

# Double-skin Façade Technology and its Aspects in Field of Aesthetics, Environment and Energy Consumption Optimization

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## Abstract

According to the increasing growth of buildings with various forms and uses and more congestion of urban areas, in addition to preservation of standards of their indoor spaces, the outer skin of these buildings should be considered significantly, because it is under direct impact of natural and unnatural environmental factors. Also, the link between indoor and outdoor space should be provided like the body of a living thing and at the same time, different face should be given to structure of these buildings in each dimension and use. Hence, it is important to use a method that in addition to reduce energy consumption as a human challenge at the current age can make no limitation for quality of life. In this field, modern technologies of double-skin facades play key role as novel technology in architectures, structure and mechanics of materials and other knowledge-based sectors. In addition to strengthen aesthetic aspects of building and intelligent and creative change in view of the buildings based on the time and climate, the technologies can provide many facilities in field of natural air conditioning in addition to control sound, wind and rain. The structure of double-skin facades can provide conditions for optimal use of factors such as natural light and wind in addition to provide possibility to control heat, cold, light, wind and other factors and environmental pollutions like outside noises. In addition to create comfort for the residents, it plays key role in minimizing consumption of fossil fuels, protection of natural environment and increase in building durability. In addition to investigate modern technologies of double-skin structures, this study has also reviewed the performance and view of these structures in the implemented or designed projects. After measurement and analysis of relevant studies, this study has tried to show that use of double-skin facades can act as a survivor in architectural design.

**Key words:** Energy crisis, Optimization, Double-skin façade, Breathable construction, Aesthetic element

## INTRODUCTION

The functional and aesthetic role of building as the mediator and key element between outdoor and indoor space to create a beautiful work, in addition to observance of technical requirements and helping protection of environmental resources and in field of using clean energies are very important in the current architecture and its relevant concerns. Proper designation and implementation of double-skin façade can be good solution to create

innovative architectural works, along with welfare and comfort facilities in structure of a building.

The concept of double-skin façade could be developed in opinions of community of architects since late 1970s decade and this issue could enable access to full-glass facades to improve beauty and daylight penetration without disrupting function of heating system of building. With deep penetration of daylight and more control of heat load of the building, double-skin façade has been accepted by majority of people as a green technology and has provided wide range of different visual forms.

Progressive traditional façade systems (full-glass with fixed canopies) could provide the thermal comfort in vast facades for all direction in hot seasons and north-south directions in cold seasons. However, solar control systems in cold seasons and for low radiation angles in early and

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late hours of day in east and west directions, no measure was taken.

### The Initial Concept of Double-Skin Façade

Double-skin façade is a multilayer structure composed of an outer skin (usually of glass) and a middle space and an inner skin (again usually of glass) (J. Zhou and Y. Chen., 2010).

### The Causes of Using Double-Skin Façade

Firstly: double-skin facades are under implementation in areas with no acceptable condition in terms of climatic conditions. Secondly: double-skin facades are not designed properly. Dr. Grates believes that lack of reports based on real output for double-skin facades and lack of appropriate modeling tools can be causes of such events.

Reduction of energy consumption is a global concern and the researches are being increased rapidly to achieve tactics and techniques to modify energy of buildings. The physic of building is considered as the main consumer of energy. The main energy resource for facades is generally electricity, which is provided by fossil fuels. The studies show that out of the energy produced for buildings, only 1.3 is consumed optimally (G. B Hanna, 2013) and this amount is almost equal to 1.4 of CO<sub>2</sub> at the world. Hence, urgent actions should be taken to avoid dangerous upcoming results for future generations. Therefore, using double-skin facades has been developed rapidly and this has been because of its advantages in field of energy preservation. The main goal is to meet human needs with no destructive impact on future generations.

### Architects and Double-Skin Façade

The issues of increased energy of buildings, prediction of providing resources, effect of proper use of energy to reduce future costs of building and increased role of the projects in field of energy consumption optimization and use of clean and renewable energies have possessed important part of architectural design process. These problems have had significant effect on attitude of architect towards the style of designation and hence, architects should have more comprehensive and vast attitude towards principles of sustainable architecture. Designing modern structures with highest standards in field of energy consumption efficiency has been changed into a big challenge for architects and has made them cooperate with other engineering-academic experts. As a result, majority of buildings have gained special 3-D form and they have been attached to their ventilation system in terms of implementation details and aesthetics. At the same time, they can maximize use of natural light by the residents like the efficiency of energy consumption.

A good example in these fields is presenting LEED<sup>1</sup> certificate for the already implemented projects and buildings in form of Acknowledgements. As nature of climate is not fixed and has its special conditions depending on geographical conditions, climate and difference of sea level, modern technologies of double-skin façade have been also changed to cope with these changes and conditions. Such coping can play role in structure of building like a living member that shows reaction under such conditions and how beautiful would be if the living element is used in terms of aesthetics in maximum level. Hence, this study has investigated use of double-skin facades technology and has presented the results from 3 aspects as follows:

- a) Aesthetic aspect of double-skin façade
- b) Efficiency aspect of double-skin façade in protection of natural environment
- c) Fuel consumption optimization aspect

### Literature Review

Role of outer skin of buildings has been changed a lot. These changes were begin from the time in first half of 19<sup>th</sup> century that these walls used to separate indoor and outdoor spaces of building as a thick carrying element (Semper G, 1851, 66). Also, an important change was made by Maysoon in Rohe at the beginning of 20<sup>th</sup> century by the concept of "Skin and Bones" (Blake P, 1946).

