The Role of Buildings Envelope Renovation to Improve the Visual Image for Existing Buildings Toward Ecological Balance

Amal Ismail and Haby Hosney

Abstract

Recently, there has been a growing interest in ecological issues worldwide. On the contrary, scientists have demonstrated that humans face two significant problems; first, many natural resources that we consider their presence for granted are now near to depletion. Second, the environment suffers from the ever-increasing pollution levels due to the enormous production processes and associated waste that we produce, affecting the planet's well-being and its inhabitants. Therefore, ecological conservation is a significant issue in various fields, particularly architecture. The aim of this research is to focus on the critical role of buildings envelope in improving the visual image of buildings and how we can use it to promote the ecological balance. Furthermore, the research focused on existing buildings because they account for a significant percentage of the building stock. In order to achieve this, the research hypothesized that there are treatments that could be used in existing buildings envelope to preserve the environment, energy and reduce emissions.

Keywords

Ecological balance • Buildings envelope • Buildings renovation • Building materials • Envelopes renovation • Eco-friendly architecture

1 Introduction

The building sector plays a fundamental role in mitigating the impact of climate change and conserving energy consumption. Furthermore, the majority of existing buildings are not compatible with ecological balance. On the contrary, there are successful experiences of many new buildings that have benefited from modern materials and construction strategies technology. Consequently, renovating existing buildings to achieve ecological balance has become a significant challenge.

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2 The Applied Research Work

The building envelope is a middle interface between a building's internal and external environments. In addition, numerous materials have been developed to optimize the envelope role toward the environment, making it more energy efficient and eco-friendly. For these reasons, the research aims to investigate the worldwide experiments of changing building envelopes, especially in existing buildings, to find solutions to improve the efficiency of the building envelope. It also highlights the importance of changing the properties of building materials for existing buildings as a solution to simultaneously improve the visual image in the components of the existing cities. There are still many gaps in the research field of building materials compatible with the environment and could be used on existing building envelopes. Consequently, there is a need to study some projects that applied renovation to achieve ecological balance.

3 Ecological Balance

Ecological balance is a component of the accurate balance of the universe's system, such as the equilibrium between different living organisms and their environment. Human activities can contribute positively to the creation and maintenance of ecological balance. In contrast, these activities can influence the potential of natural ecosystems and lead to environmental disruption. Therefore, this balance is

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crucial because it ensures the existence, survival, and stability of the environment as well as human beings (Ghoneem, 2011).

4 Building Envelope Renovation Strategies and Techniques Compatible with the Environment and Their Properties

4.1 Vacuum Insulation Panels (VIPs)

Vacuum insulation panels (VIP) are highly efficient thermal insulators. Since the vacuum is one of the most effective thermal insulators, low thermal conductivity is accomplished not by containing air pockets but by completely emptying them (i.e., the existence of a vacuum is the principle idea), in which heat is only transmitted by radiation, not by convection, as it would occur in an air environment. The panels consist of a core and outer skin envelope made from plastic foil. It creates a vacuum around the fill material and is frequently coated with aluminum or stainless steel; the fill material may be foam, powder, or glass fibers and must always be permeable and porous, resistant to pressure, and can be evacuated (Fig. 1). The hermetically sealed ends protrude on either side and are typically folded back and adhered to the panel. Compared to others already massively marketed in the market, the great advantage of this system is its great capacity as an insulator with the smallest thickness, ranging from 2 to 40 mm.

VIP panels are suitable for buildings under construction and existing buildings renovation. They are mainly used in the rehabilitation of buildings and be incorporated as an insulating element to replace the more traditional actions that did not provide insulating capacity in the envelope of the repaired buildings.

The disadvantage of these panels is their elevated costs and complicated production processes. The vacuum-enclosing skin must not be penetrated to ensure the proper operation of the panels. Similarly, the panels must be handled carefully on-site and during transportation to avoid damaging the panel's delicate skin (GarciaRama; Hesham et al., 2019).

4.2 Double-Skin Facades System

It is a two-layer facade system with a space between them of about 20 cm, and air could flow through the intermediate space naturally or mechanically to act as insulation against the external environment (Fig. 2). Additionally, double-skin facades have become more adaptable to their surroundings. By the movement of inlet and outlet fins or activating air circulators, the facade's behavior can be altered in response to changing climate conditions and building requirements. As a result, designing a double-skin facade system is a complex process that begins with collecting critical data concerning sun orientation, temperature conditions, local radiation, context, and building occupancy (Souza, 2019).

