High performance building façades for Zero Energy Buildings in Greece: State of the art and perspectives

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Abstract. Pursuing high energy performance with the least environmental impact of a building, along with ensuring the well-being of the occupants, is the ultimate goal of an institutional framework that addresses energy efficiency and environmental sustainability. The building sector is responsible for 38% of the total final energy consumption in Europe and is therefore in the epicentre of the effort to achieve improvements. This is being expressed by the targets of EU policies for 2030 and 2050, which set truly ambitious goals.

Part of this effort is the improvement of the building’s envelope thermal performance, along with the respective one of the HVAC systems, but also integrating those two in the best possible way. The façade is the crucial factor, as it is the interface between the building and its environment, but also between the environment and the HVAC system; it is truly the building’s skin, which is therefore much more than a simple state boundary, if we want to have truly advanced buildings.

Main scope of the paper is to present the results of an in depth investigation regarding the best available technologies and the upcoming trends of intelligent building façades, to be used in Zero and Positive Energy Buildings. This cannot be done without discussing the legislative and regulatory framework that applies for the building envelope, as solutions have to comply with regulations and standards, both national and international. In this line of approach an investigation of the practices and technical approaches best suited for Greece is being made, specifying their performance, possible drawbacks and approaches that are to be applied and the implementation of which is expected to contribute to the improvement of the buildings’ performance.

Furthermore, the constructional approaches and the effectiveness of both naturally and mechanically ventilated façades are discussed, along with their adaptation to the Greek building practices. The integration of ventilated façades with the building’s HVAC systems may offer advantages, especially in spring and fall when preheating the air may lead to reduced energy requirements. In the opposite direction, heat rejection may be a problem in summer, where alternative cooling techniques can provide a solution. Finally, integration of innovative design elements such as the use of different final coating materials on the façades, the use of phase-changing materials (PCMs) and the integration of photovoltaic systems are evaluated.

Keywords. Smart facades; ventilated facades; non-residential buildings; Mediterranean region; nZEB
1. Introduction
Climate change affected the policy makers’ and stakeholders’ attitude towards development. In this line of approach, the term of sustainability was initially presented in 1948, but it was not until 1987 and the Brundtland report that a definition was established [1]. According to this, sustainability is the growth that meets today’s human needs without undermine the ability of future generations to catch up theirs [2]. Therefore, and in order to achieve this goal, a variety of measures reducing the energy consumption need to be adopted.

Based on Eurostat data for 2016, the transportation sector is the major consumer of final energy (33%), followed by the building and industrial sector with 26% and 25% respectively [3]. However, considering services, which grows steadily (Figure 1) and accounts for some 15%, and which as a rule are provided in buildings, it becomes evident that the building sector has to be in the centre of our efforts.

![Figure 1](https://example.com/f1.png)

**Figure 1.** Final energy consumption in EU28 by sector [3], [4].

Considering this tendency, a gradual tightening of the legislation framework regarding the building sector has been noted within the last 20 years. The first integrated effort to reduce the energy loads and consumption requirements, was denoted in the European Directive 91/2002, the so-called Energy Performance of Buildings Directive (EPBD) which foresaw a reduction on energy requirements, the use of cleaner energy sources and the introduction of mandatory energy studies and audits [5]. The recast of the EPBD, in form of European Directive 30/2010, introduced the goal of the nearly Zero Energy Building (nZEB), promoted smart metering as well as the provision for economics and support measures [6]. Whilst this Directive stated the need of every country to determine the characteristics of her nZEBs, the latest EPBD recast, Directive 844/2018, emphasizes on the need of turning the existing building stock into nearly zero energy by 2050, utilizing advances in ICT and supporting electric vehicles [7].

In order to achieve these goals a variety of measures and strategies have been applied over the last decade aiming to the reduction of energy consumption in the building sector. When examining the development of publications regarding the reduction of final energy in the building sector (Figure 2), a rapidly increasing interest since the introduction of the first EPBD. Also, the development of the publication regarding the nZEBs as well as the measures leading towards this direction is analyzed and the results are shown in Figure 3 (a-b). The analysis noted that in both cases the scientific interest started, as expected, in 2010 when the term was initially established in the institutional framework and until today an intense increase over these areas has been noted. It therefore seems suitable to carry a more detailed analysis of the recent literature focusing on the measures of upgrading the building envelope towards nZEB.