Double-skin facades are abbreviated as D.S.F and have become common today because of their successful position in reducing energy consumption in buildings.

However, use of physical natural phenomena to improve indoor space of building is not a modern concept and has been and still is one of the desires of human. For example, people of Middle East used to apply wind controllers (windward in Iran) (Jaworska-Michalowska M., 2007).

### Similarity of Windward and DSF

Windward was common in Iran since last times and it is clear from the ancient letters and documents that it is not a novel phenomenon. Windward has different types and has been made based on climate and different forms in Iran. The most beautiful and applicable windward is existed around the dry and hot plains and especially in Kashan, Yazd, Bam, Jahrom, Tabas Cities and Shores of Persian Gulf and Arvadrood. The mechanism of the windward is on this basis that it uses wind flow to pull the pleasant weather and airflow inside the building and uses also the suction system to push the hot and polluted airflow.

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.

As wind is confluence to the barriers or inner blades of windward, it has to drop. Other cracks of the windward back to wind flow can leave polluted and hot air flow for the wind and take action of an air conditioner (Figures 1 and 2). The air conditioners of shores of Persian Gulf and the meshed walls in buildings of south shores the Mediterranean take same action (Pirnia, 2013).

It could be mentioned that windward is clearly one example of using double-skin façade of its time and used to apply clean and renewable energy resources absolutely; although it is not applicable anymore because of pollution of outside space; For example, in caravanserais, windward used to be built in the front of entrance gate on porches like Robat Zeinedin at Yazd-Kerman Road and Jokar o Jokhah Caravanserai near to Tabas (Ghasemi, 2015).

#### Double-skin façade and Western Architecture

Almerica Capra Villa designed by Andrea Palladio has natural ventilation system to cool rooms (Figure 3).

By 1849 (Heim D, 2010), Jean-Baptiste Jobard, Manager of Brussels Industrial Museum, displayed a model of a

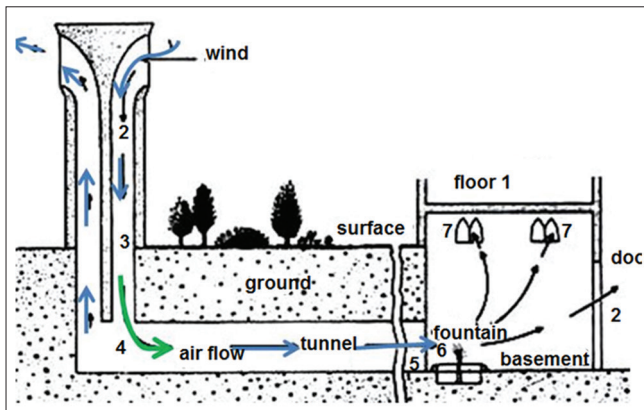


Figure 1: Windward Mechanism

multilayer façade that could provide conditions for air conditioning mechanically. He used the space between two glass walls to provide hot air flow in winter and cold air flow in summer. On 1903, the first real double-skin façade was made in a section of Steiff Toy Company in Giengen of Germany (Fissabre A, 2009). The innovative solution in structure of this building has been use of two layers of glass (Figure 4). The outer layer of wall implemented by Richard Steiff in Giengen was absolutely in consistence with the new definitions presented by Rolf Schaal on 1961 (Schaal R, 1961).

15 years later, Willis Jefferson Polk designed his building “Hallidie Building” in San Francisco with glass coverage and this building was the first building in its type in America (Here Today, 1968). The composition has been formed as a pattern for commercial buildings across the world.

On 1903, Otto Koloman Wagner, Australian Architect and Urban Planner, won the Postal Saving Bank Award in Vienna. Form of the structure is simple and includes a modern system of double-skin walls integrated with skylight of main hall. On 1928 in Russia, Moisei Ginzburg tested the experiences in field of using double-skin façade in construction of group accommodation project. At the beginning of 20<sup>th</sup> century, Le Corbusier took some measures with a system using natural physical



Figure 3: Almerica Capra Villa



Figure 2: Windward house of Borujerdi in Kashan



Figure 4: Steiff Toy Company



phenomena and could improve in indoor weather to some extent. On 1929, Corbusier opened his La Cite de Refuge project at Paris (Le Corbusier). The idea was used for many other buildings constructed during 1928-1933 as a part of Centrosojuz (Le Corbusier, 2001, p.104-105) in Moscow.

On 1957, the first solution project specifying air circulation between two series of windows was founded in Scandinavia. The first administrative building with channel air conditioning system was built in Helsinki, Finland on 1967 similar to central office of Ekono by 1973-79. The age of rise of energy crisis caused creation of a research intensification for rational explanation of energy consumption in structure of buildings. In 70 and 80s decades of 20<sup>th</sup> century, majority of buildings, especially in Europe, were implemented with double-skin facades with mechanical ventilation system. Since 1980, conscious growth of energy consumption and new concepts in field of environment were conducted towards double-skin façade. Multinational institutions wanted to be seen as environment-friendly institutes and started studies in field of new architectural solutions for buildings as their central office. The process was accelerated with the help of rapid development of digital technology, since it could provide strong instruments for designers to accelerate process of designing form of a building, full modeling of building and calculating structural loading. The process paved the way for vast and comparable use of double-skin façade.

