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VENTILATED GREEN FACADES AS A PASSIVE DESIGN STRATEGY

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Abstract. *Before air conditioning systems, the facade was crucial in providing a well-ventilated and thermally regulated indoor environment. After the integration of air conditioning systems in buildings, this protective enclosure has ceased to provide such services. Our reliance on the mechanized environment has led us to passive strategies that are used to reduce the needs for heating and cooling, as well as for ventilation and interior lighting. Therefore, this paper will present an analysis of natural materials used as insulation in the facade. The influence of ventilated green facades on the energy efficiency of the building will be considered along with the basic classifications and elements. As tenants and designers of these buildings, we now realize that strict reliance on mechanical equipment comes with "a high price"- more energy to operate and maintain all these mechanisms, as well as poorer health due to inadequately ventilated interiors and unchangeable temperatures. As a result, some guidelines and good practices will be presented. With the envelopes of buildings that become the main focus in reducing the energy load of objects, we begin to understand the role of intelligent facades in transforming the way we design buildings. Due to aesthetic and performance reasons, this innovative facade technology should be considered an opportunity for energy efficiency strategy of the building. Green ventilated facades can improve living conditions and help to alleviate climate change.*

Key words: *Green ventilated facade, Energy efficiency, Insulation materials, Living facades*

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1. INTRODUCTION

In architecture, the facade of a building is often the most important aspect from a design standpoint, as it sets the tone for the rest of the building. From the engineering perspective of a building, the facade is also of great importance due to its impact on energy efficiency. Global climate changes caused by the increasing exploitation of raw materials are becoming more and more intense. In Serbia, there are short and long-term national energy efficiency programs with the main goal of ensuring a good microclimate in buildings with minimal energy consumption and least pollution. The contemporary passive design relies on understanding the climate and design processes in order to create buildings that accomplish excellence while reducing the need for energy-consuming equipment to provide comfort and health. Passive design requires focusing on the architecture first, before supplementing with active systems, thus shifting the first cost from equipment to improvements of the building enclosure.

Building envelope, or building enclosure, is part of the building that physically separates the exterior environment from the interior environment(s). The building enclosure has to provide the “skin” to the building, not just separation but also the visible facade. The word facade is derived from the Latin facies – face, thus facade is the face of every construction object. In parallel with the development of construction, facades have also developed both in their shape and in the way they are made. In general, the requirements of the facade may be grouped into four categories:

- Support requirements - to support, resist, transfer and otherwise accommodate all the structural forms of loading imposed by the interior and exterior environments, by the enclosure, and by the building itself. It is essential to provide resistance, stability, compatibility, durability, and fire resistance.
- Comfort requirements - to control, regulate and/or moderate all the loadings due to the separation of the interior and exterior environments (thermal control, moisture protection, hydrothermal control, lighting control, acoustic control).
- Finish functions - to finish the enclosure surfaces with the interior and exterior environments. Each of the two interfaces must meet the relevant visual, aesthetic, cultural, social, psychological, and other relevant requirements.
- Distribute functions - to distribute services or utilities such as power, communication, water in its various forms, gas, conditioned air, etc., to, from, and within the enclosure itself.

The facade selection is conducted by available materials, type of building, and aesthetic requirements. One of the basic tasks of the facade is the best possible thermal insulation. High heating costs, global warming, and environmental protection have imposed the adoption of strict laws and regulations for different systems of thermal insulation of residential and commercial buildings. Inadequate thermal insulation can cause consequential heat losses and gains increasing the cost by approximately 20% through so-called thermal bridges. Thermal bridging in buildings reduces energy efficiency and can allow condensation and thermal comfort problems, which can result in indoor air quality problems and building deterioration.

2. TYPES OF FACADES

Different types of facades are used nowadays, and the basic classification is according to the system of the facade itself, which can be made of heavy or light elements and with or without air cavities (Table 1). In recent years, many modern facade constructions have been realized in Serbia, which are remarkable achievements and according to highest standards. Nevertheless, contact facades are still the most common type of different heat protection systems, where the insulation is attached directly to the wall of the building on the outside.

