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Adaptive Façades' Technologies to Enhance Building Energy Performance and More

A literature review and case-based analysis

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تقنيات الواجهات المتكيفة لتحقيق أكثر من مجرد تحسين أداء الطاقة في المباني تحليل مبنى على المراجعات الأدبية والحالات الدراسية

ملخص:
مع زيادة دخول التقنيات الرقمية وتطبيقات الحاسب الآلي الحديثة في جميع مجالات صناعة البناء والتشييد، زادت معايير ومعدلات التنافس وارتفعت مستويات مقارنة جودة وكفاءة الأعمال، وازدادت أهمية هذه التقنيات مع دخولها في مجال تحسين إستهلاك الطاقة في المباني، التي تمثل مشكلة عالمية. ويزداد تأثير هذه المشكلة في المناطق الصحراوية الحارة، مثل بعض مناطق المملكة العربية السعودية، التي يتجه فيها أغلب المستخدمين لقضاء أغلب الوقت في الفراغات الداخلية المكيفة مما أدى إلى ارتفاع استهلاك طاقة تبريد الفراغات الداخلية ليصل إلى 40% من إجمالي الطاقة المستهلكة في المباني. وعلى الرغم من انتشار استخدام واستثمار فوائد هذه التقنيات عالمياً في العديد من المشاريع في مناطق مناخية مختلفة، فإن ارتفاع نسبة استهلاك الطاقة في المباني بالمملكة قد يكون مؤشراً بان استخدام التقنيات الحديثة في مجال حل هذه المشكلة غير مستثمر بالصورة المأمولة، ولم ياخذ الأهمية الكافية في مجال التطبيق، وهو ما يمثل إشكالية هذه الدراسة التي تهدف إلى استكشاف وتأكيد أهمية تقنيات تحسين أداء الطاقة لواجهات المباني التي تتكيف مع متغيرات المناخ الخارجي وتحقق أيضًا المزيد من الفوائد لكل من المستخدمين والبيئة الداخلية لهذه المباني. تبنت الدراسة المنهج الوصفي التحليلي من خلال مراجعة وتحليل الأدبيات والحالات الدراسية لتحقيق هدفها، وخلصت الرسالة إلى تأكيد أهمية هذه التقنيات وفعاليتها في حال دمج أكثر من تقنية وفق خصائص السياق المحيط بالمبنى، وإلى تحديد أهم خصائص التقنيات المستخدمة في الحالات الدراسية التي تم تحليلها والفوائد التي نتجت عن ذلك سواء على مستوى تحسين أداء الطاقة اوعلى مستوى الفوائد الإضافية المتعددة الناتجة عن استثمار هذه التقنيات. وتتضح أهمية الدراسة من توافق موضوعها واهدافها مع مبادرات رؤية المملكة العربية السعودية 2030 المتعلقة بالتحول الرقمي، ومع اتجاهات الأبحاث الحالية والمستقبلية المتعلقة بتقنيات الواجهات المتكيفة، ومع التوجهات العالمية لمعالجة أزمة ارتفاع استهلاك.

الكلمات المفتاحية: : أداء الطاقة في المباني، غلاف المبنى ، الواجهات التي تتكيف مع البيئة الخارجية، الزجاج الذكي، الواجهات المولدة للطاقة.

Abstract:
With the increased enrolment the digital technologies and modern computer applications in AEC industry, a parallel increase and upgrade happened in the work competition leading to new benchmarks in such fields. The importance of these technologies increased with their investment of improving energy consumption in buildings, which represents a world crisis. The problem got worse in hot arid desert zones, as the case of some regions in KSA, where most users tend to spend most of their time in internal air-conditioned spaces, which led to the increase of the consumption of cooling energy, that reach 40% of the total Energy consumed in buildings. Despite the widespread global use and investment of the benefits of the new technologies in many projects in different climatic regions all over the world, the high percentage of energy consumption in buildings in the KSA may be an indication that the use of such technologies is not well invested, and that its application has not taken the needed weight and importance. This represents the research problem of this study that aims to explore and confirm the importance of adaptive facades' technologies that could not only enhance building energy performance, but also achieve more benefits to building users and environments. The study adopted the descriptive analytical approach through the review and analysis of literature and case studies to achieve its goal. The results confirm the importance of the new adaptive facades' technologies and the preference of combining more than one technology as per the building surrounding context, in addition to identifying the main technologies' features used in the analysed case-studies and the resulted benefits on the level of enhancing energy and the additional benefits resulted from investing these technologies. The significances of this paper emerges from the importance of its subject, results and conclusions that matches Saudi Vision 2030 initiatives related to digital transformation, current and future research trends related to adaptive facades' technologies, and the global energy crisis responsive actions..

Keywords: Building Energy Performance, Building envelope, Dynamic and Adaptive Facades, Intelligent Glazing, Energy Generative Envelopes.

I. Introduction

For a long time, IT have been supporting and enhancing people lifestyle, health, education, and performance in many levels, and its impact was clearly noticed in different fields. Nowadays New technologies were employed for solving the global energy high consumption and to enhance building energy performance (Kabosova, Foged, & Katunsky, 2019). One of the related studies showed that between 1980 to 2012, the total primary energy consumption and CO2 emissions have grown by 85% and 75% (Cao & Dai, 2016). Other Studies showed that buildings account for almost a third of the global energy consumption, while refrigeration and air conditioning are responsible for about 15%of the total electricity consumption in the world (Prieto & Knaack, 2017).

In the Kingdom of Saudi Arabia, as an example, the energy high consumption issue was explored, and many researches showed that in residential sectors, as an example, 40% of the total energy used by utilities (electricity and water), and 53% of this primary energy is consumed in the residential air conditioning used to cool indoor spaces and reach the desired thermal comfort (Ghabra, Rodrigues, & Oldfield, 2016). This is mainly because of the negative impact of the harsh climate on buildings, leading to 90% of people spend their time in indoor spaces rather than outdoor spaces (Nady, 2017). This situation shaped the new technology development tendency towards enhancing the building envelope energy performance that are considered the main barriers between the outdoor environment and the indoor man-made environment, and can be maintained according to the occupant's requirement, preference and thermal comfort (Luo, Zhang, & Bozlar, 2019). Ayoub (2018), as an example, noted that 33% of annual energy demands can be saved if only the building envelope is ideally designed.

Many studies were done regarding the building envelope materials, systems, and elements, to help understanding how new technologies could enhance the performance of the building envelope and make it dynamic and adaptive to the climate and environment, in order to save more energy and successfully achieve thermal comfort in buildings.