### Façade as Inseparable Component in Building Structure

Façade plays key role in saving energy. New innovations have created considerable advancements in field of materials in updating or reconstruction of old buildings or to enhance functional efficiency of buildings (Compagno, 2002). Architects enter to action with the cooperation of other engineers (Karsai 1997; Szokolay 1980a; Watson 1993) and made façade have a portion in energy consumption like the body of building (Amato, 1996), especially in cold-mild climate (like Europe) and tested new concepts. They analyzed outdoor space (Figure 5) and calculated it (Givoni 1992; Szokolay 1980b; Wigginton 1996). The advanced technologies of façade were developed considerably in sector of sale of special and luxury administrative buildings (Wigginton, 2002) in effort to link the building facilities to façade and the consequences include: useful building area, reduced overall value of building by reduced area of the building.

### Classification of double-skin façade

A common classification can be obtained for types of DSF (Parkin, 2004). Table 1 has presented summary of main structure of double-skin facades:

### Mechanism of Double-Skin Façade

Modern façade of DSF, depending on position of louvres regulating air flow in the internal space of façade like indoor space of building (Figure 6), can be done in following ways:

- Creating an internal air curtain
- Creating an external air curtain

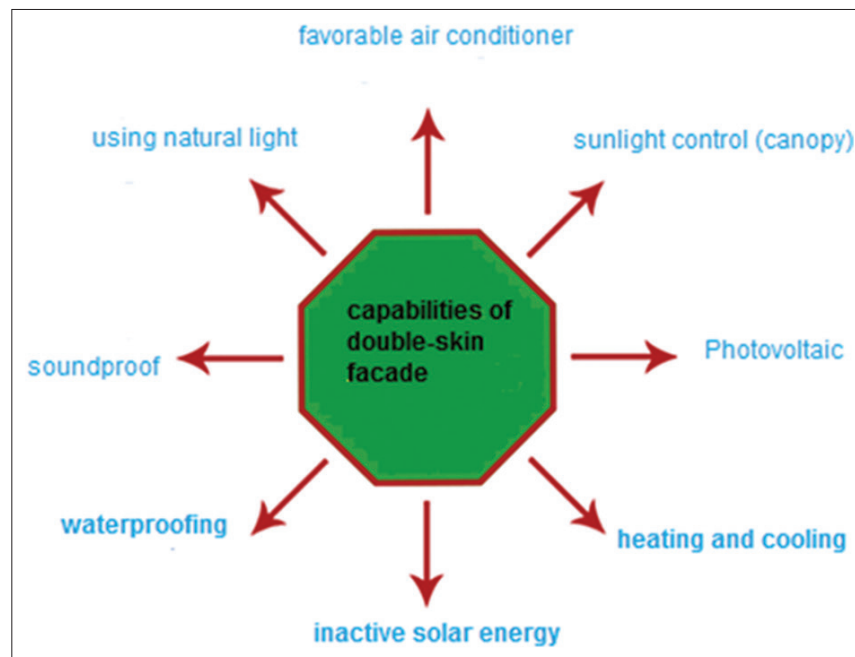


Figure 5: Functional capabilities of façade

**Table 1: summary of main structure of double-skin facades (Haase, 2007)**

Main type	Box window facade	Corridor facade	Shaft-box window facade	Multi-storey facade
Cavity ventilation		Natural	Mechanical	Hybrid
Airflow concept	Supply air	Exhaust air	Static air buffer External air curtain	Internal air curtain

- Creating air supply
- Creating air exhaust
- Creating static air buffer

Figure 6 has illustrated different concepts of air flow that are applicable in double-skin facades. Majority of new DSF systems have been advanced to a level that can play role like a climatic reactive element or hybrid ventilation (natural and mechanical), which can change the air flow state depending on different climate situations.

### Properties and Advantages of Double-Skin Façade

#### *Reduction of heating energy*

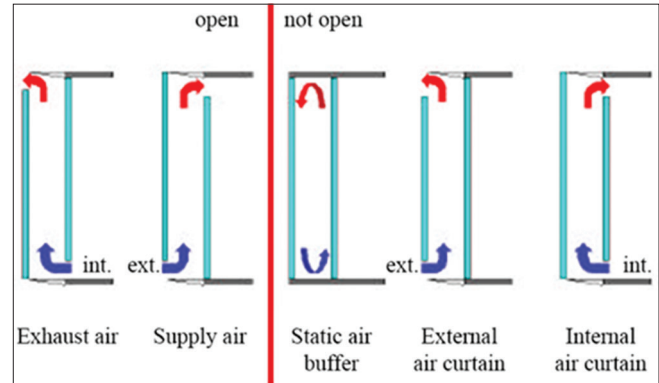
Results: a) the pore between internal and external skin has a function similar to thermal insulation that can prevent heat loss b) the hot air flow inside the chamber can be used for favorable air conditioning inside the building c) vast resolution of façade can provide conditions for use of sunlight in form of inactive thermal energy for the indoor space (Author Pollard, 2000).