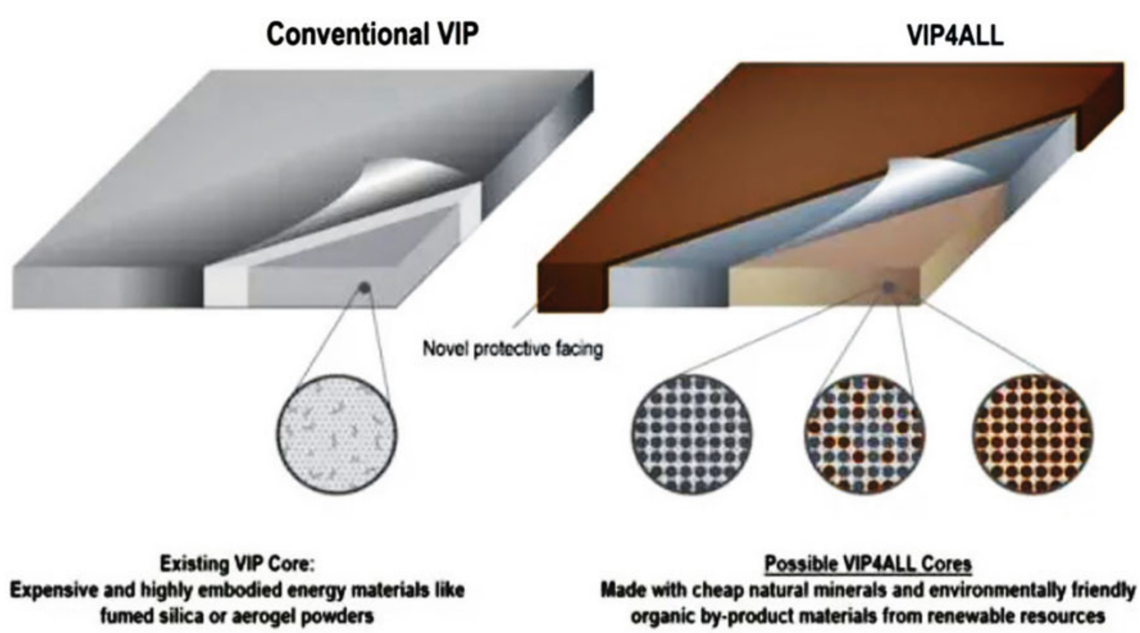

Fig. 1 VIP consists of a core and outer skin envelope (Rinnovabili.it, 2016)

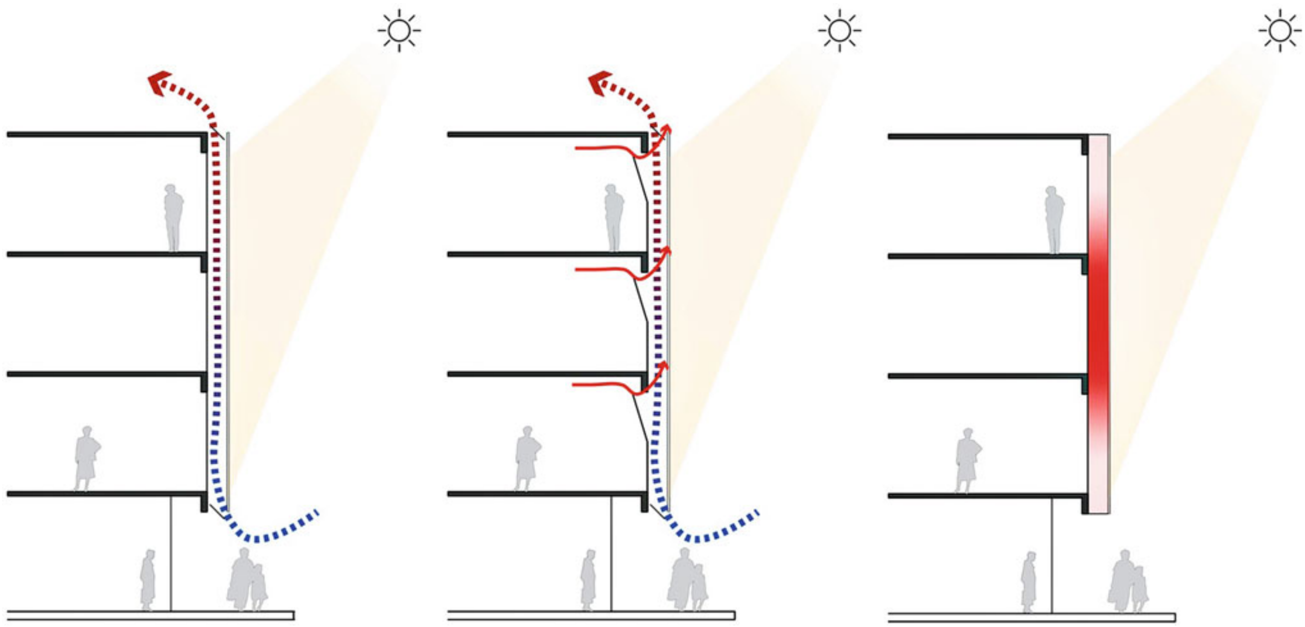

Fig. 2 Double-skin facade role in protecting the building and improving thermal comfort (Souza, 2019)

4.3 Aerogel

Aerogel is a translucent gel composed primarily of air and composed of a dry silica particulate. Aerogel has a unique structure with special properties, including the least density, thermal conductivity, refractive index, and dielectric constant of any solid material. It is among the lightest and most effective insulating materials in the world. Due to these reasons, it is high performance in reducing glare, sound transmission, and thermal transfer (Fig. 3). Aerogels have a variety of applications in construction, including optical transparency control in window panels and solar collector coverings, in addition to low thermal insulation and noise reduction (Riffat & Qiu, 2012).

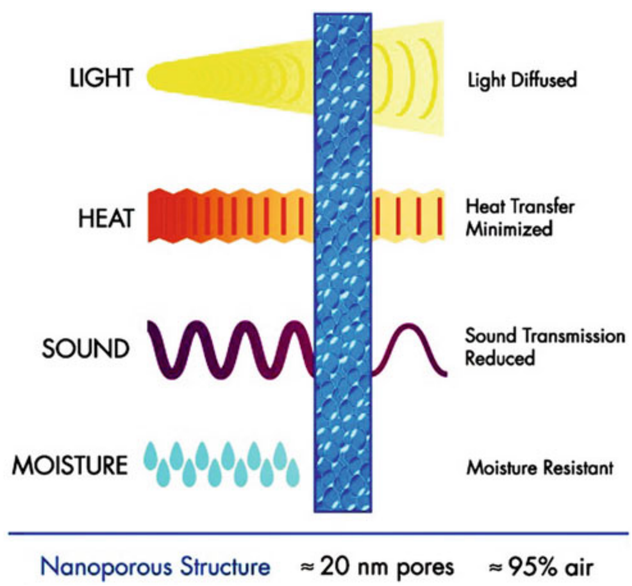

Fig. 3 Aerogel has a high performance in insulating (Solarwall)

4.4 Smart Glass

This material is based on the operation mode, and there are different types of smart glass; it depends on the user's needs.