In order to understand the real benefits of the new technologies used in buildings envelopes and achieve its objectives, this paper will focus on such technologies through related literature review that can be integrated with buildings envelope to enhance its performance, related main challenges that may face its applications, and through the analysis of case-studies related to such technologies.

Problem Statement: Despite the spread of new technologies in many aspects of design, the increase need for new technologies in buildings is becoming essential due to the higher building energy demand, there is a lack of public understanding of technologies' benefits and it still seems that it is not well invested and does not take its right weight.

Objectives: The main Objective of this paper is to help public and designers to be more aware of the potentials and capabilities of facades' technologies that could enhance not only the building envelope energy performance, but also achieve more benefits to building users and environments, and encourage researchers in this field to actively participate in developing these technologies and resolve its related challenges.

Methodology: The paper adopted the analytical descriptive approach through a literature review, in sections (II&III) to explore adaptive facades' technologies used to enhance building envelope performance and the main challenges related to its application. And a case-based analysis in section (IV) to confirm the applicability & ability of such technologies in enhancing the building energy performance and more benefits to the internal building environment and its users. The methodology of selecting and analyzing the case studies will be discussed in that section.

References' sources and screening: Four sources of literature used to collect references for this paper: "Scopus", "Saudi digital library", "Research Gate" as well as "Google Scholar". The procedure of screening and filtering the related references started with identifying five key words: "The Use of new Technologies to enhance The Building Envelope performance", "Adaptive and Dynamic Building envelops", "new technologies in building Envelops", "the use of Artificial intelligence in building envelops" and "new building Envelops in Saudi Arabia". After applying some more filters related to refining the key words and the date of publishing, another selection efforts were done to add extra references from specialized websites that have the state-of-art information about the latest technologies in the subject of the paper. By the end of this process, the number of the reference reached (46) as shown at references' section.

II. Adaptive Facades' Technologies to enhance Building Energy Performance

Nowadays, Building envelopes are attracting a lot of attention and becoming one of the new trends in building energy performance studies showing a radical improvement in the level of awareness needed to reduce energy consumptions (Perino & Serra, 2015). In addition to the dynamic adaptation features that will be discussed later in this study, literature review revealed two more supportive integrated technologies that could increase building energy performance: Intelligent/smart glazing and power generation related technologies.

The glazing is used in all façade types and it is essential to invest its new technologies in achieving the power saving related objectives such as the thermal comfort and the required daylighting level. In addition, technology can transform building envelop to become an energy source. Photovoltaics or flexible solar thin films can be integrated into facades to simultaneously generate power and shade a building. The next section will discuss these technologies, namely: Dynamic and Adaptive Building Envelopes, Intelligent Glazing System, and Energy Generative Envelopes.

A. *Dynamic and Adaptive Building Envelopes:*

The perception of architecture, changed towards utilizing digital tools and simulations for improving the buildings' energy consumption and the interior wellbeing environment. As per Luo & Bozlar (2019) and Kabosova, Foged & Katunsky (2019), utilizing digital tools and simulations not only help to improve the buildings' energy performance, but also to achieve the aesthetic values, and the interior wellbeing environment. Nady (2017) categorized the dynamic adaptive building envelope into five main categories:

1- User Control Dynamic Façade
2- Light Control Dynamic Façade
3- Energy Control Dynamic Façade
4- Façades Designed to Manage Water
5- Wind Responsive Dynamic Façade

All of the five types are aiming to enhance energy consumption of the interior space by interacting with the surrounding environment for a maximum benefit, in addition to achieving other benefits. Figure (1) shows examples of different types of adaptive building envelopes, some of which will be discussed later in the following sections.

Figure 1. Examples of Adaptive building envelopes (different web sites).

B. *The Intelligent Glazing System:*

Glass is considered a "double egged sword", as it could give the building a beautiful exterior appearance and, in the same time, could badly and negatively affect the interior thermal comfort if it is misused or misplaced (Amirifard & Sharif, 2018). Glass became one of the new advanced materials in the fourth industrial revolution (4IR), due to the use of new technologies that added new characteristics to the glass and developed it to be smart to share in reducing the glare, direct sunlight, and energy consumption as well as regenerating energy (Aldawoud, 2013) & (Alias, Abhijith, & Thankachan, 2018).

Electrochromic glass, as an example, is an electronically tinted glass that can be directly controlled by building occupants and could improve occupant comfort, maximize access to daylight and outdoor views, reduce energy costs and provide architects with more design freedom. As per Aldawoud (2013), electrochromic glass could provide the best performance in reducing solar heat gain.

By 2017, technologies and approaches of using glazing to save energy improved and gained more attention in research and studies. The use of retrofitting approaches in glazing and insulation could reduce 15% of the building electrical energy consumed. More development was applied to the glazing industry allowing maximum window to wall ratio (WWR) without compromising the energy consumption and user comfort (El-Darwish & Gomaa, 2017). An emerging smart glass coatings could block inbound Near-infrared light from the sun, that accounts for about 50% of solar energy, during warm weather conditions, provide heat retention inside a room in the cold seasons and allow the customization of the window settings to maximize energy efficiency (Anurag Roy, 2022).

As per Sadek and Mahrous (2018), applying such advanced, intelligent and smart glazing in building facades, could enhance envelope performance by improving the users comfort, and energy consumption through its different variables such as visible transmittance (Tv), solar heat gain coefficient (SHGC), the self-dimming and the overall heat transfer coefficient (U-value) as shown in (Figure 2).

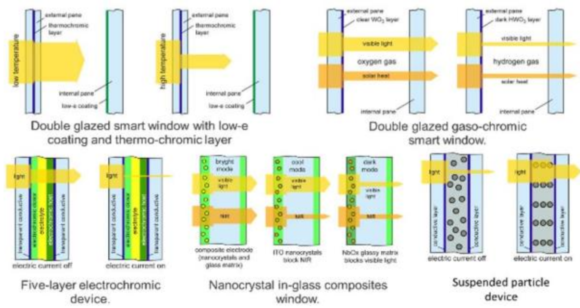

Figure 2. Examples of glazine technological concepts to control light and solar heat transmission (Zakirullin, 2020)

C. *Energy Generative Envelopes:*

There are significant opportunities for the building envelope to share in solving the aforementioned problems of energy consumption in buildings. Many papers have been discussing renewable energy and zero energy buildings' trends (Cao & Dai, 2016). Technologies are trying to support the building integrated envelopes to interact with the energy sources from the surounding environment, making the building not only reduce energy consumption but also regenerate it (Talaei, Mahdavinejad, & Zarkesh, 2017) and (Luo, Zhang, & Bozlar, 2019).