Table 1 Facade's usual combination according to the layer's quality and position

	HEAVY STRUCTURE				**LIGHT STRUCTURE**
	Single-Leaf	Multi-Leaf			
WITHOUT Air cavity	Without a specific insulation material	Internal insulation	Intermediate insulation	External insulation	
WITH Air cavity		Non ventilated	Ventilated with intermediate insulation	Ventilated with external insulation	Ventilated

Expanded polystyrene (EPS) and extruded polystyrene (XPS) are most common in a variety of installations for the entire building envelope as external insulation in a multi-leaf heavy structure facade. EPS foam is closed-cell insulation manufactured by expanding a polystyrene polymer, the appearance of which is typically a white foam insulation board. XPS foam is rigid insulation also formed with a polystyrene polymer but manufactured using an extrusion process and with a distinctive color to identify product brand.

Neopor, a newer BASF insulating material, is composed of small black beads of polystyrene containing particles of graphite and a blowing agent, which makes it expandable. Particles of graphite enable the production of insulation boards that perform up to 20% more efficiently than conventional EPS.

Insulated wall panels are interlocking, composite metal-faced sandwich panels or concrete panels with insulation between internal and external concrete elements. Steel-faced insulated panels are frequently used on single-story and low-rise industrial buildings.

Wooden panels are more and more represented on the facades. Flat surfaces, quick installation, and environmental application make them very interesting materials for facade coating.

Stone facades are one of the most expensive finishing methods, due to the high quality of the stone itself, the specific weight of the material, the cost of operation, exploitation, processing, installation, and transport, especially when it comes to importing materials.

Vertical Greening Systems, also known as green-wall technologies, are innovative natural approaches. They consist of vertical structures that spread vegetation that may or may not be attached to a building structure.

The use of glass as a component of the building envelope has been increasing since its early introduction as a building material, accelerating in the twentieth century due to the development of high-rise steel framing systems and curtain wall cladding techniques [1]. Structural and Semi-Structural glass facades integrate structure and cladding and are used in long-span applications where heightened transparency and dematerialization of the structure are often predominant design objectives. Curtain wall systems are cladding systems intended for multi-story buildings. The systems typically span between floor slabs. The vertical and horizontal mullions provide full perimeter support to the glass. Vertical mullions of extruded aluminum are most commonly used as the spanning members. Structural glass facades span longer distances, with an upper range defined only by the limits of the structural design. Curtain wall-type systems can and have been used on structural glass facades, but their integration with a supporting structural system tends to differentiate them from the conventional curtain wall.

3. VENTILATED FACADES – CONCEPT AND CHARACTERISTICS

Ventilated facades got their name after the ventilated layer i.e. the air cavity between the insulation material (wall) and the external cladding. In the European academic community, it is considered the most efficient system for resolving the building's insulation, eliminating the unwanted thermal bridges as well as the condensation problems, achieving excellent hydrothermal control. There is a wide range of opaque, translucent, and transparent ventilated facades with natural, mechanical, or hybrid ventilation.

3.1. Hinged ventilated facade (HVF)

The hinged ventilated facade is constructed from fully finished components and assemblies. The facade cladding material protects the building's external surface from the environment and keeps its integrity. A cladding is joined to the building using an anchored structure, and by the type of material used for the cladding we can classify the types of HVF as:

- Ceramic facades of various types, e.g. terracotta and porcelain tiling.
- Stone facade e.g., marble, slate, granite.
- Metallic facades e.g., polished aluminum, zinc.
- Composite material facades e.g., polymers, plastics.
- Glass facades.
- Wooden facades.

The recommended width of the air cavity, necessary for the natural convection, is between 40 and 80mm. The air cavity protects the building from overheating during the summer and cooling down during the winter, also eliminating the condensation inside the building.

The research investigated the thermal behavior of an opaque naturally ventilated façade through Computation Fluid Dynamics (CFD) simulations during summer days was performed [2] to analyze the behavior of HVF under different wind conditions in the summer period, utilizing the weather data of the City of Catania. For different investigated scenarios, the authors calculated the temperature and air velocity profiles inside the air cavity of the facade, highlighting the different effects of buoyancy and wind forces. The reduction of the heat flux during the summer period was evaluated by comparing the thermodynamic performance of a naturally ventilated and an unventilated facade with the same geometry and thermophysical characteristics. By allowing the peak load to be shifted, the behavior of the naturally ventilated facade showed improvement in terms of passive cooling of the building compared to the unventilated facade, offering energy savings in the range of 47% to 51% depending on the climate.