#### *Sunlight radiation control*

In hot months and climates, the amount of energy consumption is increased to create cold air flow because of penetration of light throughout the windows or through adsorbing thermal energy by physic of building. DSF can reduce effect of sun radiation with the probability of embedding canopies in the space between two skins and prevents light reaching internal skin. Canopies can be usually regulated, so that they can maintain the outdoor landscape from inside as much as possible. The hot air flow trapped in chamber is also pushed towards outside by natural or mechanical air conditioner to prevent rise of indoor temperature. The chamber protects canopies against wind and rainfall (especially in high-rise buildings) and provides condition to have access to them for repairing purposes (Author Pollard, 2000). Because of using beveled flower-shaped fiberglass (like Islamic Shanahil), the parts would be opened and closed in response to temperature of façade (Figure 7). According to Peter Obron, Manager of Aedas, majority of them are wrinkled at night, but major part of façade is visible.

#### *Possibility of natural air conditioning*

Natural air conditioning created by special type of windows in internal layer can cause considerable reduction in loading level of HVAC system with comfort in terms of cooling and fresh air for the residents. DSF can protect

**Figure 6: Concepts of air flow in DSF (Haase, 2007)****Figure 7: Reactant façade coverage in Abu Dhabi Twin Towers**

windows against wind and rainfall even in state of natural air conditioning. Use of inactive cold weather at night to make body building cool has a mechanism like chimney and can play key role to improve air flow and to push hot air flow from the building (Author Pollard, 2000).

#### *Reduction of artificial light use*

Increased access to daylight is possible through using lucid skins in this system. Daylight reduces the amount of using artificial light inside a building. Daylight can be the main light supplier; unless sunlight radiation is not available anymore. Hence, electricity consumption is also reduced and as a result, energy is saved (Author Pollard, 2000).

#### *Improvement of accommodation comfort*

Daylight is the factor to provide comfort for the residents and can increase work efficiency and reduce eye fatigue and stress (Author Pollard, 2000).

#### *Soundproof*

It refers to creating acoustic insulation for buildings, especially buildings near to streets or railways. The external skin plays role of a barrier to surrounding noises; although



**Figure 8: Secondary coverage of façade of New Mexico Hospital**

the windows of internal skin are open for natural air conditioning with no special problem.

#### *Improvement of landscape*

Because of having facades with high transparency, the residents have more access to surrounding landscapes and this can have positive impact on their health and can also reduce their eye fatigue (Author Pollard, 2000).

#### *Increased security*

One of the causes of increase in security in these buildings is existence of an extra layer (external skin) in physic of building; although internal windows are open for natural air conditioning. Under special conditions, external skin can be reinforced to create higher security (Author Pollard, 2000).

#### *Futurism and increased lifecycle of building*

Arrangement of furniture and partitioning the spaces inside the building is more flexible and there is no wall or barrier in plan of building. As a result, the building can meet future needs of residents with no reconstruction or destruction.

#### *Decontamination*

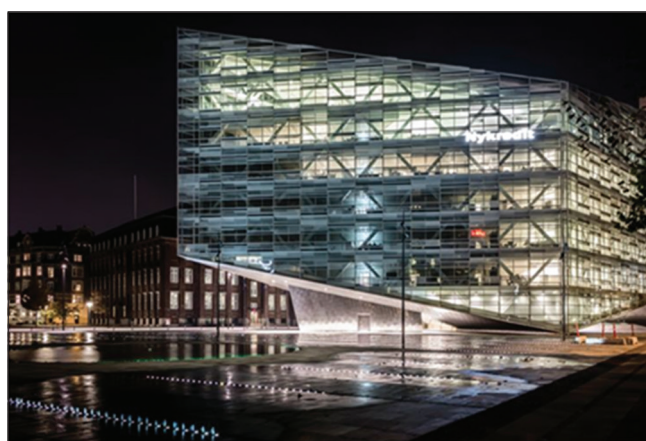
The outer skin plays role of pollutant in polluted areas and provides conditions for inner windows of internal skin to be open to get air flow or using compositions of titanium in external skin, it produces clean air for the surrounding area near the building. for example, on 2011, Alcoa Chemicals Company used exceptional technology to clean surrounding air. Recently, this system has been used in façade of a hospital in New Mexico City called Torre de Especialidades (Figure 8).

#### *Access to emergency exits*

If the routes related to repair and maintenance are predicted between the hollow chamber of two skins, the routes can be used for emergency exits.



**Figure 9: Use of alga in second ski**



**Figure 10: External façade of Nykredit Bank**

#### *Environment*

Environmental capabilities of this system can be in two forms:

First: environmental protection: Using fossil fuels has made people being away from the environment and has also provided conditions for the destruction of the environment. Hence, using technologies that reinforce the natural environment along with protecting it can be important. The process of DSF is also one of the protectors of natural environment.