The top and sides of the building envelope (roof and facades) have potentials to apply a number of energy generative technologies. As an example, Transpired Solar Collector (TSC) is one of most popular emerging solar thermal technologies and active building envelope (Wang, Shukla, & Liu, 2017). The Building-integrated photovoltaics (BIPV) is another example of such technologies that could be applied, with different approaches to the building envelope's roof or façade. With the continuous improvement of this technologies, it will empower architects by offering colorful photo voltaic panels that looks pleasingly like a glass while performing highly efficient PV. In this technology, the PV cells are carefully masked behind the atomically coated glass, to blend harmoniously with the facades. Such BIPV takes advantage of passive façade, converts it to an active solar wall producing extra solar energy that can save up to 6 or 7 per cent of electricity in a typical office building (WFM, 2022). Figure (3) shows examples of such technologies that could be well invested by the Kingdom of Saudi Arabia due to the nature of its climate zone.

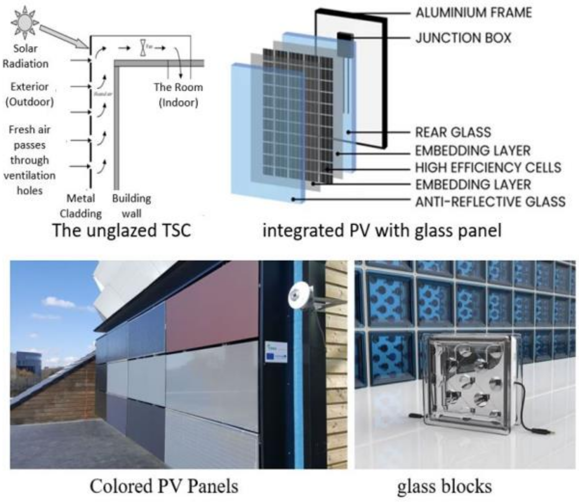

Figure 3. Examples of power generative components of building envelop (wang 2017, WFM, 2022)

From the bottom side of the building envelop (ground), the opportunity to generate heating and cooling power could be achieved through geothermal concepts. The United States Environmental Protection Agency (EPA, 2022), stated that the Geothermal technologies are considered important as one of the renewable resources that could harnesses the Earth's heat and invest it in different climate zones to heat or cool the internal environment. Such technologies could be categorized into three main types: Ground source heat pumps, Direct use geothermal, and Deep enhanced geothermal systems. Figure (4) shows how the ground source heat pumps technology works.

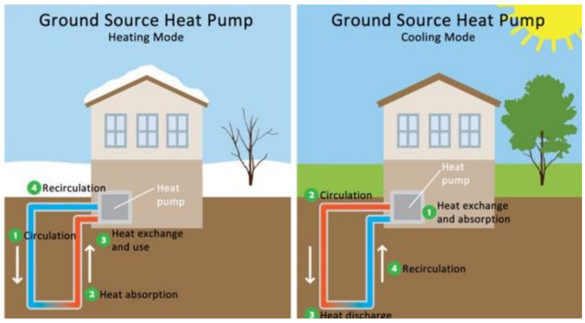

Figure 4. The concept of the ground source heat pump in both heating and cooling modes (EPA, 2022)

III. Challenges Facing Adaptive Facades' Technologies to Enhance Building Energy Performance.

As other technologies, the use of new technologies in building envelopes faces challenges, many of which were discussed in the literature. Between the common main challenges they all face, this paper will shed light, in brief, on challenges related to the initial cost, the lack of awareness of the new technologies benefits, and the rapid change of climate with its related crisis.

A. *The Initial Cost:*

As per Aldawoud (2013), the initial cost of the materials and systems used in the building envelope are not the only challenges building envelopes are facing, but maintenance cost as well. Cao & Dai (2016) have discussed the cost of some renewable materials, and presented studies to prove that the energy payback duration was not longer than 2 years, whereas the energy return could be 35 times the initial cost. Although the initial cost will be higher, the life cycle cost will be enhanced by using the new building envelopes technologies, as shown in table (1).

Table1. shows the cost of the renewable energy (Cao & Dai, 2016)

Category		Technology	Principle	Applicability/feature	Cost
Renewable energy generation	Solar energy	PV; building integrated photovoltaic (BIPV)	Convert incident solar energy into electrical energy by photoelectric effect	Better under tropical and sunny regions; relatively low conversion efficiency; BIPV can reduce the space, material and infrastructure costs	Medium
		Hybrid photovoltaic-thermal (PV/T)	Generate electricity and heat simultaneously	Low temperature thermal output; less commercialized; high energy generation efficiency per module	High
	Wind energy	Wind turbine	Generate electricity from wind energy	Sensitive to location and weather; need CFD-assisted design; can be integrated with PV	High
	Geothermal energy	Ground source heat pump (GSHP)	Use the constant earth's temperature as a heat source in a heating mode and a heat sink in a cooling mode	Better to balance the building heating and cooling loads all year round; high COP	High

B. *Lack of Awareness of Technology Benefits in Enhancing Building Envelopes:*

Public awareness is one of the reasons holding back the use of new technologies. In general, lack of awareness is related to the understanding of the technology real benefit in enhancing the building envelope energy performance leading, and in the understanding of the overall picture and the long run result of the technology cost including the initial and life cycle cost (Prieto & Knaack, 2017). This challenge was repeated in a number of literature with a recommendation to raise the public awareness in order to get the harness the benefits of new technology and get the best building envelopes performance which will help in solving the energy high consumption in buildings as well (Abanda & Byers, 2016) and (Abdul & Alshamrani, 2016). Despite the researchers' increase awareness of building envelopes technologies, as shown in Figure (5), the public understanding and of such benefits still needs to be raised for building envelopes technologies in order to be well adapted and applied in new and existing buildings.