![Figure 2](https://example.com/f2.png)

**Figure 2.** Number of papers published concerning reduction of final energy consumption in case of nZEB based on Scopus Database from 1979 to 2020 [in accordance to [8]].
Based on the preliminary collected data, an in depth analysis on the strategies and measures applied for the upgrade of the building’s envelope is essential. In this respect, the determination of the existing applications and practices are to be presented within the scope of this paper and the need of further analysis in certain aspects are to be highlighted.

2. Conventional building façades

In national level, every country based on its geographical position and climate characteristics determines its construction approaches regarding the building envelope. The climate in Greece is Mediterranean with hot/warm summers and mild winters, Csa and Csb based on the Köppen climate classification system. This type of climate applies practically to the whole European Mediterranean coastal area and also in the coastline of Morocco, Algeria and to part of Tunisia, leading therefore to similar building envelope structures [9].

Contemporary design approaches apply to both the vertical and horizontal surfaces of the envelope, with the insulating material being the main tool to improve the buildings’ envelope efficiency, whilst thermal storage properties were traditionally utilized to establish thermal comfort in summer. Regarding the construction details a variety of approaches are followed based on the type of the surfaces, reaching around 8 different construction element types (Figure 4).

The double brick wall structures was for decades the dominant typology in Greece and the Mediterranean region, due to their advantages, however, they are reaching their limits on energy performance, unless super insulating materials are used. In conventional construction elements, the main differentiation refers to the placement of the insulation material, either externally or internally. External thermal insulation composite systems have been applied in northern Europe since the 1960s, while in Greece they have been applied sporadically since the 1980s and on a large scale since 2000. The state of the art on external thermal insulation composite systems achieve a higher energy performance, but there are issues that need to be considered, especially considering their seismic behavior and the their performance under hot summer conditions.

The advantages met in external thermal insulation composite systems (Figure 4a) are the protection of the building envelope from the temperature variations, the utilization of the building elements’ thermal storage and the reduction of appearance of humidity condensation in the interior. The second option (Figure 4b), offers both advantages and disadvantages: it enables the fast heating or cooling of the indoor area and provides more degrees of architectural freedom in the design. On the other hand, this approach is the least favorable for residential buildings, as there reduced thermal inertia and one cannot avoid the presence of thermal bridges. Also, in cases that the construction element are in touch with the ground (Figure 4c) additional attention should be given to the insulation material regarding its protection against moisture and probable destruction due to wear and tear effects [10], [11]. In both cases, the existence of insulation leads to a reduction of the heat transfer coefficient around 50% to 70% [10], [11]. Another strategy is the placement of the insulation material in the core of the building element, usually as a double brick wall with cavity. This solution (Figure 4d) combines to some extent the advantages of the two previous approaches, but is has some structural weaknesses, especially with respect to its seismic durability. A typical double brick wall with insulation and an air gap in its core is depicted in Figure 4e. In this case, the indoor building element is protected from the outdoor climate conditions and therefore has a longer life cycle period. Moreover, through this construction approach

Figure 3. Number of papers published concerning (a) nZEB and (b) measures leading towards nZEB, based on Scopus Database [in accordance to [8]].
the phenomena and the impact of humidity and condensation are magnified and a reasonable energy efficiency is achieved.  

There are also other construction details that constitute typical traditional building elements (Figures 4f-g). In Figure 4f a façade with external plants is presented, with two final coatings, either climbing plants or vertical gardens, when referring to vertical surfaces, and green roofs when referring to horizontal ones [12]. In those cases the same layering of the façade is followed, except for the final coating, where the supporting system differs [13], [14]. This construction approach offers a series of advantages, such as the improvement of both indoor and outdoor environment conditions and the evapotranspirative cooling effect of the building [12], [15]. There are also the well-known passive solar elements, like the Trombe and thermal mass walls that constitute good examples of indirect solar gain elements, giving emphasis on the energy savings, the delayed heat transfer and the improved thermal comfort. The most common materials used in these construction approaches present high heat capacity like stone, concrete or even water in tanks. Main goal is the best possible utilization of incident solar radiation, so that the highest gain for the adjacent room can be achieved on a daily basis [16], [17]. The main difference between a thermal mass and a Trombe wall is the existence of vents on the upper and lower positions of the wall, that allow air flow and hence quicker heat transfer in the room [18], [19].