The optimum thickness of the insulation material in HVF systems is offered in [3] as a result of thermomechanical and economic calculations. Insulation thickness equal to 160mm was an optimum insulation thickness of the considered system. Heat transmission resistance of walls with such thickness of thermal insulation conforms to requirements of normative documents. If thermal insulation thickness increases, heat transmission resistance would increase, costs of heating would reduce but the cost of substructure and insulation would increase. It could lead to spending for a substructure and thermal insulation more than saving on the electric power in 10 years.

3.2. Thermal storage wall

The Trombe wall (Fig. 1) is comprised of exterior glazing and thermal storage wall combined functions of solar collector and storage into a single unit. Heat is transferred from the wall to the room air and the air between the glazing and wall, by radiation and natural convection. Reducing indoor air temperature oscillations is one of its primary functions.

Considering the need for indoor and outdoor comfort concerning the daily variations of temperature, a graphical tool that indicates the daily swings of temperature was presented in [4]. On a typical sunny winter's day when the outdoor air temperature varies between 5 and 12ºC, the external conditions were well outside the comfort zone. But at the outer dark surface of the Trombe wall, behind the glass, the average temperature and the temperature range would increase significantly on sunny days, reaching 25ºC and 40ºC, respectively. By day, the surface temperature would reach 45ºC, but by night would drop close to 5ºC. However, on the inside of the thermal storage wall, the high thermal inertia would dampen down the temperature swing, to an average temperature of 25ºC and a range of 4ºC. Since the internal design temperature was 21ºC, the surface temperature of this wall would provide a useful source of heat to the interior never dropping below this level.

Paper [5] investigated energy conservation, mitigation of CO_2 emissions, and economics of retrofitting for a honey storage building with a Trombe wall for winter heating application. The passive heating potential of the Trombe wall was estimated using TRNSYS building simulation software. The location of the honey storage building was at Gwalior in India. The conclusion was the potential of energy conservation up to 3312 kWh/year and the associated reduction in CO_2 emissions (approximately 33 tons/year) using a Trombe wall.

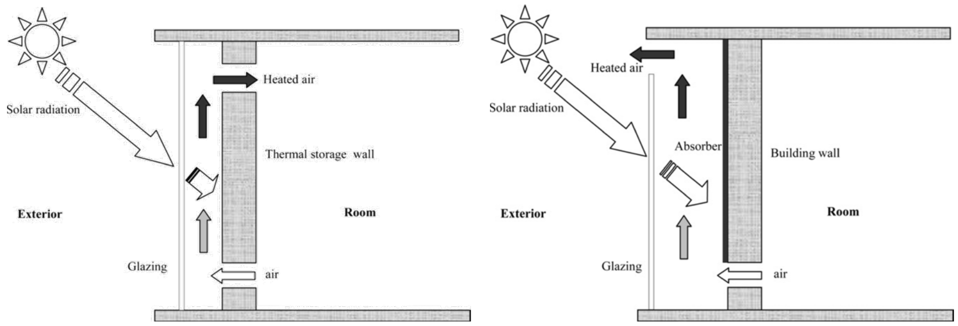

Fig. 1 Schematic diagram of thermal storage wall (left), schematic diagram of the solar chimney (right) [6]

3.3. Solar chimney

A structure that consists mainly of one heat absorbing glazed surface constructed on the wall facing the direction of the sun is a solar chimney (Fig. 1). When solar energy heats the chimney and the air within it, it produces an updraft of air in the chimney. The natural aspiration created at the chimney's base can be used to ventilate the building.

The feasibility study of a solar chimney reduction of the heat gain in a house by natural ventilation and the effect of openings on the ventilation rate was conducted [7] using a single-room test house of approximately 25m^3 in volume. The southern wall was composed of three different solar chimney configurations of 2m^2 each. Experimental observations indicated that when the solar chimney ventilation system was in use, the room temperature was near that of the ambient air, indicating a good ability of the solar chimney to remove the heat gain in the house and ensure thermal comfort.

A new module in the EnergyPlus program for the simulation and determination of the energy impact of thermal chimneys was developed [8]. Using the new module, the effects of the chimney height, solar absorptance of the absorber wall, solar transmittance of the glass cover and the air gap width were investigated under three different climate conditions. The research showed that chimney height, solar absorbance, and solar transmittance had more influence on the ventilation enhancement than the air gap width and that performance of a thermal chimney was dependent on the climate of the location.

