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DOUBLE-SKIN FAÇADES – THE SHAPING OF MODERN
ELEVATIONS – TECHNOLOGY AND MATERIALS

ELEWACJE PODWÓJNE – KSZTAŁTOWANIE
NOWOCZESNYCH ELEWACJI – DOBÓR TECHNOLOGII
I MATERIAŁÓW

Abstract

With the evolution of architectural form, the notion of the façade and its look undergoes changes as well. The paper discusses modern solutions applied in external curtain walls of buildings and presents new capabilities provided by new construction materials including double-skin façades. The paper presents buildings that achieved high energy efficiency due to, among other factors, adequate façade construction.

Keywords: curtain walls, double-skin façades, technology, architectural form, construction materials, scientific research

Streszczenie

Wraz z ewolucją formy architektonicznej i postępującym rozwojem architektury zmienia się zarówno pojęcie elewacji, jak i jej wygląd. W artykule omówiono nowoczesne rozwiązania zewnętrznych ścian osłonowych współczesnych obiektów architektonicznych, w tym elewacji podwójnych. Przedstawiono możliwości, jakie dają nowe technologie i materiały budowlane. Zaprezentowano obiekty, w których uzyskano wysoką efektywność energetyczną – m.in. dzięki odpowiedniej konstrukcji elewacji budynku.

Słowa kluczowe: ściany osłonowe, elewacje podwójne, technologia, forma architektoniczna, materiały budowlane, badania naukowe

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1. Introduction

the problems associated with energy efficiency of buildings, their resource needs, as well as attempts to reduce those needs stemming from the latest developments in the economy and the increasing role of alternative energy generation methods and renewable resources are becoming ever more important in the process of designing buildings and structures. These problems have a significant impact on the way an architect approaches his or her work and give rise to the ever wider adoption of the principles of sustainable architecture [1]. Designing modern structures, which must meet high quality standards in terms of energy efficiency, has become a challenge for architects and has forced them to seek the help of specialists in other fields of engineering and science. That which now shapes a buildings spatial form, its aesthetical character and architectural detail is more often tied to the way its ventilation works, how it provides optimal lighting conditions for its users, as well as the systems that allow it to achieve the highest possible energy efficiency. a good example of the rising importance of these fields of design is the awarding of LEED¹ certificates to currently designed and existing buildings. The role of a buildings exterior wall has undergone a certain degree of change. The definition of its purpose has evolved since the first half of the XIXth century, when it was thought of as a thick, solid barrier between the outside environment and a building's interior [12], changing in the direction proposed by Mies van der Rohe [2] at the onset of the XXth century through his "skin and bones" concept. The double-skin facade is a clear continuation of this idea, which postulates a supporting structure of steel and concrete clad in glass. Double-skin facades, often abbreviated as DSF, are currently becoming more widespread due to the high demands placed on the reduction of energy used by buildings.

2. History of double-skin facade use

The exploitation of natural physical phenomena in order to improve the interior environment of a building is by all means not a modern concept. The peoples of the Middle East have used windcatchers (badgir in Persian or maqlaf in Arabic) [3]. The Villa Almerica Capra designed by Andrea Palladio has a natural ventilation system which cools its rooms. The first mentions of using design solutions typical of double-skin facades are dated to the XIXth century. In 1849 [4], Jean-Baptiste Jobard, the head of the Industrial Museum of Brussels, described a prototype of a mechanically ventilated multi-layered facade, which uses the space between two glass walls to provide warm air in the winter and cools the building in the summer. In 1903, the first true double-skin facade is built as a part of the Steiff toy factory in Giengen, Germany [5]. The innovative design solutions used in the construction of this building including twin layers of glass, were so effective that they were copied in 1904 and 1908. The exterior curtain wall constructed by Richard Steiff in Giengen is fully compatible with the modern definition that was formulated in 1961 by Rolf Schaal [6]. Fifteen years later Willis Jefferson Polk, designed his Hallidie Building in San Francisco,

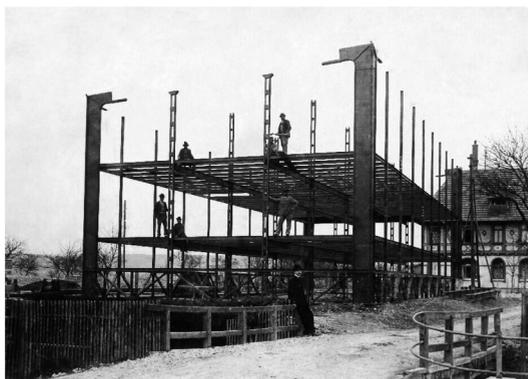
¹ The LEED system (Leadership in Energy and Environmental Design) was created and developed in 1998 by the american non-government organization Green Building Council, which propagates the idea of Eco-Construction.

fitted with a glass curtain wall: probably the first one in America [7]. This feature has since dominated commercial architecture around the world. The Giengen toy factory, even after successive modernization, is still in use today in its original form.