4.4.1 Passive Dynamic Glass

The passive dynamic glass system is not based on electricity but responds to natural catalysts such as light or heat.

A. *Photochromic glass*

The photochromic glass changes its transparent characteristics in response to the intensity of incident light. When directly exposed to solar radiation, the difference in spectrum absorption between the energy layers of glass and the added chemicals causes a reversible coloring process.

B. *Thermochromic glass*

Thermochromic glass alters its optical characteristics in response to the temperature of the exterior surface. When the ambient temperature is lower than the transition temperature, the material remains transparent and becomes opaque for higher temperatures (Fig. 4).

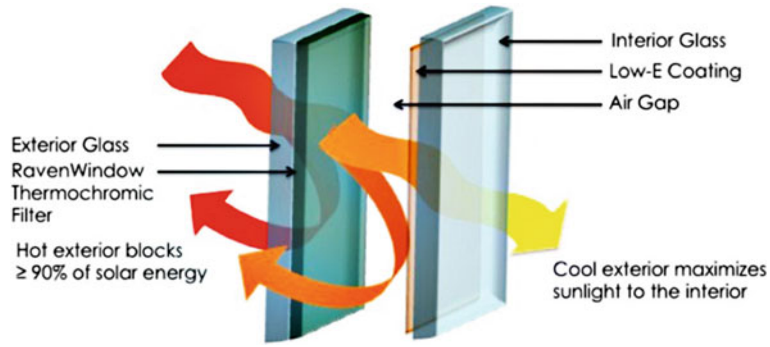

Fig. 4 Thermochromic operation process (Smartwindows)

4.4.2 Active Dynamic Systems

In order to respond to changes in the external environment, internal climatic conditions, or user needs, active dynamic systems can be operated directly or through a computerized building management system.

A. *Electrochromic glass*

Electrochromic glazing benefits from the potentials of certain materials to alter the parameters of solar radiation reflection, absorption, and transmission, in response to an externally adjusted electrical stimulus.

B. *Suspended particles glass*

Suspended particles glass is made of a double sheet of glass (Fig. 5), with a thin laminated layer of suspended particles similar to rods immersed in fluid sandwiched between two transparent thin plastic film conductors. The suspended rod particles align when power is applied, allowing light to pass and clearing the smart glass display. When the electricity is turned off, the suspended rod particles become randomly orientated, obstructing the light and making the glass appear opaque (Casini, 2014; Dashdoor).

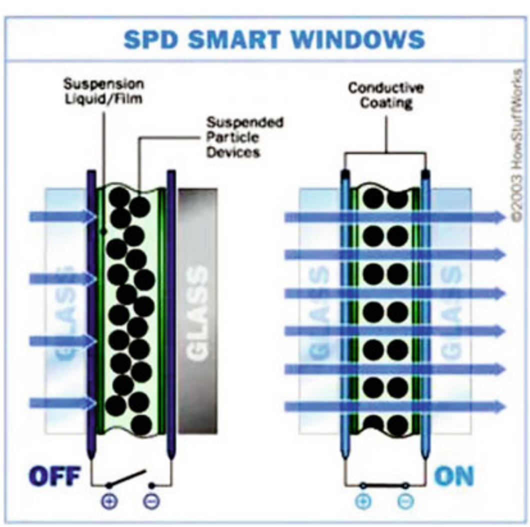

Fig. 5 Suspended particles smart glass and how it works (Bonsor)

4.5 Insuladd Insulating Paint

Insuladd paint was created by Mr. David Page, the founder of Tech Traders, participating in the 1995 NASA Technology Exchange Program. These paint products are proven ability to decrease unwanted heat gain and heat loss from homes (Fig. 6), other buildings to which they have been applied, and its environmentally friendly. It incorporates a special ceramic microsphere-based insulating ingredient designed to be mixed into conventional paints to create a radiant barrier paint. Insuladd is a paint additive that has been used for a long time to make buildings, warehouses, and ships more energy efficient. Using Insuladd paint additive in painting projects is an excellent method to reduce energy consumption and save money on electricity bills. It has been demonstrated to save households up to 40% on their typical heating and cooling bills (Flowers, 2017; Insuladd).

4.6 StoLotusan Paint

Lotusan is a paint inspired by the lotus leaf, which is always clean and dry even after rain. The paint facilitated the transfer of the lotus leaf concept from biology to technology by

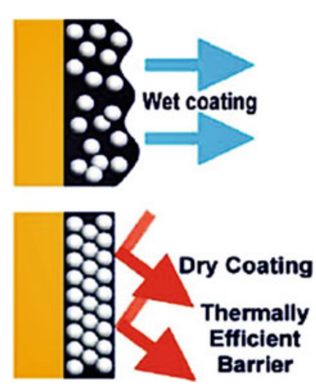

Fig. 6 Insuladd insulating paint with a unique ceramic microsphere creating a radiant barrier paint (Flowers, 2017)