Another conventional construction system are the dry construction systems (Figure 4h). Dry building systems are particularly popular in Europe and the USA, but only slowly are finding their way in the Greek market, as the traditional construction solutions are dominant. However, during the last decade, new technological approaches giving emphasis on dry construction systems are becoming popular, especially in refurbishment of buildings and also in cases where is required by the architectural design [20].

3. Ventilated and double skin façades

3.1. Design and construction

The envelope plays a crucial role in the building’s efficiency, as an outcome, many studies concentrate on the characteristics that could be improved, so for the total building efficiency to be further increased. Passive systems applied in the building field, are the ones that may be improved scoping in increasing the total efficiency of the system. Ventilated façades and especially double skin façades are one of the most intriguing fields of investigation ever since they were introduced in the 1900s. The combination between the internal demands of the building and the need of exterior design and improvement lead to the development of ventilated façades. Ventilated façades have been traditionally applied in cold
climates, but they have become popular also in warmer climates [21]. Therefore, many studies have already been conducted regarding the design and construction application of ventilated façades in hotter climates, many more factors should be investigated so for their efficient application to be achieved [22]. Ventilated façades have started being investigated in the early 1900 in Germany [23], however, it took quite some time before improvement with respect to their building physics’ could be reported [24]. Additionally, apart from the specific design and façade parts that should be further investigated, the specific thermodynamic effects occurring in ventilated façades have also to be studied in depth [25].

The double skin façades consists of the external surface (skin), internal surface (skin) and the space in between. External surface is usually constructed with glass elements, due this material’s mechanical characteristics, its transparency and the maximization of daylighting and its contribution to natural heating resulting in energy cost reductions [26]. Heat transfer from the exterior to interior environment through the ventilated façade is one of the most important factors that should be taken into account, in order to select the appropriate type of surfaces with the suitable specific characteristics considering radiative behavior, thermal gains and transparency [27], [28]. The glass type selected for the exterior surface is mostly hard and durable type, of increased mechanical qualities, to reduce wear and to avoid damages [29]. Flat glass panels are the ones that offer durability and increased resistance to the wind effects [30]. Apart from glass, other materials used for the exterior surface of a ventilated façade are the metal panels and aluminum panel [31].

Stone and wood are two other options that can replace glass mainly due to design preferences [30]. The distinguished difference between ventilated and conventional façades is the air space within the exterior and interior surface leading to energy and building efficiency improvement. Air space may result in negative outcomes of energy consumption increase, if its design is not the proper one [32]. In this line of approach, the air gap size can vary from 10 cm to 2 meters [27]. That limit is mostly based on enough space for maintenance and sun protection systems’ installation, the proper air ventilation and avoidance of tensile effect, which is also affected by the building’s height. Additionally, any shadowing device may be set in the air gap so for the excess solar radiation and heat gains to be managed. Color, positioning, angle and distance between the shadowing device, external and internal surface are some of the factors that affect the device’s efficiency [33]. Regarding the interior surface, two of the materials mainly be used are glass or concrete. For the best air fluxion and air gap ventilation but also for the management of façade temperature, the most common approach is using single glass panel for the exterior and double glass panel for the interior surface of the façade [34]. State of the art composite materials like sandwich-type aluminium – polyethylene composite panels (the –bonds) and Glass Fibre Reinforce Concrete (GFRC) provide options which ‘traditional’ materials cannot easily achieved. The interior glass type selection but also the analogy between interior surface and panel size may differ based on the climate and country that are applied [35], [36].