In 1903, Otto Koloman Wagner, an austrian architect and urbanist won the design competition for the Postal Savings Bank in Vienna [14]. The building was constructed in two stages, from 1904 to 1912. The structure itself is simple in form and has quite a modern system of double skin walls incorporated into its main hall skylight [8]. In 1928 in Russia, Moisei Ginzburg made experiments in the use of double skin facades during the construction of the Narkomfin communal housing project. In the beginning of the XXth century, Le Corbusier experimented with systems that used natural physical phenomena that could possibly improve the indoor climate of his buildings. The idea of the *mur neutralisant* was first used in 1916 in his Villa Schwob, also called the Villa Turque (La CHaux – de Fonds, Rue de Doubs 167, Switzerland). In 1929, Le Corbusier introduced his La Cite de Refuge [9, p. 106] project in Paris, where he incorporated the idea. The system was also proposed for many other designs of structures constructed in the years 1928–1933 as part of the Centrosojuz [9, p. 104-105] in Moscow and his competition entry for the League of Nations building in 1927.

In 1957, the first design solution that featured the flow of air between two sets of windows was patented in Scandinavia. The first office building to make use off a system of ventilated

III. 1. The construction of factory buildings in Giengen, Germany, 1903 (source: [5])



III. 2. Current state of the Steiff toy factory in Giengen, Germany (source: [13])



windows was used in Helsinki, Finland in 1967, as the headquarters of the EKONO company. In the years 1973–79, during the rising energy crisis, an intensification of research into energy rationalization and a decrease in overall energy use in the construction of buildings occurred. In the 70's and 80's of the XXth century more and more buildings were fitted with mechanically ventilated double-skin facades, especially in Europe. A good example of such a building is the British Sugar Company building in Peterborough. From the year 1980 onwards, a growing awareness of energy use and the newly formulated concepts in the field of ecology led to a rise in the use of double skin facades. Multinational corporations, which wanted to be perceived as environmentally friendly, began searching for new architectural solutions for the buildings that were to be their headquarters. This trend was further magnified by the quick development of digital technologies, which delivered powerful tools to designers that greatly sped up the design process of creating a building's form, drafting complex technical schematics and calculating complex load bearing structures. Due to the large budgets involved in the construction of high rise buildings, new and expensive technologies were implemented, including the double skin facade. This led to the comparably wide usage of double skin facades, which met the aesthetic needs of corporations and firms, and at the same time provided, even in the case of really tall buildings, the possibility of opening windows. Due to very strong air currents at high altitudes, this was practically impossible in single skin facades.

3. How double skin facades work

Modern double skin facades, depending on the setting of the louvres that regulate the flow of air through the interior space of the facade as well as the interior of the buildings itself, can be applied to:

- 1) create an external air barrier,
- 2) create an internal air barrier,
- 3) air supply,
- 4) air return,
- 5) air buffer.

4. Early examples of double skin facades

The Occidental Chemical Center – also known as the Hooker building – in Niagara Falls, NY in the United States, was the first building in North America fitted with the glazed double-skin facade [10]. The Hooker Building is still perceived as one of the most energy efficient commercial buildings in the world and has received the Energy Conservation Award from the Owens Fiberglass Corporation, as well as an EPA Energy star (EPA, 2001). Finished in 1980 [15], it became one of the oldest examples of a “modern” building with a glazed double-skin facade, which during its 30-year existence, has provided us with a wealth of information on the way this once controversial technology works. The building's facade was constructed as a double-skin glazed buffer facade, which utilizes



III. 3. View of the Occidental Chemical Center facade in Niagara Falls, NY, USA, 1980, design: Cannon Design Inc., Principal, Mark R. Mendel (source: [15])

an undivided space along the entire height of the structure with air supply inlets at ground level, fitted with mechanical dampers and air return outlets at roof level which allow the air to leave the buffer section of the facade.