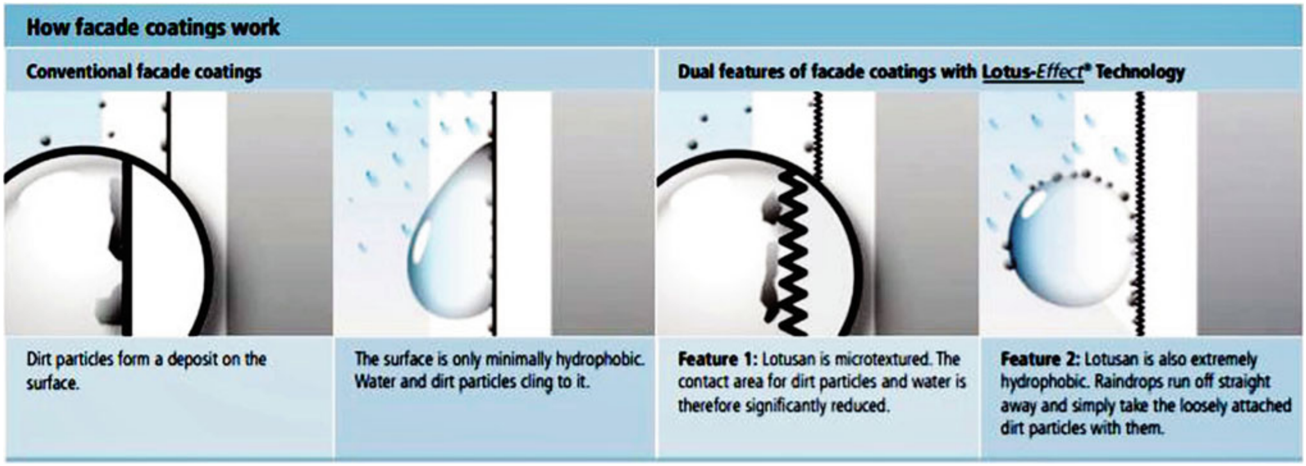

Fig. 7 Before and after using StoLotusan paint on façade (Sto)

utilizing specifically selected raw ingredients and binder combinations with a microstructure made of extremely fine mineral rock flour and metal oxides. Due to the paint's strong water repellency, dirt is washed away by rain (Fig. 7), a deft blend of a water-repellent surface, and a unique microstructure resembling a lotus leaf. As a result, most dirt particles fail to cling to the facade surface correctly and are rinsed away by rains during the next rain shower (Nessim, 2016).

4.7 Titanium Dioxide (TiO_2)

Photocatalytic materials are a recent breakthrough that contributes significantly to reducing pollution. These materials are self-cleaning, absorb many pollutants in the air, and operate as an antibacterial agent by converting the surfaces to that they are applied into multifunctional constituents due to solar radiation. It is a particular titanium dioxide mineral form (TiO_2) (Fig. 8). By integrating anti-pollution and antibacterial properties, a photocatalyst speeds the oxidation process by assisting pollutants to degrade into water-soluble inorganic salts. Nitric oxide (NO_x), particulate debris, and volatile organic compounds (VOC) are converted into harmless substances for humans and the environment, like sodium nitrate ($NaNO_3$) and carbonate. Additionally, photocatalytic paints applied on the exterior of buildings may help reduce (CO_2) and other chemical pollutants. In addition, the envelope serves as a protective barrier between the interior and the exterior (Di salvo, 2018).

4.8 Photovoltaic Panels (PV)

Solar energy is a renewable source that is both free and clean. By photovoltaic cells, we can transfer light energy into electricity. Hence, this energy can provide us with most of our electricity needs. There are different types of photovoltaic cells; the first type or old one contains crystalline silicon. After that, the new generation contains amorphous silicon, and other types contain thin technology layers; however, more than 90% of solar cells still consist of wafer-based silicon cells.

Light carries energy flowing into the cells, where it is converted into electricity (Fig. 9). Light dislodges electrons from highly energetic silicon atoms; the internal electric field forces electrons to the front of the cell and conducts electricity to adjacent cells. The fundamental building block of a

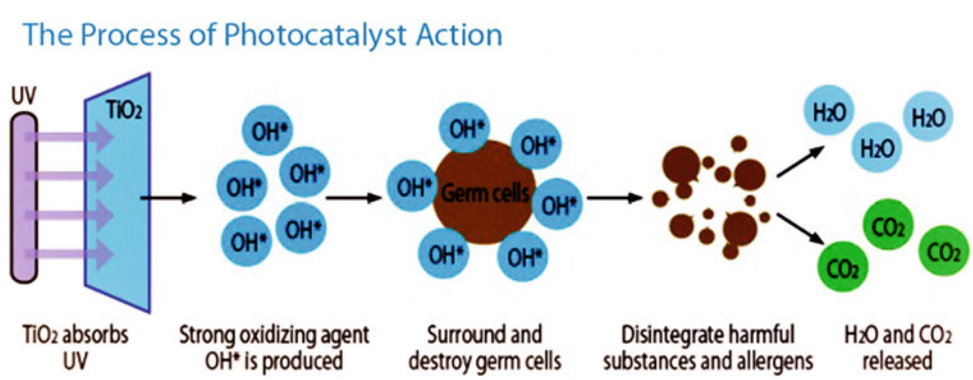

Fig. 8 Photocatalyst process (J, 2013)

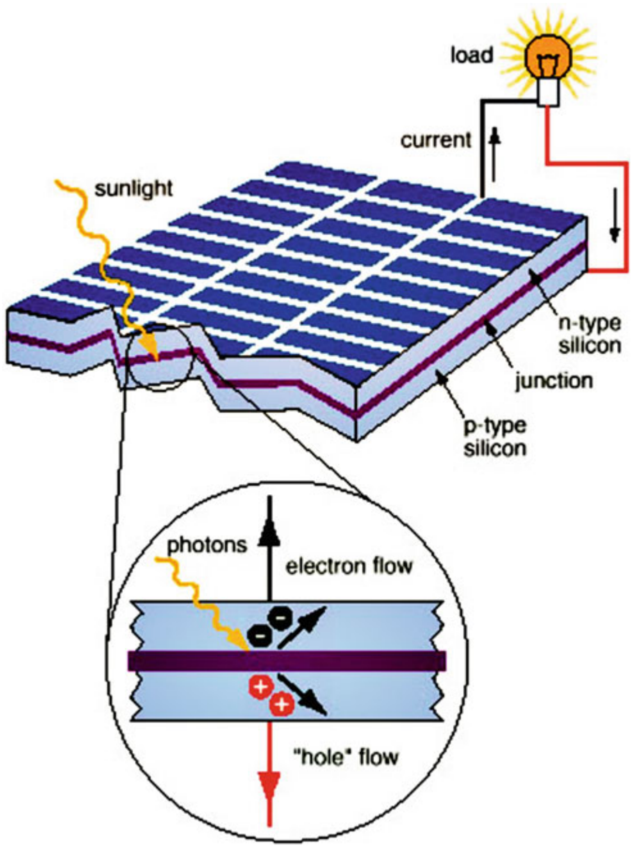

Fig. 9 Process of converting sunlight energy into electricity (Alec, 2011)