3.4. Building-integrated solar thermal system (BIST)

A building-integrated solar thermal (BIST) system for facades (Fig. 2) can be interpreted as a building envelope constructed of solar collection equipment that simultaneously collects solar energy for heating purposes while performing the function of the facade.

The design, modeling, and computational simulation of solar air heaters installed at the first bioclimatic hospital of Argentina were presented in [9]. The solar air heaters were made of V-corrugated black metal plates. A specific simulation program for modeling of these solar air heaters was developed. The air outlet temperatures and the useful energy generated was determined and daily efficiencies of 67% were obtained.

The research and development concerning a solar air collector suited for winter heating and summer ventilation installed on the scientific high school in Umbertide were described in [10]. The collector physical and numerical modeling of heat transfer and fluid flow in winter operation was presented in the paper. The system performance was estimated as a function of different parameters to provide a tool for the design process. The solar air collector studied showed good performance as an auxiliary heating system and predicted exit air temperatures during most of the winter exceeded 20ºC.

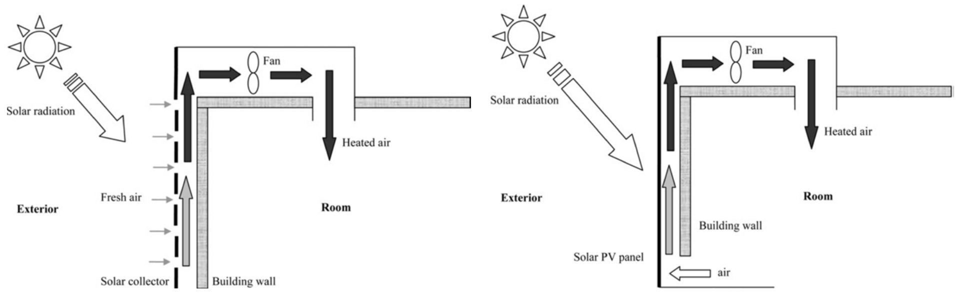

Fig. 2 Schematic diagram of BIST system (left), Schematic diagram of BIPV/T system (right) [6]

3.5. Building-integrated photovoltaic thermal (BIPV/T) system

A building integrated photovoltaic thermal (BIPV/T) system (Fig. 2) combines the functions of a building integrated photovoltaic system with those of a building-integrated solar thermal system. This combination could achieve the most efficient use of a solar energy-collecting surface in terms of both an optimal electrical conversion and air/water heating.

A computational thermal model used for analyzing the annual performance of facade integrated hybrid photovoltaic/thermal collector system for use in residential buildings of Hong Kong was presented in study [11]. The application of EPV (film cell) and BPV (monocrystal cell) panels in this hybrid photovoltaic/hot-water system was investigated. Simulation results based on the reference annual data showed that the annual average electrical efficiencies of the hybrid EPV and BPV modules were 4.3% and 10.3%, respectively, the corresponding annual average thermal efficiencies to hot water were 47.6% and 43.2%, and, compared with a normal concrete wall, the reductions of space heat gain in summer season through the collector wall with the hybrid EPV and BPV were 52.9% and 59.1%, respectively. The annual overall energy efficiencies were 58.9% and 70.3% respectively, which is much better than the conventional solar collector performance.

3.6. Double Skin Facade System (DSF)

There are various definitions of the DSF System. A double facade or double-skin facade is a facade system that consists of two skins placed in such a way that air flows in the intermediate cavity. Typically, insulated glass units form the inner skin and the outer skin is made of a single glass layer, but other combinations are possible. The Belgian Building Research Institute, in their Ventilated Double Facades report [12], set three main criteria for distinguishing between types of DSF systems. The first distinction is between the types of ventilation:

- Natural ventilation relies primarily on the stack effect for air movement, but also pressure differences created by the wind. The level of ventilation is dependent on the exterior climate and the air temperature in the cavity.
- Mechanical ventilation requires that the building envelope is carefully sealed and monitored.
- Hybrid ventilation is a mixed mode system. It requires a complex, centralized environmental management system that can switch the DSF from the natural mode to the mechanical mode depending on the climate and users need.