The Commerzbank Tower in Frankfurt am Main, Germany, is a good example of new developments in the field of facade construction, as well as a system of ventilation that is integrated with it. Each floor of the building has access to daylight and openable windows that allow it to be naturally ventilated throughout the year. The building was designed with energy conservation in mind. Its energy use is half of what can be expected from a building that is comparable in size and scale. Its design incorporates an original idea of locating office floors around internal gardens roughly four stories high. These gardens are linked with the external facade of the building and are home to a diverse range of plants, depending on the orientation of the garden in relation to the direction it is facing. This idea has allowed the



III. 4. Commerzbank Tower exterior facade, interior and ventilation scheme, Frankfurt am Main, Germany, 1997, design: Foster + Partners Ltd Riverside, 22 Hester Road London SW11 4AN (sources: a) author, b, c) [16])

achieving of spatial identification in a unified spatial structure of this large building and it creates an environment that fosters the creating of friendly interiors filled with natural light and with natural ventilation. These winter gardens are located around the internal atrium of the building and allow it to share these characteristics [16].

5. The evolution of the process of facade design, technological progress, new construction materials as the layers of the double skin facades

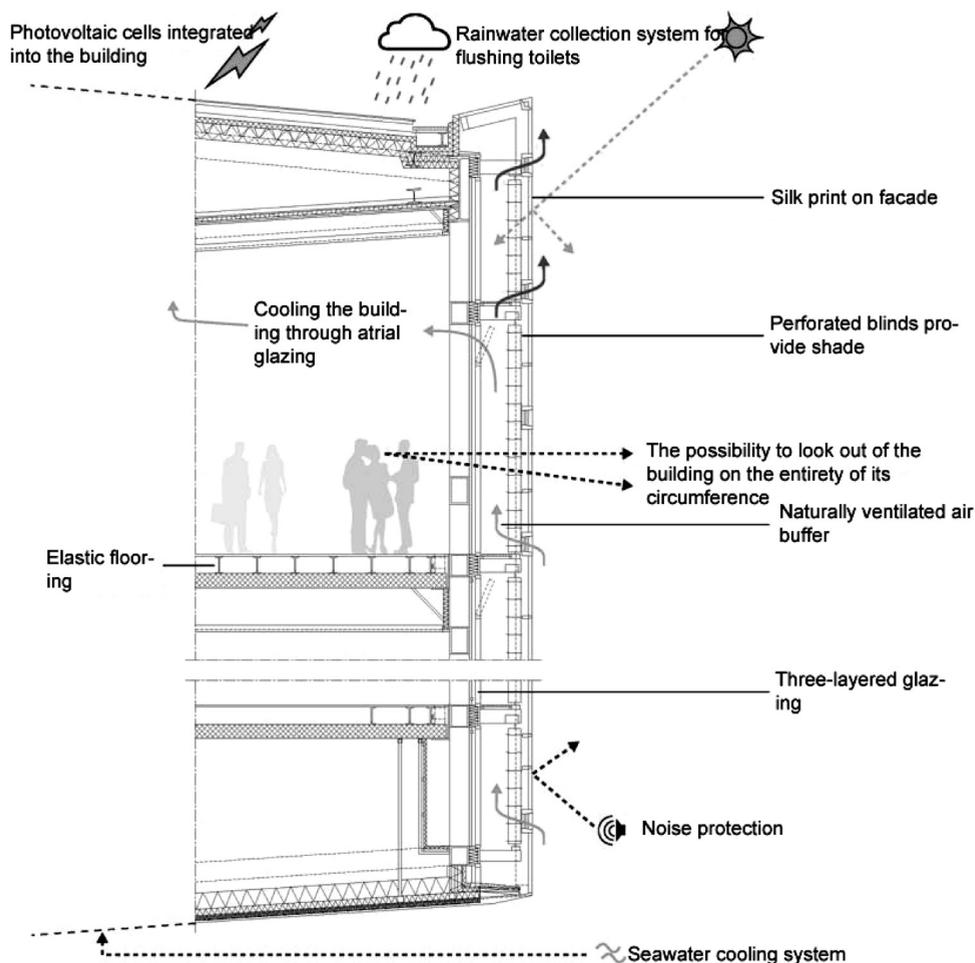
An interesting example of the approach to designing public service buildings using a synergy with renewable energy sources in order to increase its energy efficiency is the Nykredit bank building in Copenhagen, where the double skin facade is a part of an integrated HVAC system. The double skin facade of the building is composed of large, three-layered glazing sheets fixed to steel frames. The glazing has variously colored patterns printed onto it. They serve as elements that protect against the sun's rays. It is divided into two-storey segments with horizontally aligned, low-width ventilation mechanisms with louvres set in a fixed position.