3.2. Efficiency of ventilated and double skin façades
Ventilated and double skin façades may lead to various positive outcomes, some of which are analyzed as follows. Reduction in energy consumption is one of the main positive outcomes that ventilated double skin façades may result in. Overall energy requirements are reduced due to the heat gains achieved and the reduction in heating loads. Respectively, during the cooling seasons, a temperature decrease in the buildings can be achieved due to the ventilation of the air gap within the double skin façade and the extraction of the warm air. As it was deduced by [37] ventilated façades may lead up to 26% reduction in energy consumption during air-conditioning season by achieving the reservation of desired temperature. Additionally, user comfort within the building is achieved by the exploitation of ventilated façade by improving optical comfort due to glass transparency and natural lighting and thermal comfort by controlling the inside temperature by the proper air gap ventilation [38]. Moreover, the air gap’s ventilation results in user’s comfort and reduction of humidity especially during rainy days [39]. Noise isolation may also be achieved by using the ventilated double skin façade as the extra air gap acts as a protection system from the cities’ and crowded areas’ noise. Within the advantages of double skin façades, building aesthetics plays an important role as modern design and architectural combination can
be applied based on the design preferences. Building protection and life cycle of it are of favorable when using double skin façades. However, fire safety decreases as the air gap results in faster air flame distribution across the façade [26], thus excess ventilation is needed so as to avoid flame phenomena [25]. Internal façade protection from weather conditions and raining increases the life cycle of the building to almost 30 years as it has been calculated through numerous studies [25]. Contrary to the benefits of ventilated and double skin façades, there are some challenges that should be taken into account, mainly for the economic evaluation of them. Due to the second skin needed, the initial cost is increased compared to conventional options. Hence, maintenance cost and economic evaluation should be further investigated before choosing this option [40]. Finally, external building parameters that influence its efficiency are referred to be the orientation and proper placement of them so for the solar radiation to be efficiently used [27]. For that reason, south based orientations are concluded to be the most appropriate for ventilated double skin façades [36]. Wind speed may influence to a greater extent the efficiency of a façade as even wind speed of 4 m/s may decrease the exterior and interior temperature difference by up to 70%, compared to calm conditions. Thus, investigating the area and the weather conditions, is also a field of studying so for the proper façade placement to be achieved [41].

4. Alternative surfaces used for the ventilated façades

4.1. Photovoltaic Panels

Using photovoltaic panels at the exterior surface of the ventilated double skin façade is getting popular nowadays. The consumption of the HVAC system decreases, as the PVs act as insulation and thermal losses are minimized and the electricity produced by the PVs can be used for the HVAC systems, given its temporal coincidence [30]. Regarding the Building Integrated Photovoltaics (BIPV), monocrystalline or polycrystalline panels may be used mainly placed to the south side of the building so as to benefit from the solar radiation [42]. Additionally, the vertical placement of them on the façade may increase the heat gains for winter but also reduce the excess heat production during summer season due to their vertical positioning, thus avoiding excess heat production. Transparent or semi-transparent panels and even square or cylindrical panels are used based on the preferences of the user. The design parameters regarding panel’s dimensions, should also be examined so for their efficiency when integrated to façades to be achieved. For cylindrical panels, it has been studied that the best design approach is for the ratio between the length and the diameter of the panel to be around 20, leading to minimization of losses and sufficient ventilation of the air gap [43]. For that kind of ventilated double skin façades, the façade gap at the top or at the bottom of the façade may not be enough for its ventilation, thus more air gaps within the façade should be used across the façade and within photovoltaic panels so for their sufficient ventilation to be achieved. However, that referred approach of façade ventilation is not that proper for Mediterranean climate as the cooling loads will get increased if excess gaps are applied to the façade. In this line of approach, mechanical or natural ventilation can be applied for the air gap temperature control based on the needs and climate condition. As it is deducted, proper air gap dimensioning is crucial for façade’s efficiency thus based on studies for the fraction between width and length of the air gap it should be around 0.11 for the maximization of building’s efficiency [30]. Approaching the Mediterranean climate, the best distance between the photovoltaic panel and the inlet surface, so for the efficiency optimization and the overcoming of overheated phenomena may achieved for 0.15-0.20 m [43]. Apart from photovoltaic use at the external surface of the façade, they can also be used at the air gap as shading devices for the solar radiation control and simultaneously the electricity production. Additionally, hybrid photovoltaic-water heating system may also be integrated in buildings for increasing the power output per unit area [44]. The heat absorbed by the system is used to preheat the domestic water. Thermal efficiency of such a system was measured to be around 38.9% and electricity conversion efficiency about 8.56% [44].

4.2. Phase Change Materials (PCMs)
Phase change materials can be applied both to photovoltaic panels and shading devices. The heat capacity of them is the characteristic based on which latent heat is efficiently used for the control of temperature. Latent heat is used for receiving or giving heat by changing the phase of the material from solid to liquid or from liquid to gas. Within the thermal comfort temperature range (20°C-30°C) there can be met many materials able to receive and offer latent heat 5 to 14 times greater than the conventional materials [45]. The application of phase changed materials to building envelope can be applied to building’s stone or concrete wall with the form of small capsules. Another type of material used as a final coating of the building envelop is the cool materials. Researchers have worked on this type of materials aiming to decrease the surface temperature especially of roofs, where during summer with the use of conventional materials the surface temperature can reach up to 56°C, whilst the use of cool materials can lead to a reduction of up to 12°C [46], [47].