Second: use of existing processes in the environment: Every living thing at the world tries for survival. Hence, people can use the processes used by those living things in this filed and use in daily life; like use of Nano Technology that an example of it can be found in natural environment like Lotus leaf with self-cleaning properties. In Germany, new innovation is formed. In this innovation that is created by the effort of 3 years experiments of two companies of Splitterwerk Architects and Arup, natural alga is used for energy supply. The varying yellowish green color of them has not decorative aspect, but also they have been created in fact by millions of microscopic alga plants, which are fed



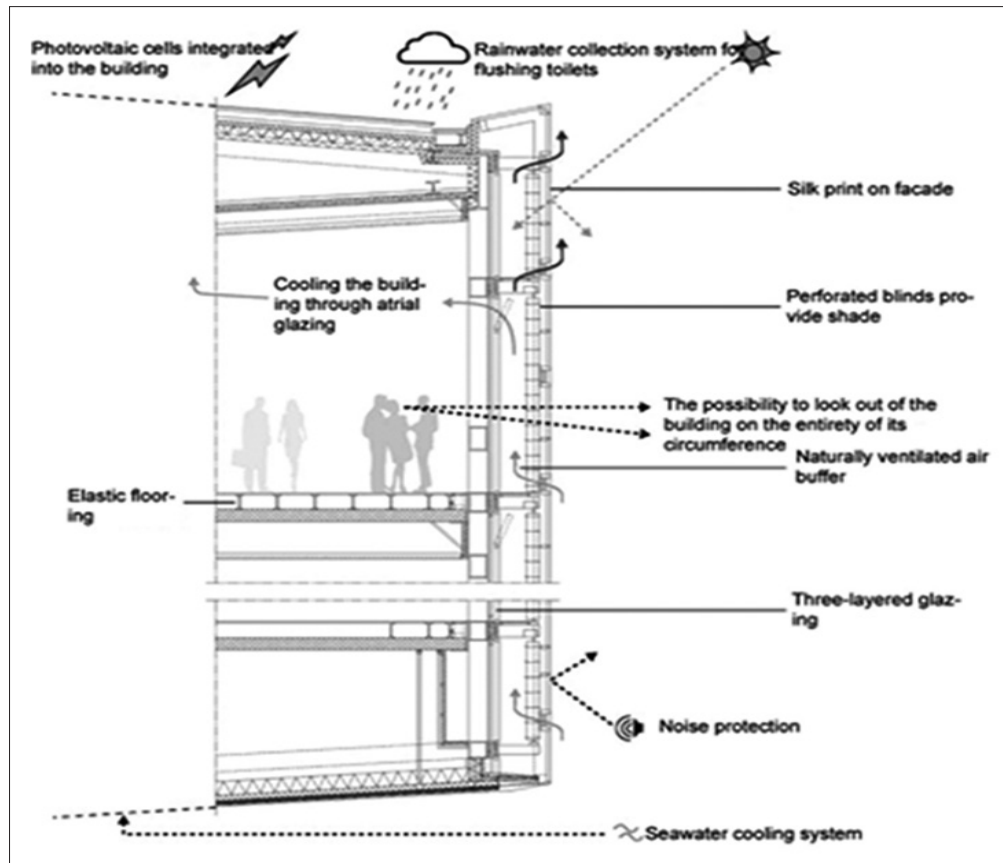


Figure 11: Water supply mechanism



Figure 12: A view of Roche Diagnostics AG building with CCF façade system

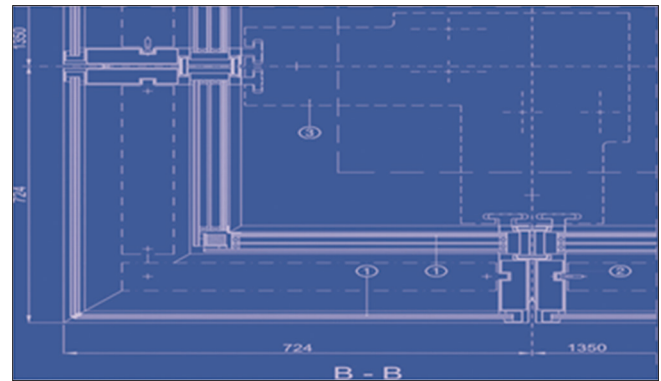


Figure 13: Horizontal section of CCF façade  
1-Glasses processed by laminate  
2-Aluminum structure  
3-Façade support

for activity in this process by nutrients and oxygen. Using direct sun radiation, fast growth of cells can maximize water temperature and such heat is product of this system and is stored for household consumptions (Figure 9).

#### Beauty and diversity

The key element in description of DSF is possibility of using clarity extended in all façade with preserving

both functional properties and idea of transparency in architecture and the same time. Hence, the details and the innovations can have innate and not only physical effect on building's beauty.

Real function of DSF in implemented buildings

An attractive example of approach of designing buildings with service-public uses by renewable energies done to