Between the two layers of the facade is a space 70 cm wide, which protects against the outside environment.

This allows for the natural ventilation of offices, along with a far better acoustic insulation, improved cooling during the night with the use of natural air circulation that occurs inside the building due to the openings in the facade and the return outlets at roof level. The building is also equipped with photovoltaic cells placed on the roof, which produce up to 80 000 kWh per year, a rainwater collection system which allows it to be used to flush toilets and the use of seawater as a component of the HVAC system. These are all parts of the energy efficiency improvement concept of the building, which brings its energy usage down to 70 kWh/m² per year. This is a very low figure [17], considering it is 25% lower than the current legal standard



III. 5. External view of the Nykredit bank building facade, which is an integral part of its integrated heating and HVAC system, design: schmidt hammer lassen architects, Aarhus
(source: [17])



Ill. 6. Facade cross-section of the Nykredit bank building, which is an integral part of its integrated heating and HVAC system, design: schmidt hammer lassen architects, Aarhus (source: [17])

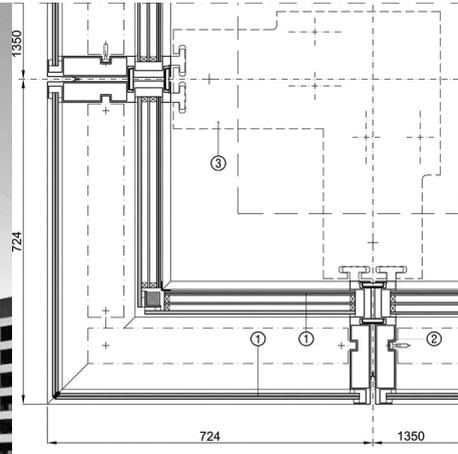
in Denmark. The building, widely named “Crystal” and finished in 2010, was awarded many prestigious prizes including the European Steel Design Award in 2011, as well as the IABSE Denmark’s Structure Award in 2013.

The Roche Diagnostics AG building in Rotkreuz, Switzerland, was designed with a combination of new technologies including the closed cavity facade variation of the double-skin facade (abbreviated to CCF) and a clearly perceivable architectural form in mind. The double-skin CCF type facade has a high heat resistance, a high level of transparency, high sound insulating properties and the costs of cleaning it are half of those of a traditional double-skin facade. It also has a higher degree of protection against the sun’s rays and takes half the time to be fitted onto the building. The costs of cleaning a CCF type facade are comparable to those of cleaning a standard facade, with all the benefits of a typical double-skin facade.

a)



b)



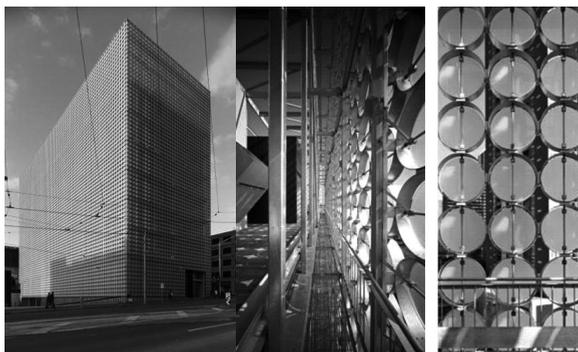
B - B

III. 7. Roche Diagnostics AG building in Switzerland, CCF type double-skin facade. Design: Burckhardt + Partner AG, facade design: Josef Gartner and Co, a) facade view (source: [19]), b) horizontal cross-section of the CCF facade: hardened safety glass, laminated (1), aluminum structure (2), facade fastening (3) (source: [18])

The systems that control the functioning of a CCF facade are designed to provide the easiest possible maintenance of the wall. The CCF elevation allows the adjacent rooms to meet the requirements of clean, hygienic spaces and is meant to be used as a wall in laboratories. The economical effectiveness calculations have produced results that indicate that this new type of facade allows the attainment of an effective use period of 30 years [18]. The CCF system can be modified to allow natural ventilation using either of two technologies: decentralized ventilation devices or fully openable facade elements.