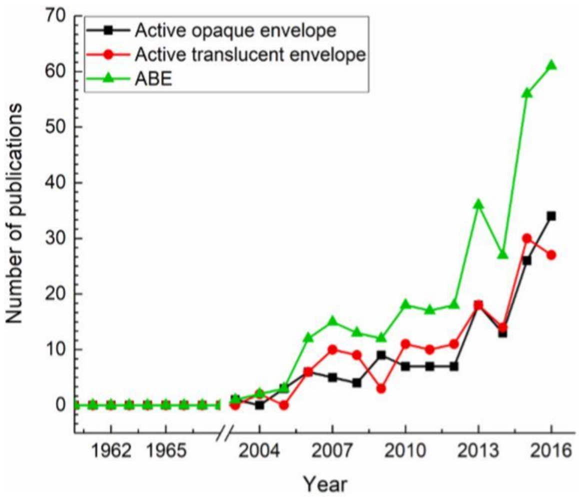

Figure 5. The number of publications in building envelopes new tecnologies: AOE, ATE and ABE (Luo, Zhang, & Bozlar, 2019).

C. *The Rapid Change of Climate:*

Climate change is impacting human lives and health in a variety of ways. It threatens the essential ingredients of good health – clean air, safe drinking water, nutritious food supply and safe shelter (WHO, 2022). Climate can be considered the first challenge that the building envelope face, the recognition of climate classification / characteristics related to building design is essential. One of the common climate classification systems is the Köppen climate classification, shown in figure (6), that was developed based on the empirical relationship between climate and vegetation, considered an efficient way to describe climatic conditions defined by multiple variables and their seasonality with a single metric. Over the recent years, there has been an increasing interest in using the classification to identify changes in climate and potential changes in vegetation over time (Vakilinezhad, Shemirani, & Seraj, 2013).

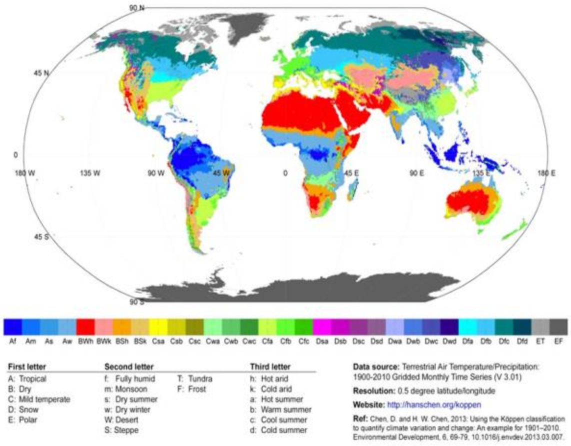

Figure 6. Koppen-Geiger Climate Classification Map (Chen, 2013).

New technologies were and are emerging to enhance the building envelope performance to be able to overcome this challenge (Ghabra, Rodrigues, & Oldfield, 2016). Because of the adaptive dynamic building envelopes technology, it became easier for the building to not only monitor the exterior environment and control the interior climate, but also benefit from the exterior climate to regenerate energy (Talaei, Mahdavinejad, & Zarkesh, 2017).

IV. Case-Studies Analysis.

Many buildings adopted new technologies to enhance the energy performance. In this section, a case-based analysis approach will be applied to demonstrate the applicability of the discussed adaptive facades' technologies and confirm its benefits in enhancing the "Building Energy Performance" from one side and other achieved benefits as well.

Methodology: In this section a case-based descriptive methodology adopted to conclude adaptive façade features and related results in saving energy and more. The procedure starts with identifying the case studies' selection criteria which include three main criteria as follow:

- The case study should represent one of the five adaptive facades' types, identified in item II-A.
- The case study should be known for its significance in saving energy.
- The case studies location should be from different climate zones.

Based on study objectives, the case studies' analysis will include the following items related to energy saving:

- Introduction showing the case significance in saving energy within its location and climate zone.
- Features of adaptive façade technologies: including shading, sun Control, glazing, energy generation and ventilation.

- Results and benefits of applying adaptive facades technologies.

After exploring many cases in different climate zones, applying the adopted criteria in multiple layers, the selection of the cases was for the following:

1- User Control Dynamic Façade: Kiefer Technic Showroom, Styria, Austria by Gieselbrecht & Partner.
2- Light Control Dynamic Façade: Al Bahr Towers, Abu Dhabi, Dubai, by Aedas studio.
3- Energy Control Dynamic Façade: Kolding Campus building, Denmark, by Henning Larsen
4- Façades Designed to Manage Water: Manitoba Hydro new headquarters, Winnipeg city, Canada, by KPMB Architects
5- Wind Responsive Dynamic Façade: One Ocean Thematic Pavilion, Yeosu, South Korea by Soma Architecture

A. *Case 1: User Control Dynamic Façade: Kiefer Technic Showroom, Styria, Austria, by Gieselbrecht & Partner,*

This project is an office and showroom building for the Kiefer metal construction company in Styria. The two-storey, free-form shape in the floor plan with the most important element of the building is the two-shell glass-aluminum façade that, with its gentle arch, is both subtle, unmissable and acts as “the company’s new calling card”. The building dynamic adaptive façade puts the emphasis not only on its separating the internal and external environment, but on its mediating qualities and becomes a method of communication between the building and people in the surrounding environment (Grabner, 2022) . Figure (7) shows exteriors of the building in different cases of the folding panels.

Figure 7. kiefer technic showroom dynamic envelope.

The building envelope is composed of 112 foldable panels, in micro-perforated aluminum, centrally or individually controlled by user to open and close, as a reaction to the outdoor conditions, to adjust the amount of direct sun rays and natural light entering the interior spaces, allow the best internal thermal comfort and also allow users to personalize their particular spaces with the “user controls system” (Nady, 2017) & (Ibrahim & Alibaba, 2019). The moving style of the façade panels gave the building a changing exterior that turns into a dynamic sculpture as shown in figures (7) & (8).

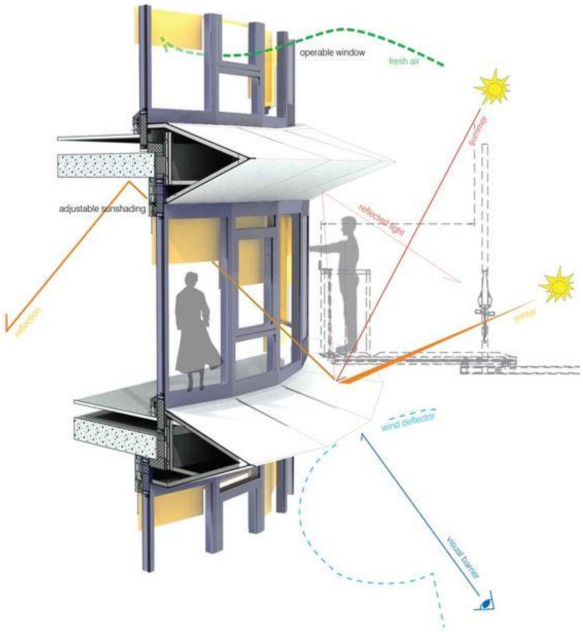

Figure 8. User Contorl Folding Panels to control Light (Vinnitskaya, 2010).