The next criterion is the partitioning of the facade, according to the geometry of the air cavity [13] (Fig. 3):

- Multistory double facade (a). In this case, neither vertical nor horizontal barriers exist. Ventilation is provided through large openings at the beginning of the building and near the roof. They are suitable for use at locations with high noise and higher temperatures. The structure does not require openings along the entire height of the building.
- Box window (b). Horizontal and vertical bulkheads share the facade into less independent parts. These barriers prevent the room to room transfer of sound and odor. In each part of the facade, the air inlet and outlet holes are required. Through the lower inlet and upper outlet opening, the airflow is permitted and thus the intermediate space is ventilated, but also the interior ear travels through the window from inside. It is commonly applied to buildings subjected to heavy noise.
- Corridor facade (c). Horizontal bulkheads are installed for fire protection, sound insulation, and ventilation.
- Shaft box type (d). Box window elements are connected via vertical shafts situated in the facade ensuring an increased stack effect. The air flows from the window through the shaft to the top where it is ejected. In the shafts, the air thermal movement is achieved. On the inside, some windows serve for natural ventilation. Air can be ejected through the duct using mechanical ventilation.

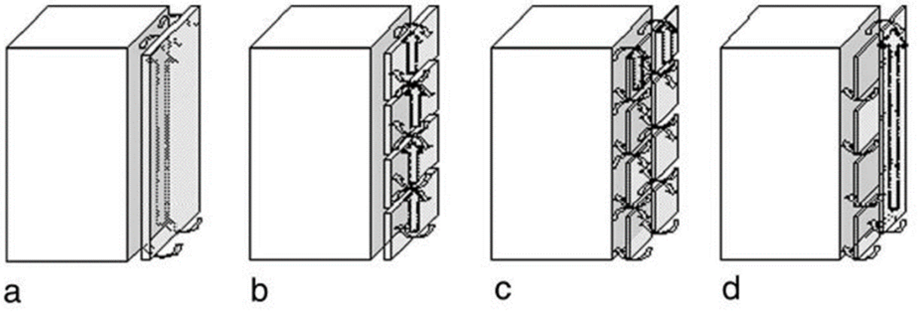

Fig. 3 DSF classification according to the geometry of the cavity [13]

The third classificatory criterion is the ventilation mode (Fig. 4). It refers to the origin and the destination of the air circulating in the ventilated cavity. The ventilation mode is independent of the type of ventilation applied.

- An outdoor air curtain (1). In this ventilation mode, the air introduced into the cavity comes from the outside and is immediately rejected towards the outside. The ventilation of the cavity, therefore, forms an air curtain enveloping the outside facade.
- An indoor air curtain (2). The air comes from the inside of the room and is returned to the inside of the room or via the ventilation system. The ventilation of the cavity, therefore, forms an air curtain enveloping the indoor facade.
- An air supply (3). The ventilation of the facade is created with outdoor air. This air is then brought to the inside of the room or into the ventilation system. The ventilation of the facade thus makes it possible to supply the building with air.
- Air exhaust (4). The air comes from the inside of the room and is evacuated towards the outside. The ventilation of the facade thus makes it possible to evacuate the air from the building.
- Buffer zone (5). This ventilation mode is distinctive since each of the skins of the double facade is made airtight. The cavity thus forms a buffer zone between the inside and the outside, with no ventilation of the cavity being possible.
- Special ventilation mode (6). Only applicable to facade concepts integrating openings at the level of the indoor and outdoor skins at both the top and the base of the component.

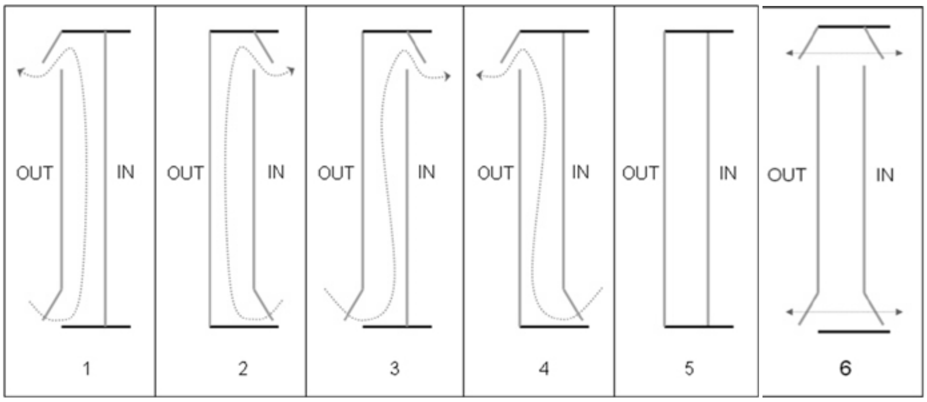

Fig. 4 The DSF ventilation modes [14]