The use of PCMs, takes place when the indoor building temperature is above the comfortable one and the material absorbs heat by capitalizing on its melting enthalpy. Material’s temperature may not increase, however the rise of the air temperature is avoided. Contrary to the previous approach, when indoor temperature is lower than the comfortable one, excess heat stored at the material is released to the indoor environment air. Additionally, phase changed materials can effectively be used at shading devices and control the receiving heat for avoidance of excess heat released to the indoor environment. Paraffin and graphite are two of the most common bases for PCMs used for the shading devices [48]. Compared to conventional materials, less amount of phase changed materials is needed so as to achieve the needed conditions. As an example it can be referred the need of 30% phase changed material to a plasterboard of 3 cm width so as to achieve the same results with a conventional wall of 18 cm width reinforce concrete wall or 23 cm of brick wall. Finally, and as PCMs is an increasing research field over the past 50 years more analysis should be done taking into consideration the environmental impact and the cost effectiveness [49].

4.3. Combination of Photovoltaic Panels and Phase Change Materials
What is of great importance and lies in the focus of research effort is the combination of PCMs and PVs used in double skin façade. For the desired ventilation of PVs to avoid their overheating, PCMs may play an important role to ensure the PVs’ efficiency. Regarding the construction specifications, it has been concluded that almost 2.6 kg of PCMs are needed for every square meter of PVs [50], [51]. PCMs are commonly be used at the external aluminum surface of the photovoltaic panel so for the heat gains to be sufficiently controlled. The described technological approach is efficient when used in warm climates, with increased solar radiation values. For Mediterranean climate the PCMs used should be one that offer a melting point of at least 35°C, such as paraffins, a mixture of paraffin and sodium, the calcium chloride or the composite metal wax [26]. Given that the needs for cooling the PV during the summer season may be reduced by up to 48% [50], as an outcome of the PCMs presence, the panel’s electrical efficiency may increase by to 3-5% under the most disadvantageous conditions.

5. Conclusions
Main scope of this paper was to present the state of the art of available technologies and the upcoming trends of building façades, which can contribute towards Zero and Positive Energy Buildings. The bibliographic review conducted, covered both conventional and upcoming design applications and procedures, and highlighted the research gaps and direction towards which further research needs to be directed. The review showed that four are the main construction solutions developed and implemented in buildings: double-brick wall masonry, external thermal insulation composite systems, drywall systems and double skin, or ventilated, façades.

Considering the double brick wall structures, which was for decades the dominant typology in Greece and the Mediterranean, it is a type that has certain advantages, but is reaching the limits of its energy performance, unless one would use super insulating materials. External thermal insulation composite systems have been applied in northern Europe since the 1960s, while in Greece they have been applied
sporadically since the 1980s and on a large scale since 2000. The state of the art external thermal insulation composite systems achieve a higher energy performance, but there are issues that need to be considered, especially considering their seismic behavior and the their performance under hot summer conditions. Dry building systems are particularly popular in Europe and the Americas, but have only lately emerged in the Greek market. Their combination with mechanically or natural ventilated façades presents an interesting option, but has to be further analyzed.

Particular attention is being paid to the constructional choices of ventilated façades either mechanical or natural, concerning their geometry, the ratio between the openings and surfaces, the size of the gap and the appropriate choice of materials; significant changes in the building's energy characteristics can be monitored depending on the combination of those features and they have to be studied both in vitro and in the field. Considering all these parameters, it is considered necessary to further investigate these constructive approaches.

Emphasis is placed on changing the final layer of cross sections, focusing mainly on the use of materials with innovative thermophysical properties and construction techniques. Particularly, in case of ventilated façades, cool and phase change materials can be used both as a final coating of the façade and as solutions in shading devices within the air gap. Furthermore, the combination of photovoltaics or even hybrid PV-Thermal systems can lead to an improvement of thermal comfort, maintaining the desired temperature, avoid overheating and providing a useful energy yield to the air-conditioning system.

It is clear, that are quite some issues considering the technical, economic and environmental features of the individual materials and of the system as a whole. The number of such applications is still limited, not only in Greece but also in other areas with warm summer and mild winter climate conditions; hence there are not many data available on their performance in practice and this is a gap that has to be bridged.

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