the device.

E. Modeling in Daylight

The utilization of natural light in structures may play a significant role in improving interior environmental quality as well as energy efficiency.

As a result, daylight must be employed to the greatest degree possible without negatively impacting the visual well-being of the inhabitants. [20] A physically based simulation software named RADIANCE is used for daylight modeling in intelligent façade systems. This Lawrence Berkeley National Laboratory (LBNL) software is regarded as one of the most advanced daylight simulation programs.

To evaluate the influence of louver angle on interior daylight distribution, this investigation depends on RADIANCE simulation output under various sky conditions. RADIANCE simulations are done for a chosen prototypical office area surrounded by a intelligent façade system. The standard office area is four meters wide by six meters deep by three meters high. All photometric parameters, such as floor, wall, and ceiling reflectance, are based on IESNA (Illuminating Engineering Society of North America) office building design requirements. Because of the relatively long simulation time required for RADIANCE to create the output data (the calculation time is dependent on the hardness of the simulation model and computer capacity). It takes many hours to complete this investigation on a Pentium IV 1.7GHz with 512 MB of RAM. Each hour, a series of pre-simulations are run under CIE sky conditions (cloudy, intermediate, and clear). The data are then evaluated and treated to create a simplified method for predicting interior daylight distribution.

F. Optimal control functional

The entire performance of smart façade systems is divided into three components that provide for three of the most significant system utilities: visual comfort, thermal comfort, and energy savings. Some of These utility are defined as a function of the system's observed variables, while adhering to a set of extra control variable restrictions The element of value is which created using the user summation of these three benefits, balanced by preference. The constrained nonlinear optimization issue arises when the cost function is minimized.

As previously stated, solving this optimum control issue analytically is challenging due of the systemic dynamics' extreme nonlinearity and other limitations on the control variables.

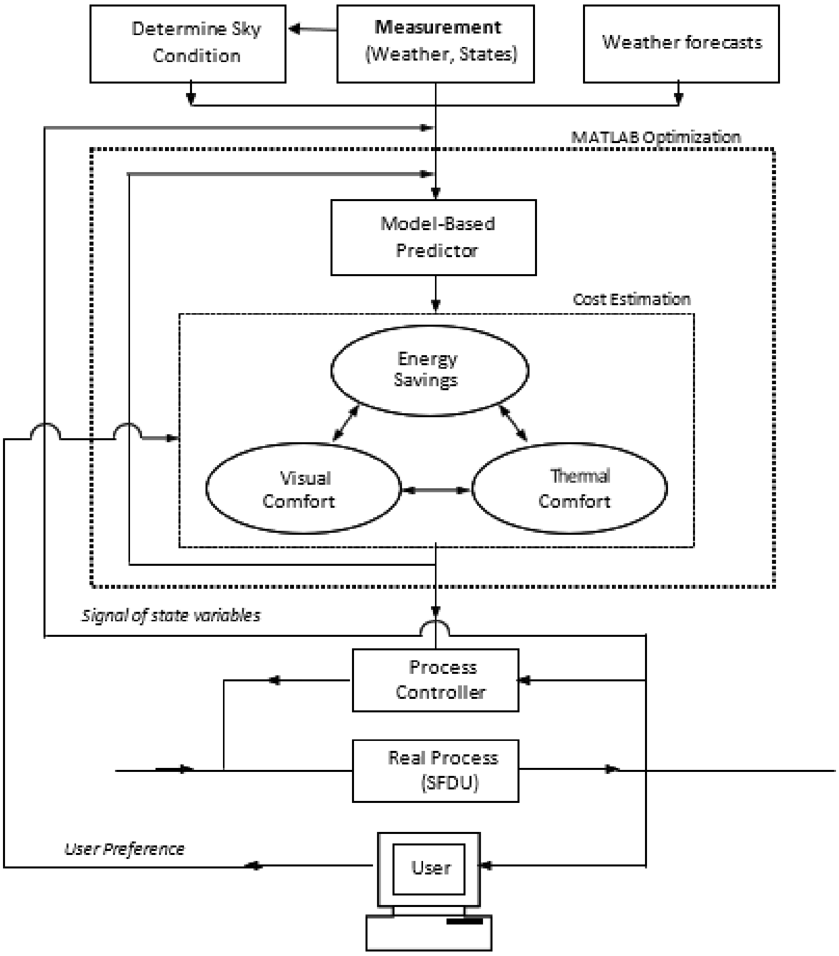

Fig 6:- Inhabitant responsive optimum control technique for intelligent facade systems