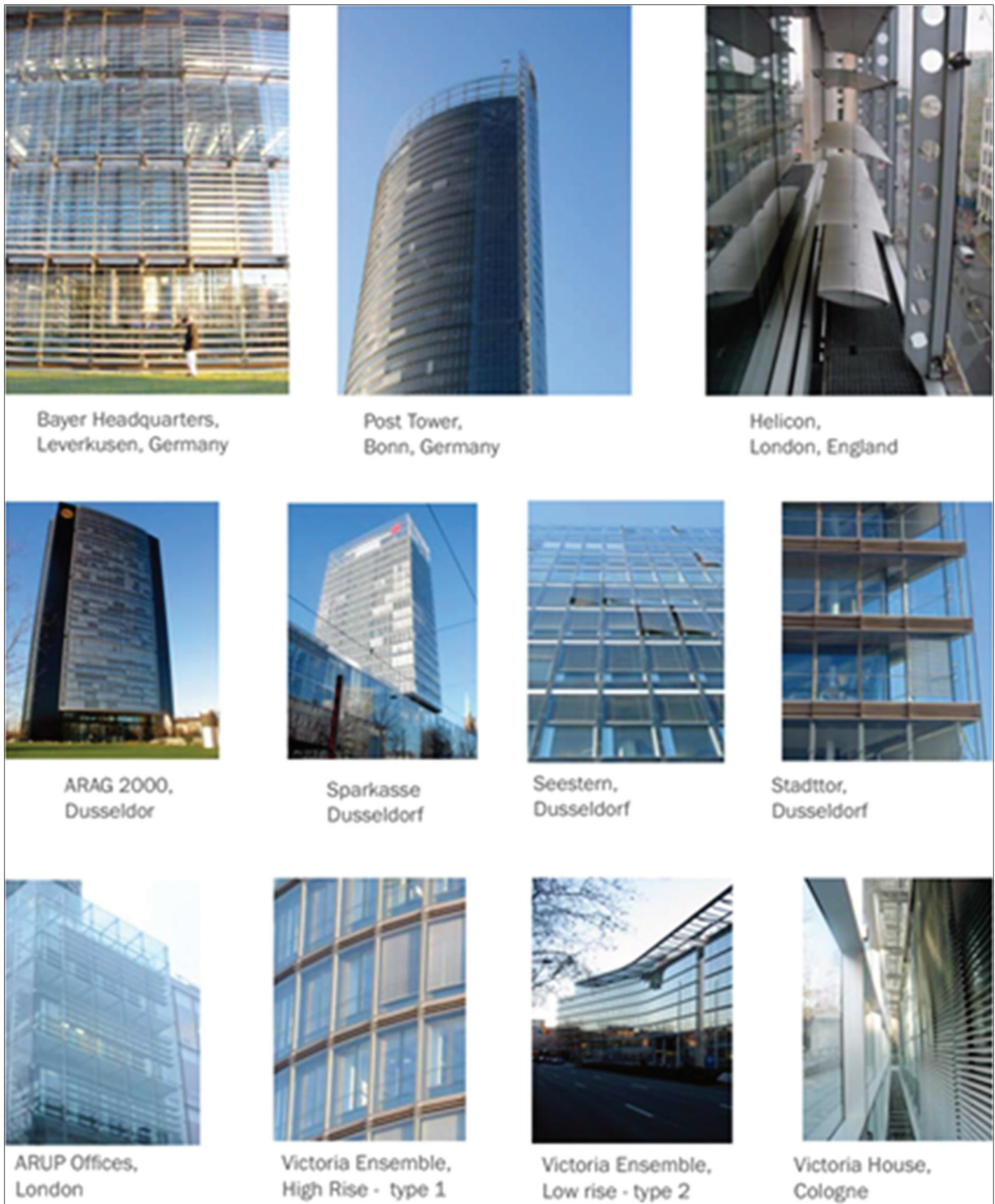


Figure 14: Successfully implemented cases of DSF

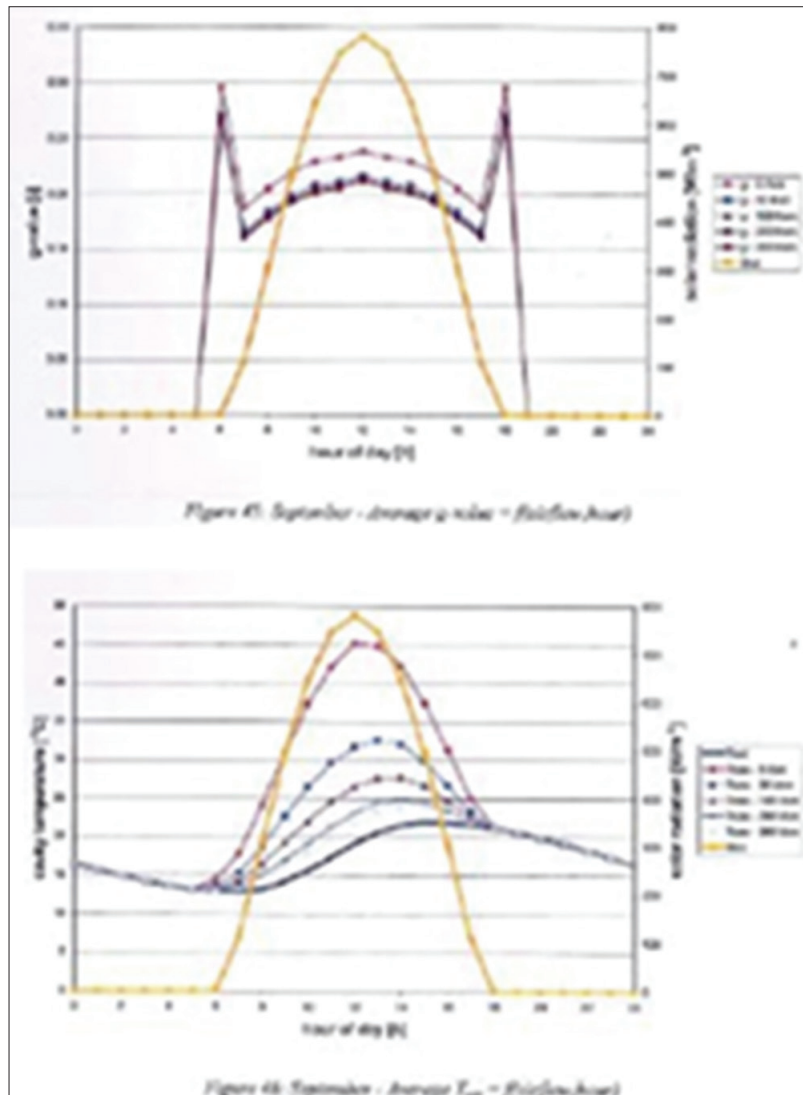




**Figure 15: Façade in Gundelfingen was built in Germany by GmbH and Josef Gartner. Before casting the façade, they made a Maquette of it in real scale and performed tests such as air infiltration, water penetration and deformations caused by earthquake on it**