The construction of the envelope consists of solid brick walls, reinforced concrete ceilings and floors, and steel encased concrete columns. The facade consists of aluminum posts and transoms with protruding bridges for maintenance, with an Exterior Insulation Finishing System (EIFS)-facade in white plaster (Vinnitskaya, 2010). The dynamic façade is powered by 56 engines that activate automated shutters and folding panels of perforated aluminum and can be programmed to move automatically.

B. *Case 2: Light Control Dynamic Façade: Al-Bahr Towers, Abu Dhabi, Dubai, by Aedas studio:*

Located in the financial center of Abu Dhabi, Al Bahar Towers represent one of the most impressive and famous example of adaptive architecture and integrated design completed in recent contemporary architecture. The project consists of two towers with dynamic façades comprised of curtain wall cladding layer with clear weather-tight glass and a high performance coating (40% visible light transmission and 18% external light reflectance).

A dynamic shading system is separated from the cladding and fixed through a substructure by means of movement joints. The buildings won the Best Innovation Award 2012 by the Council for Tall Buildings and Urban Habitat (CTBUH). The pair of towers won recognition for its performance-driven form, and dynamic facade that operates following the movement of the (Karanouh, 2015). This dynamic shading system comprised of triangulate units such as origami umbrellas. It was inspired from the traditional "Mashrabiyah" (Nady, 2017). Each tower has 1049 shading units consist of stainless steel supporting frames, aluminum dynamic frames, and fiberglass mesh infill as shown in figures (9 & 10).

Figure 9. Al-Bahr Tower exterior adaptive façade external and internal shots (different websites)

However, Despite all the environmenta measures taken in this project, it did not get certified by any LEED rating system and Arup modified its reporting by stating that the project is designed in accordance with the US Green Building Council's LEED rating system instead of stating that the project failed to get certified (Attia, 2017).

The triangular units act as individual shading devices that unfold to various angles in response to the sun's movement in order to obstruct the direct solar radiation. It is a computer-controlled to respond to optimal solar and light conditions. The mashrabiya shading devices are grouped into sectors, with 22 diverse variations in its geometries, and are operated through sun tracking software that controls the opening and closing sequence according to the sun's angle.

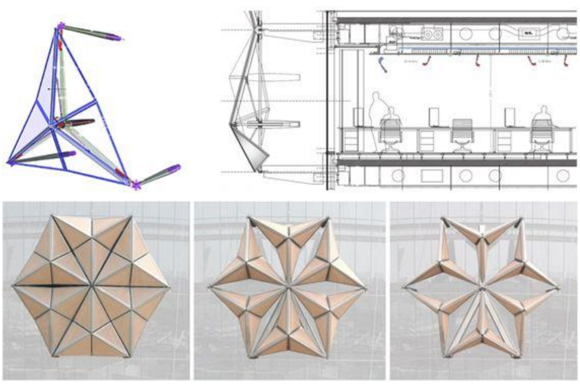

Figure 10. Section and Detailed 3D model of the shading device (Karanouh, 2015) and (Schumacher & Vogt M. & Krumme, 2022)

The pattern is used as a device for reaching environmental control and privacy including natural ventilation, solar control, and glare reduction. The building envelope of this project, that covers all the building but the north orientation, leads to reduce 50% energy savings for office spaces alone, and up to 20% for the building overall, 20% reduction in carbon emission with up to 50% for office spaces use alone, 15% reduction in overall plant size and capital cost and 20% reduction in materials and overall weight (Ibrahim L. , 2016), (HARRY, 2015) & (Karanouh, 2015).

In addition to the adaptive facades quantitives energy related results and benefits, the project achieve many qualitative benefits such as improvement of user-comfort and improved physical and psychological well-being of occupants, the overall iconic identity of the building, better naturally lit spaces through better admission of natural diffused light, better visibility of external natural views, less use of obstructive and psychologically trapping, improved comfort by reducing heavy air conditioning loads and air draft, provide the building with a unique identity, rooted to local heritage and environment and provide a unique and entertaining feature both to occupants and passing-by public.

C. Case 3: Energy Control Dynamic Façade: Kolding Campus building, University of Southern Denmark, Kolding, Denmark, by Henning Larsen:

The Kolding Campus building project, located in the University of Southern Denmark. has won multiple design awards, including the LEAF Award for Best Sustainable Development of the Year. It has become a role model for Henning Larsen's design of educational institutions in Denmark and world-wide. It also makes the university of southern Denmark one of the world's first low-energy universities (Larsen, 2022).

The building facades features 1600 intelligent, perforated metal triangular shutters with sensors to interact with the climate conditions along with the user's preferences of light, and indoor thermal comfort in order to save and control energy (Cousins, 2015). The shutters have sensors that continuously monitor and measure the light and heat levels around the building leading to the opening/closing shutter to different position to adjust daylight scenarios and optimizes the balance between natural and artificial light in the building (Cousins, 2015). Figure (11) shows exterior of the building with different positions of the shading units.

Figure 11. Kolding Campus building by Henning Larsen: Exterior facades (Cousins, 2015) & (Brake, 2015).

Shutters are placed on the façade in a way to allow them to adjust to the changing daylight and the desired inflow of light. In south and northeast Façade, the shutters on most parts are movable except at places where these shutters provide shading to toilets, staircases and terraces, they are fixed at 30°-60°. In the northwest façade, there are comparatively fewer shutters on this façade because of the lower heat load in the northwest direction, so the shutters are mostly installed at an angle of 90°, expect at the classrooms where these are movable in nature (Sood & Patil, 2021). Figure (12) shows building section through internal spaces and open atrium, and details for plan and section of façade elements.

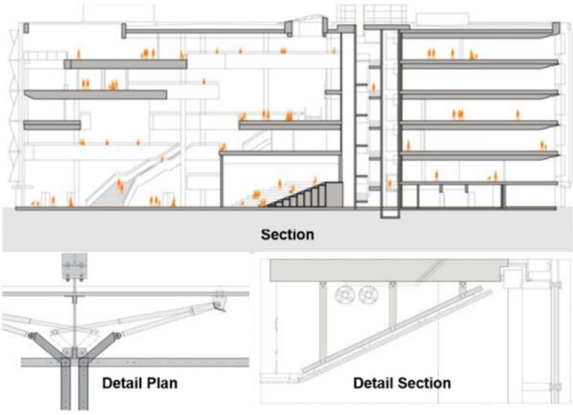

Figure 12. Kolding Campus building by Henning Larsen: Section, detail section and detail plan for building interna spaces and façade
.