photovoltaic system is modules that contain cells. On the other hand, the (PV) panel is a group of modules, and also (PV) array contains a group of (PV) panels (Bagher et al., 2015; Grant, 2016).

5 Research Methodology

The research was conducted using a descriptive and analytical method based on resourcing data from the researches relating to modern building materials, as well as a comparative method between five world experiments that applied renovation for existing buildings envelopes to find solutions to enhance the visual image in the components of the existing cities toward ecological balance.

Overall, these five case studies have been chosen and analyzed in order to highlight the importance of changing the properties of building materials for existing building envelopes to be more efficient in terms of energy consumption, construction economics, and air quality.

6 Examples of Buildings that Applied Envelope Renovation Toward Ecological Balance

6.1 Manuel Gea González Hospital Renovation as an Example of (TiO_2) Material

Criteria of selection: This case study demonstrates the use and performance of (TiO_2) material in building envelopes to clean the air that goes into the building and surrounds it to enhance the indoor environmental quality.

Location: Mexico City
Principal architect: Manuel Villagrán and Elegant Embellishment (Allison Dring and Daniel Schwaag, Berlin)
Date of completion: 2012
Building type: Hospital
Strategies used in the project envelope: (TiO_2), Prosolve 370e.

The original Manuel Gea González Hospital was constructed in 1942 and was designed by architect Manuel Villagrán (Fig. 10). On the contrary, a new medical specialties tower was built in 2013 (Fig. 11). A 2500m2 facade is built out of 100 m-long, composed of a lightweight plastic material that satisfies environmental requirements entitled Prosolve 370e. The facade panels are coated with a fragile titanium dioxide coating (TiO_2).

Pollutants and other toxins are neutralized when the new façade is exposed to direct sunlight. Excessive UV radiation levels are not required to activate the coating electrons, converting nitrogen oxides and other chemicals to water and calcium nitrate that will be rinsed away by rain.

6.1.1 Observation and Results

The hospital facade panels purify the air that enters and surrounds the site. Additionally, the tiles screen filters sunlight, reducing the need for air conditioning and avoiding damaging emissions.

The new façade of the Manuel Gea González Hospital is expected to neutralize 1000 automobiles' daily nitrogen oxide emissions.

The new, non-orthogonal grid generates an apparently random tiled pattern, leading to visual randomization, a desirable aesthetic generally accomplished through bespoke design and price.

Consequently, the sculptural surfaces exhibit a natural harmony between design form and molecular technology (Tokuç et al., 2018; Prosolve370).

Fig. 10 Manuel Gea González Hospital original facade (Bitencourt & Monza, 2017)

Fig. 11 Manuel Gea González Hospital renovation façade (Embellishments, 2014)

6.2 American Geophysical Union (AGU) Headquarters Renovation as an Example of Dynamic Glass Windows

Criteria of selection: This case study demonstrates how to use triple-pane, air-filled, 1–3/4-inch thick dynamic glass windows to regulate the solar heat gain coefficient, reducing heat, and cold transmission.

Location: Washington DC, USA
Principal architect: Hickok Cole
Date of completion: 2018
Building type: American geophysical union
Strategies used in the project envelope: Smart glass and photovoltaic panels.

The American Geophysical Union is a nonprofit organization dedicated to improving research and ensuring a sustainable future. AGU restored its existing 62,000-square-foot headquarters facility to become the district's first net-zero energy renovation. Net-zero energy will be attained using a combination of architectural, engineering, and innovative technology solutions that conserve, reclaim, absorb, or generate energy or water (Fig. 12).

To minimize energy efficiency losses, AGU will utilize a microgrid for energy distribution, which will be powered by the photovoltaic array's DC power. AGU's solar photovoltaic array comprises 720 sunpower solar panels, totaling 250 kilowatts. The system is strategically placed to maximize efficiency, with 24 panels on the vertical, south-facing surface and 696 panels lifted and set out horizontally above the penthouse roof.

Fig. 12 (AGU) Before and after renovation design (Koski, 2016)

AGU's current windows have been replaced with triple-pane, air-filled, 1–3/4-inch thick dynamic glass windows. The addition of a third pane results in a lower U-value and solar heat uptake coefficient, which reduces heat and cold transmission. Additionally, this glazing features an electrochromic layer that colors on-demand, reduces glare and heat transfer, and allows natural light and views.

The outdoor air system provides a reliable method of building ventilation. This system simultaneously conditions entering air and recovers heat from the outgoing exhaust to warm incoming air for space heating purposes. Rainwater collected from the roof and photovoltaic array will be stored in an 11,300-gallon cistern positioned in the garage of the building. Greywater will be filtered and treated before being reused for flushing fixtures and irrigation of the green roof (Fig. 13).

6.2.1 Observation and Results

AGU seeks to receive a perfect score of 100 in the LEED credit categories for water efficiency, energy and atmosphere, innovation in design, and regional priority.

Water consumption is reduced by 77% due to effective water fixtures and rainwater collection. Approximately 90% of construction waste was recycled. AGU will rank in the top 5% of the world's 110,000 + LEED projects with 96 points.