increase energy efficiency is a bank in Copenhagen called Nykredit. The DSF of this building is composed of big 3-layer cups embedded on metal frame (Figure 10).

The glass cups have different color patterns on them. The colors are responsible for protection against harmful sun radiations. They have been classified between both stories, which are in line with each other horizontally and have air conditioning mechanism using louvres. The 70-cm space between the two layers can protect building against outside factors. The facilities of this approach include natural air conditioning of offices inside the building, better soundproofing, and improvement of cooling system at night using natural air circulation inside the building because of openings in façade and outlet channels in surface of roof. Moreover, the building is equipped with photovoltaic cells on roof and produce more than 80000kwh per year. Using rain water, the water needed by flash tanks of WC and HVAC system is supplied (Figure 11). The issues can



**Figure 16: Thermal diagram prepared by (London Office) Arup Façade Engineering**

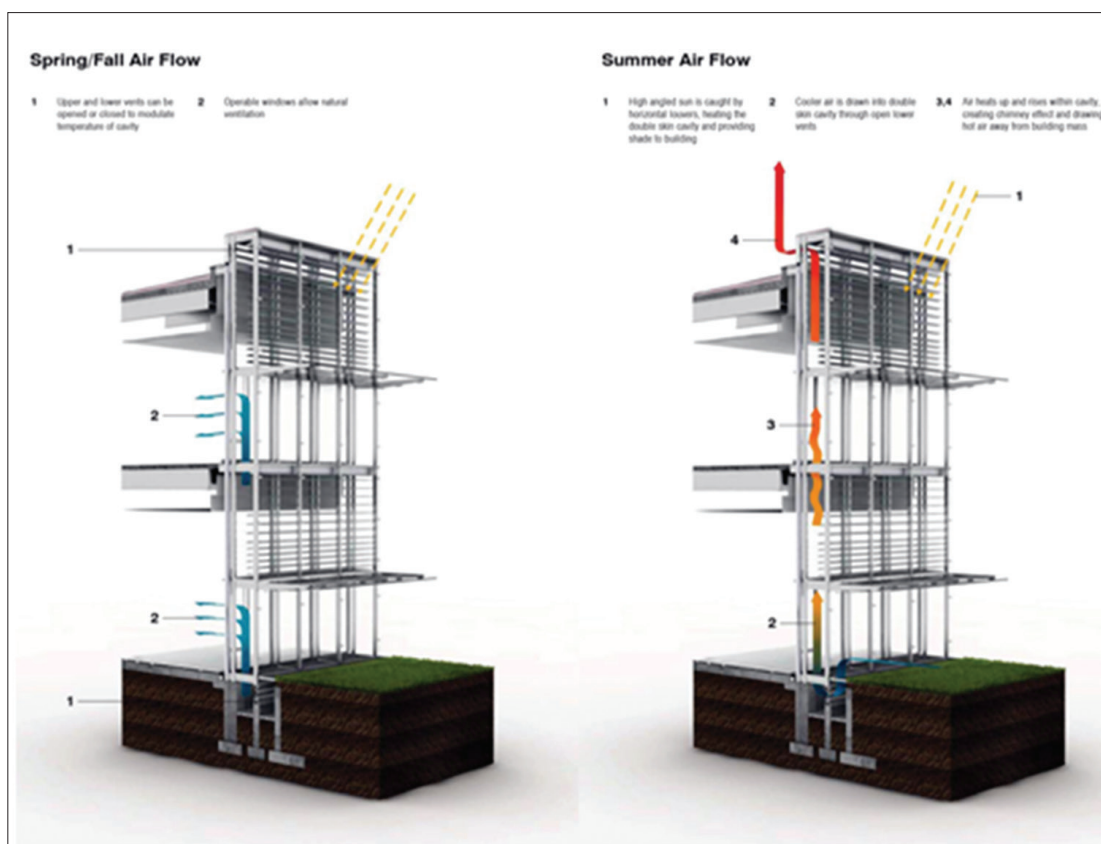


Figure 17: Structure and participating components and air-conditioning during spring, summer and fall

reduce energy consumption annually to 70kwh/m<sup>3</sup>. This number is very low (Schmidt) and is even 25% lower than the current authorized standard in Denmark. This building is known as Crystal.

Another example is Roche Diagnostics AG building in Rotkreuz in Swiss, designers of this building are Burckhardt and Partner AG and façade designer is Josef Gartner and Co (Figure 12).