6. Double skin facades as an element of a buildings infrastructure

In the course of the development of new technologies and their implementation in the design of double skin facades, they are seen to become an ever more important part of the infrastructure of the building. The RMIT University building in Melbourne, Australia, has been fitted with a spatial structure on its facade that is separated into cell-like objects, which are influenced by the interior structure of the building, composed of laboratories of varying sizes within the tower building. The double-skin facade is composed of translucent, thermal insulating glazings, which are set 70 cm away and parallel to a structure made of 1.8×4.2 m panels, made of 21 galvanized steel cylinders 130 mm in diameter, which are, depending on their location, filled with matte glass discs or photovoltaic cells. These elements are steerable and can fulfill a number of functions, including protecting against sunlight, providing thermal comfort to its users and even generate power.



Ill. 8. View of the university building, RMIT University
GPO Box 2476 Melbourne 3001, Australia, design: Sean
Godsell (source: [20])

7. Comparison of double-skin facades and single-skin facades

An analysis of a number of examples of buildings from Europe proves that the results of comparing buildings with DSF against those with standard SSF glazed facades give rise to a number of interesting conclusions in regards to both of these types of structures [11].

- **Energy use for heating purposes** – DSF equipped buildings have much better parameters of energy efficiency in the winter months than traditional buildings. Heating equipment can be very effective in maintaining the interior temperature in concert with louvre systems. The buffer effect of DSF is possible to achieve and can reduce the overall costs of heating a building.
- **Energy use for cooling purposes** – DSF equipped buildings have much better parameters regarding efficient energy usage for the purposes of cooling during the summer months, under the condition that they are also fitted with systems that protect against excessive heating (like louvres in the space between the facade layers). Thanks to the DSF buffer effect it is possible to reduce the costs of operating cooling systems.
- **The usage of integrated renewable energy generation systems** – the introduction of renewable energy generation systems is made easier due to the possibilities of integrating them into the structure and infrastructure of the DSF. It is especially true regarding photovoltaic cells.
- **Acoustics** – protection against noise is more efficient in buildings with DSF, especially in the case of lower frequency sounds in comparison to standard double glazing. In the case of a select number of technical solutions within the scope of DSF technologies, sometimes sound is carried more easily within the building itself.
- **Ventilation** – DSF facades can be used in concert with gravitational and mechanical ventilation systems; however, the overall problem of ventilating such buildings are more complex than in the case of single skin facades. Natural ventilation through openable windows is made much more feasible than when compared to single skin facades, even in the case of high rise buildings. High rise structures with single skin facades cannot have openable windows.

- **Fire safety** – the use of a DSF facade makes it impossible to naturally remove smoke from within the building without additional assistance from a proper mechanical installation.
- **Daylight penetration** – The achievement of good lighting conditions is possible in both cases (DSF and SSF). The increased area of glazing can cause problems with excessive illumination, which is a key element in designing open space offices, where the level of illumination can sometimes be detrimental to the working conditions in some areas of the office.
- **Aesthetics** – a key element in the discussion on DSF is the transparency effect, as well as the pragmatic and ideological transparency of a facade and the building as a whole. The additional feeling of the building being “high-tech” can also promote its positive image.
- **Maintenance costs** – the costs of cleaning and maintaining DSF facades are undoubtedly higher than in the case of SSF. a separate matter is the CCF DSF type where the costs of cleaning of are comparable to those of SSF, while still maintaining all the benefits of a DSF facade.
- **System quality** – buildings fitted with DSF systems are, due to their relatively short time of operation, prototypes of sorts. The problems that have been observed thus far are mainly associated with the fastening of glazing (which appears both in SSF and DSF facades) and the motor systems of the louvres. The DSF system is superior in regard to the detrimental effects of the environment on the structure of the facade, as most of the system’s elements are shielded from the environment. The CCF facade type, thanks to its construction, is a uniquely durable system. It is estimated that this system has an operational use time of 30 years [18].

8. Conclusions

Clients order double skin facades due to their transparency and the image that they give to their building, while architects praise them for their unique lightness and expression, allowing the users better contact with the outside world. Design teams are currently striving to balance the challenges of simultaneously keeping the right interior climate of the building and providing the highest possible energy efficiency. It is extremely important that a building’s facade be treated as an integral part of it. An individual and holistic approach to design is the key to obtaining high quality end results.

The history of double-skin facades is surprisingly rich, and its beginnings are much older than one might anticipate. They were tied to attempts at regulating the interior temperature and inner environment of the building. Today, this technology has become one of the leading means of shaping these parameters.

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