The shutters movements allow the facade panels to shift from open to half-open to fully open Even when fully closed, as shown in figure (11), a controlled amount of natural light is able to shine through a custom pattern of round holes, some of which are linked to create amoeba-like openings (Nady, 2017), (Pimenova, 2019) & (Brake, 2015). The mechanism of the unit is driven by a centrally positioned electric screw-jack linear actuator that operates on very low energy consumption. Each actuator uses less energy than a regular light bulb Through this building, the University of Southern Denmark in Kolding will feature solar collectors, solar cells, an opportunity for natural ventilation of the atrium at night, low-energy mechanical ventilation, computer equipment with a low energy consumption and a number of other environmental and energy efficient initiatives that will provide the university with a significant, sustainable profile (Karanouh, 2015).

Additional sustainable design elements in this building include a combined heating and cooling pump that uses ground water to regulate the temperature throughout the building and natural nighttime ventilation of the central atrium. The ventilation system is integrated into the ceiling planes, rather than through traditional ducts, which cut both energy and construction costs. Photovoltaics and solar-heating panels dramatically reduce the amount of energy taken from the grid. The energy demand is reduced by 50 per cent compared to similar buildings of the same typology in Denmark through passive design measures and the implementation of efficient and intelligent systems (Brake, 2015).

D. *Case 4: Facades designed to manage Water: Manitoba Hydro new headquarters, Winnipeg city, Canada, by KPMB Architects:*

Manitoba Hydro new headquarters is a new headquarters tower located in downtown Winnipeg city which is known for its extreme climate over the year. The building uses 70% less energy than a comparable office building of conventional design. In May 2012, it was awarded a Platinum certification for its adherence to Leadership in Energy and Environmental Design (LEED) standards by Canada Green Building Council (Manitoba_Hydro, 2022). The architectural solution clearly responds to the local climate and the client's vision, and relies on passive free energy without compromise to design quality and, most importantly, human comfort.

The building public gallery has become a major corporate, cultural and social event venue in the city. The monumental scale and material expression of two large water features which serve to humidify/dehumidify the space was inspired by the hydroelectric dam. The south atrium, as shown in figure (13), 100% fresh air into the offices is first drawn into the 6-storey south atrium, preconditioned by a water feature (tensioned stainless steel cables with conditioned water running down each strand) before being drawn into the office's raised floors. This feature humidifies the ambient fresh air in winter and de humidifies air in summer (Kuwabara, 2013).

A double façade curtain-wall system made of low-iron glass forms a one meter (three foot) wide buffer zone. It is comprised of a double-glazed outer wall and a single-glazed inner wall which insulates the building against heat and cold. Automated louvre shades control glare and heat gain while radiant slabs act as an internal heat exchange with the geothermal field (KPMB, 2022).

Figure 13. The water feature used to condition the internal air in both summer and winter (https://www.kpmb.com/project/manitoba-hydro-place/)

As shown in figure (14), many strategies used, during the adopted integrated Design Process (IDP), in the building envelope to save energy and achieve comfort to the inner spaces include solar chimney, water system, geothermal system, double and triple glazing; internal gardens and green roofs.

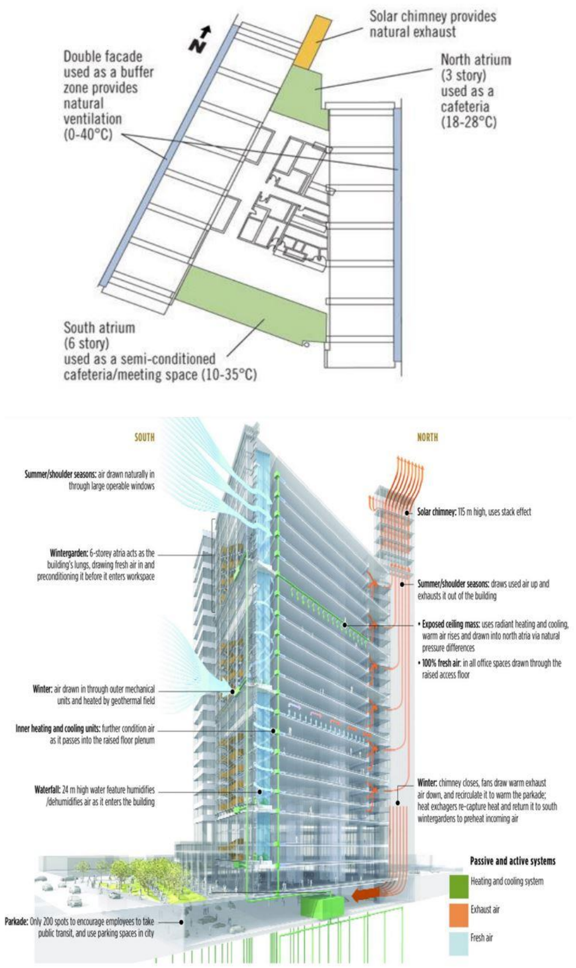

Figure 14. Manitoba Hydro Headquarters envelope energy features and strategies, (Transsolar Climate engineering) & (https://www.hydro.mb.ca/corporate/history/energy_features.pdf)

The 115m high solar chimney is considered a key element in the passive ventilation system which relies on the natural stack effect: in summer, used air is drawn up and exhausted out of the chimney while in winter, the chimney closes and the exhaust air is drawn down by fans and recirculated to warm the parkade where heat exchangers capture the heat and return it to the south winter garden to preheat incoming air. Depending on the season, the three 24-meter-tall waterfall features in each of the atria humidifies or dehumidifies the incoming air. The geothermal system of the building is considered the largest closed loop in the province. 280 boreholes, each 150 mm (6") in diameter, penetrate the site 125 meters (400 ft.) underground, circulating glycol which is cooled in the summer and heated in the winter by the ground source heat exchanger. Water is circulated through the heat exchanger and distributed through thermal mass of the concrete structure which in turn heats or cools the space consistently (Manitoba_Hydro, 2022).