Beyond net-zero energy use, the project incorporates additional sustainability features such as reusing distinctive architectural elements, repurposing existing building materials, and offsite recycling of construction and demolition waste (AGU, 2019; Jacobsen, 2016).

6.3 Leaves Performative Walls (LPW) as an Example of Solar Collectors-Pollution Control Devices and the Branches as Energy Conductors

Criteria of selection: This case study demonstrates the usage of Leaves Performative Walls (LPW), which are made up of a succession of leaf-shaped panels, some of which are photovoltaic and the rest of which are smog-eaters that are coated with chemical treatment of titanium dioxide for air cleaning.

Location: Barcelona, Spain
Principal architect: Javier F.Ponce and PGI Engineering

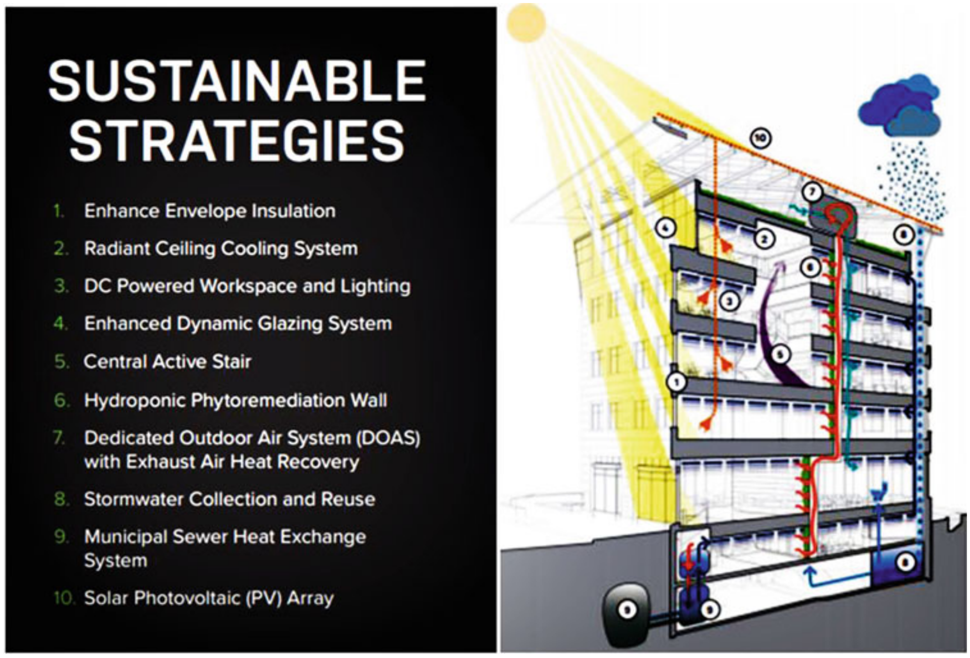

Fig. 13 Section through the (AGU) building showing renovation strategies (Hickok Cole Architects, 2019)

Date of completion: Data not available
Building type: Various.
Strategies used in the project envelope: Leaves Performative Walls (LPW).

Barcelona can try novel ways for party wall recovery and implement smart city solutions, thereby advancing into the present and future. LPW is an experimental concept inspired by the morphology of Barcelona's trees (Fig. 14). The project is a manufactured alternative that consists of a succession of leaf-shaped panels, some of which are photovoltaic and others of which are smog-eaters via the chemical treatment of titanium dioxide for air cleaning, emulating the primary internal functions of trees, solar collectors-pollution control devices on the leaves and energy conductors on the branches (Fig. 15).

6.3.1 Observation and Results

Simulation results on the energy performance of example party walls in Barcelona have an impact on ecological issues for example:

- Energy facade savings about 37 kWh
- Photovoltaic generated energy about 380 kWh
- CO_2 emissions reduction about 110 Tn CO_2
- Smog-eater production about two trees (PGI ENGINEERING, 2012; Ponce, 2014).

On the contrary, this solution helps to improve the visual image of old buildings while remaining environmentally friendly.

Fig. 14 Series of leaves shape panels applied on an old building in Barcelona (Samper & Juncadella, 2014)