G. Comparison investigating

The intelligent facade system, is frequently compared to the above-mentioned with a more standard window system and a manually managed facade system. The mechanically operated façade system must satisfy all of the requirements. as the intelligent facade system with the exception of the intelligent optimal control is changed to operations requiring manual control In looking into the manually operated façade system, According to Vine. there is no regular design of the louver angle, which is commonly used in most structures (1998). Thus, each of the subsequent louver angles, i.e., -60°, -30°, 0°, 30°, and 60°, is ready for an entire day. Furthermore, no ventilated airflow regimen is expected since individuals are not assumed to open the inlet and outflow dampers manually while taking into account the beneficial effects of the airflow regimen. The traditional window system features 12 mm outside and 6 mm interior clear glass separated by a 12.7 mm air gap and Venetian blinds for internal shade. The next metrics are chosen for those comparative investigations: energy savings (daylighting autonomy, convective heat transfer, long wave radiation, transmitted solar radiation, heat transfer by air flow regime), thermal comfort (PMV), and visual comfort (homogeneity, window surface luminance, and brightness at the plane surface). The next section has a more in-depth discussion.

H. Case Study of Buildings with Smart Facades in the Middle East

Countries in the Middle East, such as United Arab Emirates, Saudi Arabia and Qatar have been witnessing an economic and social growth, as in Asian cities, thus adding spectacular high-rises into their skylines. Dubai, Doha, Abu Dhabi, Mecca, Jeddah and Riyadh are some of the remarkable cities having remarkable tall buildings.

A geometrical form such as a pointed arch or triangle represents the uniqueness of God in Islam. The triangulated form and similar geometric features, which are characteristics of Islamic motifs, can also be seen in Al Faisalah Center (2000) in Riyadh, Saudi Arabia. The 101-story Princess Tower in Dubai, which is completed in 2012, is another example as a super tall residential building rife with Islamic motifs. The crown of the building has a dome that is similar the dome of a mosque.

➢ *National Bank of Jeddah (Jeddah, Saudi Arabia)*

Starting with Gordon Bunshaft of SOM's design for the National Financial Institution in Jeddah in 1982, A new tendency emerged that completely contradicted prior tall-building patterns.

The only glass walls, located on the inside faces of the V, are shaded from the direct sun. The rest of the building is cladded in stone from top to bottom. A vertical flue, where the alternating triangles overlap, creates a "stack effect," which increases air movement through the sky courts, and upwards through the top of the building, assisting to cool the glass faces. This natural ventilation strategy and inward orientation are the most decorated design features of Islamic architecture, due to the climatic conditions of the region.

The service core is placed to one side of the building so that it does not meddle with the internal office areas and provide additional shade on that side of the building. The design of the building decreases the external temperature at the glass facade by as much as 10°C, causing substantial energy savings.

I. Case Study of Design Variables in Daylight and Energy Performance in Residential Buildings under Saudi Arabia's Hot Climate

❖ *Introduction*

Residential structures are a significant contributor to total energy usage in the kingdom of Saudi Arabia. Due to delayed growth and private difficulties in the country, it is kind of hard to implement the rich natural resources into the architectural designs as design parameters because of Saudi Arabia's private issues and slow progress. Thus, the current study illustrates the evolution of environmentally friendly residential structure design by analyzing energy and daylight performance using design variables. The design parameters were selected taking into account the daylight system, including external shading devices, WWRs (window-to-wall ratios), and glazing types. Furthermore, the energy consumption of the building Energy modeling was used to investigate these design variables. Construction accounted for 79 percent of the overall consumption of electricity in Saudi Arabia. Residential sectors, in particular, consumed approximately 50 % of the total structure energy. Saudi Arabia's largest contributor to overall energy consumption, energy savings in residential structures has become a major concern. Different studies have been undertaken to enhance building energy efficiency, with a variety of strategies offered. These solutions primarily address the various building systems, like the HVAC (heating, ventilation, and air conditioning), envelope, and lighting. Those were:

- enhanced thermal resistance in structure envelopes
- use of sophisticated window systems
- utilization of more energy-efficient light lamps
- the utilization of energy-saving mechanical devices.

➢ *Main Givens for the Case Study*

- *Building Description*

Traditional homes, villas, and apartments, are the three main kinds of residential structures in the kingdom of Saudi Arabia. Villas and apartments have become the most common residential construction types, accounting for almost 80% of all residential structures.

- *Design Variables*

The design parameters of window systems were selected in order to analyze the energy and daylighting performance in a residential structure knowning that the permitted sun light is heavily impacted by the design characteristics of the window systems. Figure 6 depicts three distinct window system design parameters. The WWR is the first parameter. Because the reference structure's WWR was roughly 15%, three alternative WWRs (25 percent, 50 percent, and 70 percent) were employed to assess the energy and daylight performance.