E. *Case 5: Wind responsive Dynamic Facades: One Ocean Thematic Pavilion by Soma Architecture:*

The Thematic Pavilion for the EXPO 2012 was selected as the first prize winner in an open international competition in 2009. The main design intent was to embody the Expo's theme *"The Living Ocean and Coast"* and transform it into a multi-layered architectural experience. The unique dynamic adaptive feature of this pavilion makes it one of the largest adaptive structures ever built and mimics the baleen filter used by whales. The pavilion is largely known for its fish-like characteristics created by a cutting-edge façade system that was inspired by a research project at the ITKE University Stuttgart (Soma, 2022). Figure (15) shows external shots of the project with different positions and cases of the wind responsive façade feature.

Figure 15. The One Ocean Pavilion EXPO 2012, Yeosu, South Korea, https://www.soma-architecture.com/index.php?page=theme_pavilion&parent=2

Yeosu's climate is characterized by three main seasons: a cool winter, a hot and humid summer, and moderate intermediate periods. The building's adaptable kinetic facade enhances natural ventilation by capturing and guiding winds through the building during these three seasons: During moderate and nonhumid intermediate seasons, radiant floor systems are directly cooled via a seawater heat exchanger. In peak summer conditions, dehumidification of supply air and radiant floor cooling are powered by highly efficient turbo compression chillers linked to the seawater heat exchanger. During winter, these chillers are reversed to heat pump mode and use seawater as an energy source to generate heat for the radiant floors and the mechanical ventilation system as shown in figure (16) (Transsolar, 2022).

The facade covers a total length of about 140 m, and is between 3m and 13m high. It consists of 108 kinetic lamellas, which are made-up of glass fiber reinforced polymers (GFRP) capable of being morphed into a number of animated patterns and are supported at the top and the bottom edge of the façade. The lamellas are moved by actuators on both the upper and lower edge of the GFRP blade, which induce compression forces to create the complex elastic deformation. During strong wind, the GFRP units, are closed by a system of 216 coordinated servo motors. The actuator of the lamellas is a screw spindle driven by a servomotor by a computer controlled bus-system allows the synchronization of the actuators. Upper and lower motors often work with opposite power requirements (driving-braking). Therefore, generated energy can be fed back into the local system to save energy. Beside their function to control light conditions in the foyer and the Best Practice Area the moving lamellas create animated patterns on the façade. The choreography spans from subtle local movements to waves running over the whole length of the building. After sunset the analogue visual effect of the moving lamellas is intensified by linear LED bars, which are located at the inner side. In addition, Photovoltaic panels are integrated into the roof landscape to generate solar electricity, providing about two thirds of the energy consumed by the building systems over the year. (Schumacher & Vogt M. & Krumme, 2022)

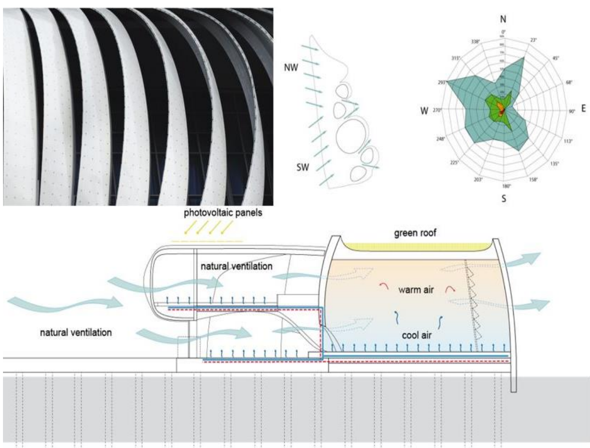

Figure 16. One Ocean – Pavilion EXPO 2012, Yeosu, South Korea, (Transsolar, 2022)

V. Results:

New technologies are evolving in the Architecture filed, to help participate in solving the energy high consumption used in buildings sector. As developing buildings envelopes is the first step towards decreasing the energy consumption, new technologies focused on enhancing the building envelopes performance. Based on the study, the following points are the results of using new technologies in building envelopes:

- The new technologies have proved its ability to dramatically enhance the building energy performance through the reduction of energy consumption and generate supportive energy.
- There are increasing focus in research and publication in the subject of Active Building Envelopes (ABE) over the Active Translucent Envelope (ATE) and the Opaque Envelope (AOE),
- Advanced Dynamic Adaptive building envelopes technologies are integrating solar panels in order to regenerate energy for buildings.
- Smart Glazing (with good insulation) could reduce building energy consumption by up to 15%.
- Geothermal technologies are considered important in the field of renewable resources that could harnesses the Earth's heat and invest it in different climate zones to heat or cool the internal environment.
- The emerging renewable energy technologies could fulfill the need of energy in buildings and reduce its demand from the public network.
- The initial cost is found to be a great challenge in the technology and building sector although the life cycle cost payback is more than the initial cost in the long run.
- The lack of public understanding of the advantage s of building envelopes new technologies is significantly impacting its spread.
- Involving the new technologies in the building envelopes design have enhanced the level of their performance, which led to a healthier indoor environment.

VI. Discussion

The Objective of this paper is directed to help designers to be more aware of the potentials and capabilities of digital technologies in enhancing building envelopes, and help the researchers in the field of building envelopes to actively participate in the developing efforts to resolve challenges facing the application of such technology. The results of literature review and case-based analysis' studies proved the applicability and ability of the new technologies used in building envelopes in reducing the energy consumption and the carbon dioxide emissions, as the case analysis of Al Bahr towers showed that the building envelopes helped to reduce the solar energy entering the building by 20% (Nady, 2017). Also, it was claimed that the design had resulted in 40% saving in carbon dioxide emissions.

The case studies analysis proved that dynamic adaptive facades' technologies can not only enhance building energy performance, but also enhance the internal spaces environment and users comfort and attitude. These case studies were taken in different regions with different climates to confirm the benefits of the dynamic adaptive facades technologies in all regions.

The case-based analysis also proved that the new technologies used in building envelopes helped in improving the thermal comfort in the buildings (Ibrahim L. , 2016), although the old techniques served the users thermal comfort but the new technologies enhanced its performance with the use of user's preferences (Bouazza & Deabes, 2019). Hence, because of the use of new technologies, building envelopes have become more interacting with the preferences of the users and the surrounding environment, leading to the appearance of smart materials such as smart glazing systems that helps also in reducing the energy consumed in a building (Talaei, Mahdavinejad, & Zarkesh, 2017), (Sadek & Mahrous, 2018) and (Aldawoud, 2013).