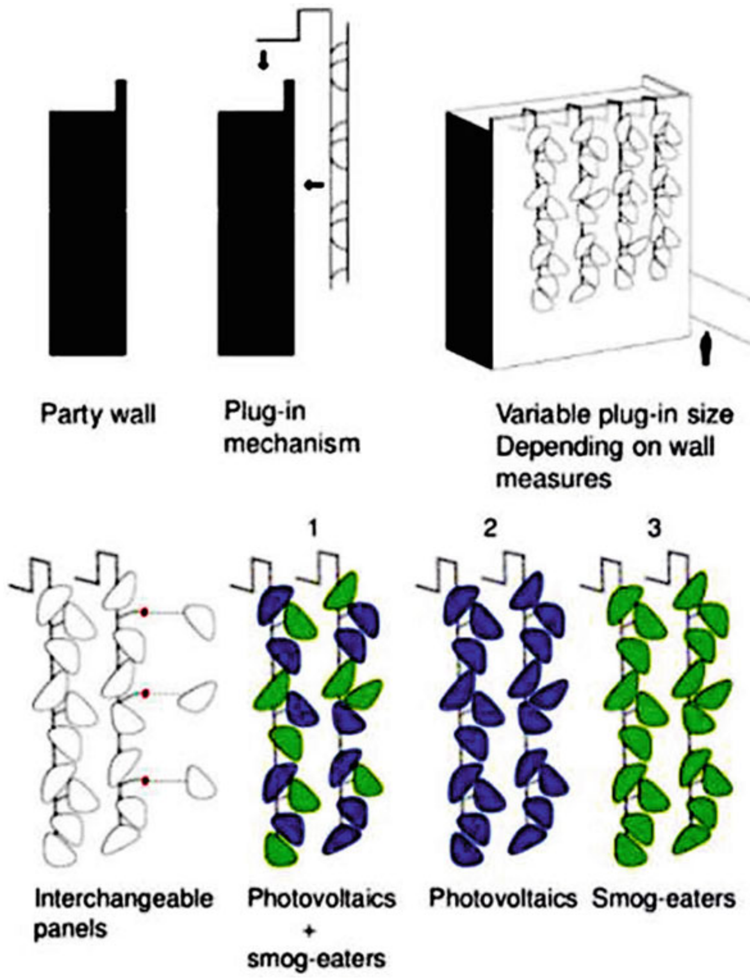

Fig. 15 Fixing system on the old building facade and the flexibility of changing leaves between photoelectric and pollution-eating leaves according to building needs (PGI ENGINEERING, 2012)

6.4 RB12 Office Block as an Example of Smart Glass Windows and Photovoltaic Panels

Criteria of selection: This case study demonstrates the usage of smart glass windows equipped with an automatic night-time opening system, which allows for the intake of fresh air and its retention throughout the day. Additionally, photovoltaic panels were installed on the building's north-facing sidewall as feasible, generating solar energy for the building.

Location: Rio de Janeiro, Brazil
Principal architect: Triptyque, a Franco-Brazilian architecture agency
Date of completion: 2016
Building type: Commercial building
Strategies used in the project envelope: Bioclimatic facade and photovoltaic panels.

The RB12 was constructed in the 1970s. Natekko, a property developer, commissioned Triptyque to investigate ways to reduce the building's energy consumption. RB12 epitomized avant-garde new principles of sustainable development centered on energy production. The technological equipment, which was installed for the first time, enables effective management of water usage, optimizes natural light, and provides a higher level of well-being to real estate buildings.

RB12 has a bioclimatic facade made up of a series of windows that reflect light like a diamond (Fig. 16). It is the first commercial building in Brazil to be powered entirely by photovoltaic panels. The suspended gardens on the terraces enable the interior sections to be more efficiently cooled and heated.

The RB12 is situated on an avenue flanked with tightly packed buildings, the architectural team explains. "Because of the height of the buildings, heat tends to accumulate between them, and the sun shines straight on the windows."

The glass facade is deliberately veiled to minimize heat intake from direct solar radiation while being transparent enough to permit abundant natural light to walk through the building indirectly (Fig. 17).

Fig. 16 RB12 bioclimatic diamond façade after building renovation at daylight and night (Finotti, 2016)

Fig. 17 RB12 bioclimatic winding facade from inside (Finotti, 2016)

At night, the windows of the building are opened to allow for air and to chill the inside. An automatic window opening system makes it feasible to bring in the fresh air and retain it throughout the day, owing to the building's insulation.

Triptyque asserts that this is the first commercial building in Brazil to generate electricity in this method. Any energy generated that is not consumed will be sold back to the grid.

6.4.1 Observation and Results

Photovoltaic panels and a small vertical installation will provide approximately 18% of the building's energy requirements. Additionally, RB12 will utilize fuel cell advancements to turn additional methane gas from city streets into electricity. The suspended gardens on the terraces reduce the electricity demand in internal areas because of the thermal control. The façade system reduces artificial lighting along the walls results in a reduction in power usage and internal temperatures.

After assessing all of the green measures implemented in RB12, it was determined that the building would consume around 60% less energy than a regular office building. Furthermore, because the facility will generate electricity 24 h a day but consume it for approximately eight, any excess energy generated will be sold back to the electrical system.

By rehabilitating the structure, it is possible to reduce material waste from demolition and carbon emissions associated with new construction (ArchDaily, 2016; Singhal, 2016).

6.5 The CDER Building as an Example of the Double-Skin Facade and Photovoltaic Panels

Criteria of selection: This case study demonstrates how a double-skin system can be used to control sunlight transmission through the facade. Also, photovoltaic panels were added to the building roof to provide clean energy for the building needs.

Location: Épernay, France
Principal architect: OuyOut
Date of completion: Renovation under construction
Building type: Office building
Strategies used in the project envelope: Double-skin system and photovoltaic panels.

The site where CDER hoped to extend was constructed in 1963 instead of demolishing the building. While developing an environmental rehabilitation, the architect chose to maintain a portion of the original structure. With double-flowered facades of vines and green roofs (Fig. 18), this building has the ambition to become a significant marker of the city center, emblematic of a city combining anchoring in the Champagne terroir and a vision of the future.

By removing the addition of three floors on rue M. Cerveaux and the one-story garage on rue de Huguenots, this solution gives views from the street toward the interior of the plot on green reception areas.

The green roof connects to the garden level of the terraced plot, 4 m higher, and creates a heart of plant block. The team created a design that insulates the building from the outside, shielding it from the sun while also capturing the thermal inertia of the concrete structure on the inside.

The double facade is a thin metal structure composed of vertical mesh strips 80 cm wide to support the vine. This structure is set back one meter from the facade and has enormous flowerpots that will enable the vine to flourish on each level of the construction.

6.5.1 Observation and Results

The final design not only shields the building from the outside, but also uses the thermal inertia of the concrete structure on the inside. Autodesk determines this insight.