The research [15] showed that DSF can control the solar gain. In warmer climates, the cooling demand can be very high due to the solar gain through the facade. DSF can reduce the solar gain impact by allowing shading devices to be installed in the cavity between the two skins, preventing sunlight from reaching the inner skin. The shading devices were normally adjustable to ensure that views through the highly glazed facade were retained as much as possible. Warm air trapped within the cavity could be evacuated by natural and/or mechanical ventilation to prevent it from heating the interior skin of the building. The air cavity provided access for maintenance and protection of the shading devices from weather conditions, especially on tall buildings.

Heat fluxes through the DSF were evaluated [16] for a DSF with/without Venetian blinds in natural and forced ventilation operating conditions to assess the influence of Venetian blinds on DSF thermal performance. Results obtained show that VB could reduce solar heat gains up to 35%. These reductions were not only due to the reflected radiation but also to the heat absorbed by the VB solid surfaces that are dissipated to the ventilation air, which may help explain the larger reductions obtained when forced ventilation is used instead of natural ventilation.

The partly or fully naturally ventilated DSFs were predicted to perform well in Hungary. The study was conducted to examine the performance of room-wide, single and multistory facade modules. Chosen facade types were evaluated through computer simulation programs to serve as a guideline for the design in similar climates [17]. The computer simulations showed that when examining heat gains from ventilated DSFs the effect of the shading was the most important, the unnecessary overheating could be prevented by giving attention to sizing the facade openings in connection with the selected shading concept. The rising cavity temperatures only had a secondary effect.

3.7. Green living walls (GLW)

When it comes to vertical greenery systems many different classifications and definitions can be found in the literature. Different terms were used to define these systems such as: vertical garden, bio shedder, vertical landscaping and green vertical system, but vertical greenery system is the most commonly used term. Based on the type of vegetation and support structures used, these systems can be divided into two major categories: green facades and living walls (Fig. 5).

3.7.1. Green facades

Green facades are type of a green wall system in which climbing plants or cascading groundcovers are trained to cover specially designed supporting structures, rooted at the base of these structures in the ground or intermediate planters. Specially designed structures such as trellises, rigid panels, and cable systems are developed to support vines and aggressive plants that can damage unsuitable walls while keeping them away from walls and other building surfaces. The plants typically take 3-5 years to achieve full coverage.

3.7.2. Living walls

Living wall systems are mostly composed of pre-vegetated panels, vertical modules or planted blankets that are fixed vertically to a structural wall or frame. Felt and panels, or boxes, are the most commonly used vegetation attachment methods to the supporting structure. These panels can be made of plastic, expanded polystyrene, synthetic fabric, clay, metal, and concrete, while supporting a great diversity and density of plant species. The systems that use either organic or inorganic growing media along with mineral nutrients to grow plants outside the soil are also known as soilless or hydroponic systems. If plants are not rooted in the growing media, but directly attached to the cloth, this is the case of a singular hydroponic system that depends on the irrigation reliability [18].

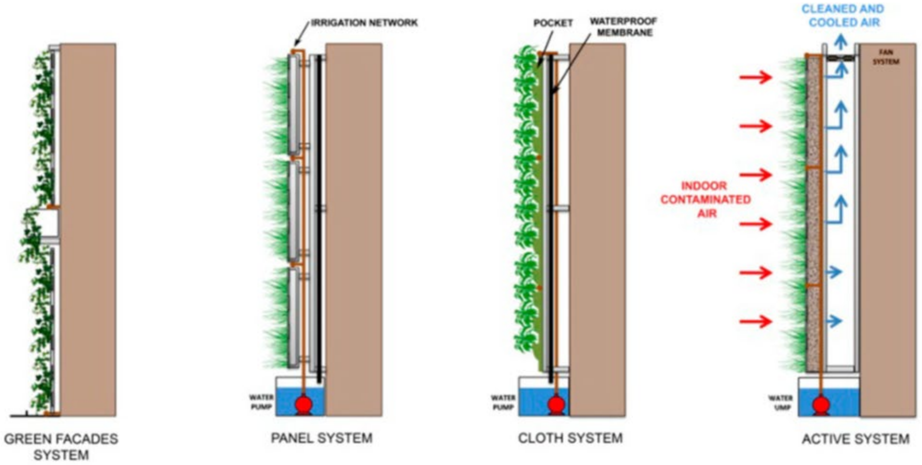

Fig. 5 The green facades and living walls [18]

Due to the plant life diversity and density, living walls typically require more intensive maintenance, due to fertilization and irrigation, than green facades.