The initial cost challenge is also raised with the argument that new technologies is expensive, although it could be a source of more saving on the longer term, the cost of renewable materials, and presented studies proven that the energy payback time in some materials were no longer than 2 years, while the energy return could be 35 times the initial cost (Cao & Dai, 2016). In addition, the lack of awareness of the new technology's benefits could create a resistance on using them. Therefore, a lot of papers discussed this point and tried to drag more attention towards this matter (Prieto & Knaack, 2017) & (Abdul & Alshamrani, 2016), especially that it needs skills in order to be managed and controlled, however, without the knowledge and skills the system could fail particularly if it is based on the user-controlled system.

From the analyzed cases, it was confirmed that one of the main purpose of new technologies is to enhance the human experience and the wellness of life inside and outside the building without compromising the energy crises issue. With the fact that the buildings envelope is responsible for most of the interior spaces level of comfort, some have questioned the level of improvement these technologies have added to the building envelopes. Therefore a lot of studies have been done to investigate this matter and prove the significant importance of these technologies.

As proved from the literature and case analysis, facades technologies, in general, share in achieving a healthier indoor environment. Hence, developing technologies in building sector could enhance the life style of humans and reduce the negative impact of buildings on the environment, which in the end will help in providing a better future for the next generation.

VII. Conclusion and Recommendations

This paper focused on the new Technologies used to enhance the building envelope performance. As it raised the importance of improving these types of technologies to help solving the high demand for energy worldwide. The handling of the paper subject included three main sections:

- Adaptive Facades' Technologies to enhance Building Energy Performance: in this section a literature review were done for the adaptive facades' technologies and two more supportive integrated technologies that could increase building energy performance were discussed in addition the adaptive facades' technologies, namely Intelligent glazing technologies and power generation technologies.
- Challenges Facing the application of building envelopes technologies: between the common main challenges they all face, this paper will shed brie light, in brief, on challenges related to the initial cost, the lack of awareness of the new technologies benefits, and the rapid change of climate with its related crisis. These challenges could be solved by raising the public awareness of the benefits of Adaptive Facaes' technologies, to help in spreading such technologies, improving its capabilities, overcoming the climate challenge, and the initial cost concerns.
- Case Studies' analysis: a descriptive methodology adopted to conclude adaptive façade features and related results in saving energy and more. The procedure started with identifying the case studies' selection criteria. The adopted criteria were applied in multiple layers; the selection included a case from each of the five categories of the adaptive facades' technologies (user control, light control, energy control, managing water, and wind responsive facades). Based on study objectives, the case studies' analysis included introduction, features of adaptive façade technologies, and results and benefits of applying adaptive facades technologies.

The case studies analysis section proved that dynamic adaptive facades' technologies can not only enhance building energy performance, but also enhance the internal spaces environment and users comfort and attitude. These case studies were taken in different regions with different climates to confirm the benefits of the dynamic adaptive facades technologies in all regions. Table (2) shows a summary conclusion of case studies main features and related results and benefits.

Table (2) Case Analysis' Conclusion Summary

Case/Climate Zone	Facades' adaptive Features	Energy Benefits and More.
• Kiefer Technic Showroom, Austria • Temperate Climate	• Nano three dimensional panels individually or centrally controlled to adjust amount of daylight and heat entering the building. • Natural Ventilation: • Clear Glazing • Energy generation: None	• Adjust the amount of natural light entering the interior of the building space. • Allow the best thermal comfort for the interior spaces. • Allow users to personalize their particular spaces with the "user controls system".
• Al Bahr Towers, Abu Dhabi, Duabi • Hot Desert, Arid Climate	• Solar rays' control shading units • Weather tight glazing with high coating (40% visible light transmission and 18% external light reflectance). • Ability to allow natural light into the building. • No power generation feature	• Block direct solar rays from landing inside occupied spaces during working hours • control over energy consumption, Solar Radiation and Glare • 20% reduction of solar energy • 40% saving in CO2 emission • increased visibility and privacy • Decrease energy plant size
• Kolding Campus building, University of South Denmark,Kolding, Denmark • Temperate Climate	• Intelligent panels that contol shading, daylight, heat • Natural Ventilation: • Passive design (orientation, landscape, open atrium,…). • Clear Glazing • Using ground water by combined heating and cooling pump to regulate the temperature throughout the building • Energy generation: photovoltaics	• Optimize the balance between natural and artificial light in the building • 70%-75% of building energy saving was locked during early design phase by passive design strategies. • 50% saving in energy demand (compared to similar buildings of same typology in Denmark). • shutters act as windbreakers in the winter months
• Manitoba Hydro Headquarters office building, Winnipeg city, Canada • Humid continental Climate	• 24-meter-tall waterfall feature to humidify/ dehumidify internal air • 115-meter high Solar chimney • Geothermal system (considered the largest closed loop in the province) • Double façade curtain-wall system made of low-iron glass (double-glazed outer wall and a single-glazed inner wall) • Three winter gardens (three storey height). • Energy generation: photovoltaics	• 70% less energy than a comparable office building of conventional design • 100% fresh Warm air in winter and cooled air in summer • The three waterfall features in each of the atria humidifies or dehumidifies the incoming air. • Water from the geothermal system runs through concrete and heats or cools the internal spaces. • Purified and conditioned air by the three Internal winter gardens, external gardens and green roofs
• One Ocean – Pavilion EXPO 2012, Yeosu, South Korea • Temperate Climate zone	• Intelligent panels that respond to wind. • Natural Ventilation: • Green roof. • Energy generation: • Wind processed servo motors and Photovoltaic Panels	• Reduction of energy consumption and increase of Building energy efficiency • Natural air conditioned in the three seasons. • Photovoltaic panels generate 2/3 of energy consumed by the building systems over the year. • The moving lamellas create animated patterns on the façade

Recommendations: In general, new technologies are designed to improve the human quality of life and reduce any danger they might face. Nowadays, one of the main concerns worldwide is the energy high consumption and the continues high demand for energy. Therefore, this paper is recommending:

- **Projects' decision makers and engineering consultants:**
  - Run life cycle analysis and value engineering to apply suitable combination of facades adaptive technologies to harness its related benefits on the short and long run.
  - Adapt these technologies in new building as well as retrofitting the existing buildings.
- **Universities:** Include buildings' state-of-art technologies and its related applications in the curriculum to raise the understanding of its related benefits on the long run.
- **Universities and Research Centers:** encourage further studies in the field of adaptive facades, its related challenges, the use of renewable energy and how they could be more integrated in buildings with the use of new emerging intelligent and smart materials.
- **Media:** Coordinate with related parties to take the necessary actions to raise the public awareness of the importance of using new technologies as well as the researchers and scientists.

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