➢ *Discussion of Results*

The energy and daylighting function of residential design variables structures in hot provinces have been studied for this investigation. In contrast to conventional residential structures in other nations, Asian residential structures feature very lower WWRs to minimize cooling loads and for other causes, like cultural traits. As a result, it is hard to locate in modern residential structures, daylighting systems are used. The basic functions of daylighting systems, as previously indicated, are to govern the quality of received daylight. and limit heat absorption in structures. From this viewpoint, he natural lighting efficiency of different WWR dimensions, shading devices, and glazing types was investigated utilizing daylighting measures. Furthermore, Various design variables' energy quality was evaluated.

IV. CONCLUSION

Given that transparent structure envelopes (facade and windows systems) offer significant potential for thermal comfort, visual comfort, and energy savings this investigation provides an intelligent façade solutions with inhabitant responsive optimal control. The significant accomplishments and conclusions are highlighted in this section the investigation. The energy-saving potential for residential structures in hot climates with natural lighting applications is based on the results have been discovered. Furthermore, by applying the right design factors, daylighting performance may be increased. Nevertheless, the design factors for the current investigation seemed insufficient to provide more useful results.

REFERENCES

[1]. Brandle, K. and Boehm, R.F. (1982), Airflow windows: Performance and applications, *Proc. of the ASHRAE/DOE Conf. on Thermal performance of the Exterior Envelopes of Buildings II*

[2]. Ripatti, H. (1984), Airflow window system - Making fenestration the solution rather than the problem in energy use, *ASHRAE Transactions*, Vol.90, Part 1B, pp.917~931

[3]. Mueller, H.F.O. (1984), Exhaust air ventilated windows in office buildings, *ASHRAE Transactions*, pp.932~947

[4]. Wright, J.L. (1986), Effective U-values and shading coefficients of preheat/supply-air glazing systems, *Proc. Solar Energy Society of Canada*

[5]. Barakat, S.A. (1987), Thermal Performance of a Supply-Air Window, *Proceedings of the 12th Annual Passive Solar Conference* 12: pp.152~158

[6]. Hayashi, T., Katayama, T., Sugai, T. and Watanabe, T. (1989), Time-Variable Numerical Model of Heat Transfer around Solar Shading Device on Windows, *Proc. of the ASHRAE/DOE Conf. on Thermal performance of the Exterior Envelopes of Buildings IV*, pp.405~413, American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA.

[7]. Cho, S.H., Shin, K.S., and Zaheer-Uddin, M. (1995), The Effect of Slat Angle of Windows with Venetian Blinds on Heating and Cooling Loads of Buildings in South Korea, *Energy*, Vol.20, No.12, pp.1225~1236

[8]. Haddad, K.H., and Elmahdy, A.H. (1998), Comparison of the Monthly Thermal Performance of a Conventional Window and a Supply-Air Window, *ASHRAE Transactions*, Vol.104, Part 1B, pp.1261~1270

[9]. van Paassen, D. and van der Voorden, M. (2000), Development of Simplified Tools for Evaluation Energy Performance of Double Façade, Proceedings of International Building Physics Conference, pp.347~355, September 18~21, 2000, Eindhoven, The Netherlands

[10]. Saelens, D. (2002), *Energy Performance Assessment of Single Storey Multiple-Skin Façades*, Ph.D. Dissertation, Katholieke Universiteit Leuven

[11]. "Crown Fountain". Archi•Tech. Stamats Business Media. July–August 2005. Archived from the original on 2007-09-28

[12]. "Crown Fountain". a weekly dose of architecture. 2005-03-07

[13]. "Chicago's stunning Crown Fountain uses LED lights and displays". LEDs Magazine. PennWell Corporation. May 2005

[14]. Cresswell, J. W. (2008). *Educational research: Planning, conducting and evaluating qualitative and quantitative research. Upper Saddle River, NJ: Merrill & Prentice Hall.*

[15]. Robbins, C.L. (1986), *Daylighting: Design and Analysis*, Van Nostrand Reinhold Company

[16]. Luecke, G.R. and Slaughter, J. (1995), Design, Development, and Testing of an Automated Window Shade Controller, Transactions of the ASME, Vol.117, pp.326~332

[17]. Onur, N., Sivrioğlu, M., Turgut, O.(1996), An Experimental Study on Air Window Collector Having A Vertical Blind For Active Solar Heating, *Solar Energy*, Vol.57, No.5, pp.375~380

[18]. Rheault, S. and Bilgen, E. (1987), Heat Transfer Optimization of An Automated Venetian Blind Window System", *ASES 12th National Passive Solar Conference*, Portland, Oregon, pp.122~128