All living walls act as a passive biofilter. Active living walls are the integration of living walls with the building's air conditioning and ventilation systems, going one step further, using new approaches and technologies for improving the air quality. In the active living wall, an air current is forced to pass through the green wall and collected afterward so that the recycled fresh air can be supplied to the building's interior as the air has been cooled, filtered, and humidified by the plants and growing media.

4. ADVANTAGES OF USE AND THE IMPACT OF VENTILATED GREEN FACADES ON THE ENERGY EFFICIENCY OF BUILDINGS

The energy efficiency of a building system can be evaluated from the aspect of energy savings and consumption for all phases in the construction and operation of the facility. Phases are the production of basic and auxiliary building materials, standardized characteristics of the built object, transport of materials to the construction site, position of the material installation, long-term energy costs for heating, air conditioning, ventilation, as well as energy consumption during the rehabilitation of the facility or the recycling of materials of the selected construction system, and in the end degradation of thermal-physical characteristics. All the features are shown in Table 2.

The specially designed ventilated facade system is the most reliable from the standpoint of construction physics. The inner layers provide the load-bearing capacity but also thermal and acoustic insulation. The outer layer effectively protects the inner layers from the atmosphere. Most of the precipitation flows through the facade lining while wind speed allows rapid and unimpeded moisture transfer from the structure to the atmosphere and prevents condensation in the interior. The negative features of this system are also shown in Table 2.

Table 2. Energy justification of ventilated facades

Characteristics	**Arguments**	
	For	Against
Heating energy	Saving energy by recovering heat	Not suitable for buildings with too much internal heat load
Cooling energy	The accumulated solar energy can be freed through the facade cavity	All conditions or benefits cannot be achieved without other systems
Sun protection	Curtains can be installed in the cavity of the DSF	The necessary protection can also be placed on an ordinary facade
Opening the windows	Allows opening of windows in high buildings	Fixing windows is often needed
Fire protection	Horizontal and vertical bulkheads can prevent the spread of fire in the cavity of the facade	External cladding prevents smoke extraction
Condensation	In the case of good ventilation, the cavity does not form condensation	On the inside of the external cladding, condensation could be generated
Noise	Provides good protection against external noise	Ventilated facade must be opened for ventilation, which reduces noise protection. Noise is transmitted through the air cavity of the facade
Costs	The operating costs are reduced	High investment and maintenance costs

Modern construction does not only mean the design and construction of facilities, but also the increasing environmental responsibility and energy efficiency. The facility must provide a sense of security, comfort, and energy efficiency. Each of these items is improved by direct application of ventilated facades.

Saelens et al. [19] found that both heating and cooling demands can be significantly lowered by controlling the air flow rate and recovery of air returning from multiple skin facades. They studied the performance of three different double-skin facades in Belgian climatic conditions. The energy effectiveness of such an approach is poor unless the facade is designed very carefully, as in the single and double skin glazed facades for office buildings in Scandinavian climatic conditions [20]. When it comes to green living walls, the installation of such systems has the most significant impact on thermal performance. The main advantage of green living walls lowering the building's solar gains during summer by blocking solar radiation can be singled out. As a secondary characteristic, living walls use vegetation cooling effects caused by plant perspiration and ventilation, which as a result lowers the temperature of the surrounding environment. These cooling features have a direct impact on energy efficiency in buildings in summer and their usage has direct economic benefits in savings. In Hong Kong, covering a concrete wall with modular vegetated panels reduced exterior wall temperatures up to 16ºC in summer [21]. In terms of internal wall temperatures, a difference of more than 2ºC was recorded, maintained even late at night, indicating that green walls have a significant ability to reduce energy consumption for building cooling. Differences in external wall temperatures up to 10ºC between vegetated and bare concrete walls were reported at Hort Park in Singapore, where various green wall systems were assessed for their thermal performance [22]. Research conducted in the Mediterranean considered the effect of different orientations of living walls on the thermal performance of a building. The results showed that its installation has an impact on any orientation but is biggest in the west and amounts to almost 20% reduction of the thermal load [23]. The field measurement results from study [24] showed a green facade's potential to optimize the thermal environment of transitional space in a hot-humid climate in the summer. Average PET at a shaded area by GF was reduced by 2.54ºC and 1.43ºC compared to the outdoor environment and an unshaded area. In addition to its effects on building temperature reduction during the summer, GLW can also be used as a wind barrier during cold seasons, which has an impact on thermal building performance during the winter.