Fig. 18 CDER building before and after renovation design (OuyOut, 2019)

Table 1 Envelope renovation case studies analysis

Project	Manuel Gea González Hospital	(AGU) American Geophysical Union Headquarters	Leaves Performative Walls (LPW)	RB12 Office Block	The CDER Building
Project location	Mexico City	Washington DC, USA	Barcelona, Spain	Rio de Janeiro, Brazil	Épernay, France
Climate	Sub-tropical	Sub-tropical	Mediterranean	Tropical	Semi-oceanic climate
Envelope renovation type	• Double-skin pieces made of a lightweight plastic called Prosolve 370e	• Enhanced building envelope insulation • Solar rooftop photovoltaic (PV)	• Leaves Performative Walls (LPW)	• Bioclimatic glass facade • Suspended gardens on the terraces • Solar photovoltaic (PV)	• Double flowered facades thin metal structure • Green roofs • Photovoltaic roof panels
Envelope renovation strategies for ecological balance	• Promote outdoor air quality by using Prosolve 370e panels covered with titanium dioxide (TiO_2) powder • The covered panels have photocatalytic and anti-microbial properties	• Energy efficiency loss and transmission of heat and cold by dynamic glass windows and the dedicated outdoor air system • Reducing glare while allowing natural light to enter and exit by new glazing • Generated clean energy from the sun by solar rooftop photovoltaic (PV)	• CO_2 emissions and generate clean energy through Leaves Performative Walls (LPW) • The leaves are composed of a succession of leaf-shaped panels, some of which are photovoltaic and the remainder of which are smog-eaters due to titanium dioxide's chemical treatment	• Generating solar electricity for the building by solar photovoltaic (PV) • Reduce energy consumption by bioclimatic glass façade and suspended gardens terraces • Provide the internal areas with fresh air and keep it all day by automatically opening the windows system	• Control sunlight radiation through the building by double-skin flowered facades • Photovoltaic panels on the roof provide the building with electrical demands
Maintenance	Easy	Special	Easy	Special	Special
Air pollution reduction	Yes	No	Yes	No	No
Benefits	Public	Private	Public	Public	Private
Reduced energy use	No	Yes	No	Yes	Yes
Temp. control	No	Yes	No	Yes	Yes
Improved indoor air quality	Yes	No	No	Yes	No
Increased market value	Yes	Yes	Yes	Yes	Yes
Renovation cost	Depends on the facade design and area	High cost	Medium	Depends on the facade design and area	High cost
Visual image	Modern	Better than before	Better than before	Modern	Nice
Envelope renovation disadvantages	• Prosolve 370e panels required special labors • Prevent visible natural solar light	• Not suitable for all kinds of existing buildings • Requires high technology for the application	• Requires solid façade for leaves supporting	• Not suitable for all kinds of existing buildings	• Not suitable for all kinds of existing buildings and layout surround

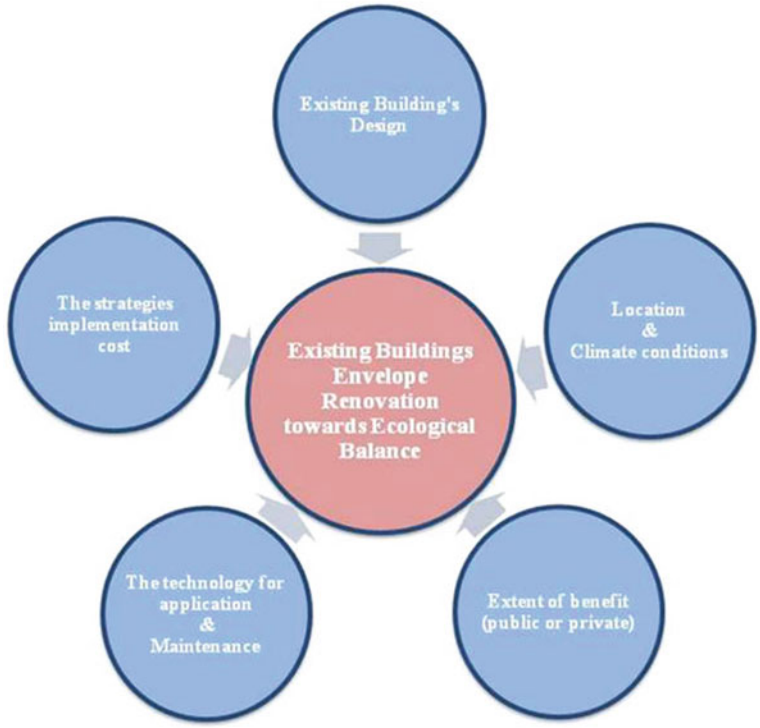

Fig. 19 Factors which impact on buildings envelope renovation toward ecological balance (author)

The smart envelope, designed for the new renovation, contains exterior insulation, a self-supporting green roof, sun protection mesh, vegetation support mesh, and photovoltaic panels to protect buildings from direct sun radiation and provide electricity demand.

The double-skin facade allows the natural light to pass through the windows without glare, reduces artificial light, and saves energy.

Envelope renovation instead of building demolition could help save the raw material and reduce carbon emissions (Autodesk, 2019; Goldberg, 2019).

7 Concluding Remarks and Further Work

In this research, we focused on existing buildings envelope renovation applications with various strategies and techniques in different types of projects. For the current research scope, three primary purposes were selected: improving the visual image, efficiency, and ecological balance compatibility. Designing the building envelope is critical because it is a building's first layer that defends against climate conditions and environmental pollution. Regarding the effect of the envelope renovation on cooling and heating demand, the results confirmed that the double-skin system in renovation could save the building from direct sun radiation to reduce energy consumption. Additionally, glazing refurbishment with smart glass reduces the use of artificial lighting, reducing energy consumption without sacrificing comfortability or outer visibility. Moreover, the building envelope renovation could improve air quality in the surrounding environment and buildings (Table 1). For these reasons, many strategies can be applied to the building envelope toward achieving ecological balance. However, they differ from one building to another due to several factors, such as the building's design, its location, climate conditions, the strategies implementation cost, the ability to provide the technology for its application and maintenance, and finally, the extent of benefit from these strategies (Fig. 19). In addition, the renovation does not mean only a beautiful visual image but should consider nature and ecological issues.

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