These thermal performance features and energy efficiency of GLW can be further improved by the addition of ventilation ducts to the facade. Some studies consider the influence of ventilation and air velocity through and around GLW, but there is limited research on the combined impact of GLW and ventilation. The effects on airflow within the building and levels of thermal comfort were studied in [28] by changing the parameters of the cavity between the double skins, the area of the openings, the height of the buildings, the height of the transparent chimney added to the top of the south double facade, and the arrangements of open and closed openings. DSF will provide thermal comfort during the winter most of the time. In summer, the benefit of the system was limited because wind effects overcome the buoyancy effects on the south cavity except when the wind comes from the north.

The green living wall has always acted as a “passive” biofilter. New technologies are moving towards the integration of living walls within the building’s air conditioning and ventilation systems. These hybrid systems are called “active living walls,” in which an air current is forced to pass through the green wall and collected afterward so that the recycled fresh air can be supplied to the building’s interior as the air has been cooled, filtered, and humidified by the plants and growing media.

One of the secondary benefits of using GLW in urban areas is its impact on noise reduction. A study was conducted in Singapore to further confirm this hypothesis and the results showed that the use of these systems leads to significant reduction of noise in residential areas [25]. An acoustic measurement campaign around a site, near Paris, France, hosting a green wall was carried out to highlight its potential effectiveness in reducing noise pollution in its environment [26]. Measurements showed a decrease in overall sound pressure levels (dBA) generated by road traffic as a result of setting up the green wall on the site. In the middle frequencies, 400 - 2500 Hz, acoustic gains were moderate (between 0 and 6 dB depending on the configuration and the one-third octave band concerned) with maximum efficiency for configurations where the source was distant from the receiver. These can be attributed to acoustic absorption due to the planting substrate. At high frequencies, 3150 to 20000Hz, except for close source/receiver configurations, acoustic gains were substantial (between 0 and 10 dB depending on the configuration and the one-third octave band concerned), where a scattering phenomenon caused by the foliage also comes into play.

There are social benefits and aesthetic impacts linked with GLW usage. According to studies conducted in China, four social benefits of using GLW have been singled out:

aesthetic value in urban areas, improving human physical and mental health, upgrading public areas and influence recognition of buildings [27]. Furthermore, green living walls can be used to develop urban ecosystems and enable biodiversity in urban habitats, especially for insects and birds by careful selection of plants.

Despite the number of studies on ventilated green facades [29-36], there is still a knowledge gap concerning their application, and architects still lack a comprehensive design tool.

5. CONCLUSION

The energy efficiency of the construction system is reflected in the reduction of the consumption of energy resources for heating and ventilation. It is necessary to approach the thermal insulation and optimization of thermal losses in the right way. One must think of future generations and the increasing influence of global warming on energy consumption. One of the important factors that influence the consumption of cooling energy is the thermal capacity of walls and interconnected structures that accumulate heat over the day and give it out during the night, creating an unpleasant environment. A natural and economical solution that does not require or requires less energy consumption, is the application of a ventilated facade system. Facade systems with adequate insulation and ventilation enhance the energy and financial efficiency of the building. This system is in increasing development and is constantly improving. By using a ventilated green facade system, the durability of the facility is significant; the duration of the occupant's stay in that area is significantly prolonged but also affects the reduction in emissions of harmful gases. Encasing the facade of a building with a ventilated wall system is the most effective outdoor covering technology that solves the problem of providing protection against humidity and weather conditions, insulating it and improving noise levels inside. At a time when the focus on using energy as efficiently and responsibly as possible is a universal tendency, the reasons for the increase in their popularity also include the extra energy savings they offer combined with the improved interior climate they provide. A continuous layer of external insulation protects it more uniformly, thus eliminating heat bridging and improving the building's energy performance.

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