The building is a composition of modern technologies including a kind of different DSF in form of closed chamber façade (CCF) and has created indicator architectural form. CCF system façade has high thermal resistance and high transparency and also high noise acoustic. Moreover, protection against harmful solar radiations is also high in this system (Figure 13). The system controlling function of a CCF is designed in such manner that has the easiest state of maintenance of wall. The calculations of effectiveness has given some results showing that this model of façade had about 30-year time period (Josef). In CCF system, some measures can be taken to use both technologies simultaneously to create natural air conditioning: decentralized air conditioning state or full opening elements in façade (Barnas, 2014) (Figures 14-21).

Implemented cases:

#### Analysis of Structure of A Case- Cambridge Public Library (Rawn, 2009)

In this section, structural-functional analysis of Cambridge Public Library is presented that was completed in 2009 and the aim is to become familiar with function, components and implementation process of this DSF.

## CONCLUSION

There are a few studies in field of structure of double-skin façade and its function and achieving to a comprehensive design to show primary regulations of this technology and to pave the way for architects and engineers in every climate with each style. In addition, the existing technologies are more costly than single-skin façade and traditional facades and this can double responsibility of architects and engineers and they should enhance their innovations and researches in this field. It should be noted that the proposed method is efficient not only for all types of climate, but also for all directions of façade of a building or the buildings should be investigated with more details. For example, in hot climates, full-glass DSF can cause abundant problems such as heating caused by sun radiation inside the building

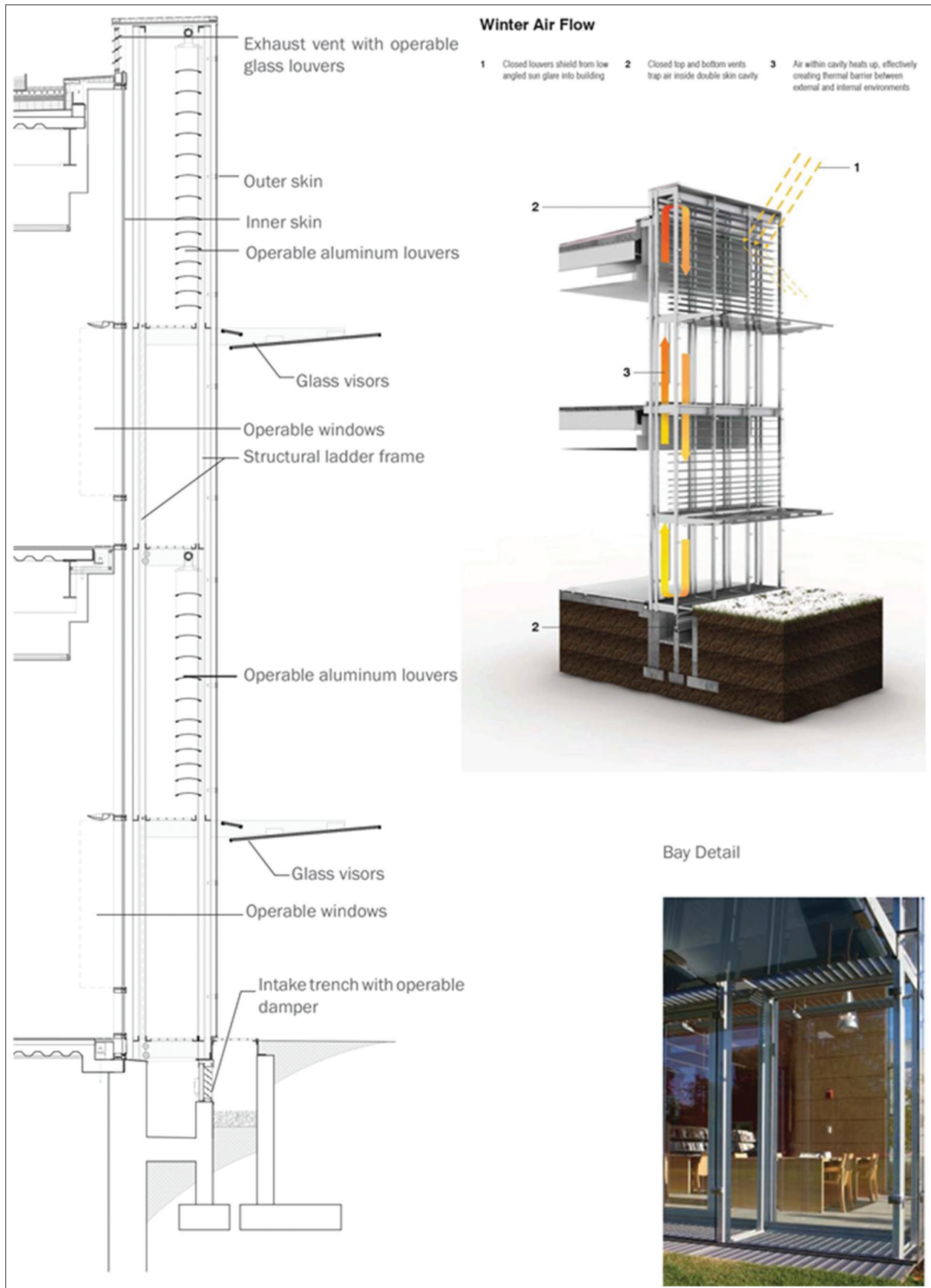


Figure 18: Structure and participating components and air-conditioning during winter



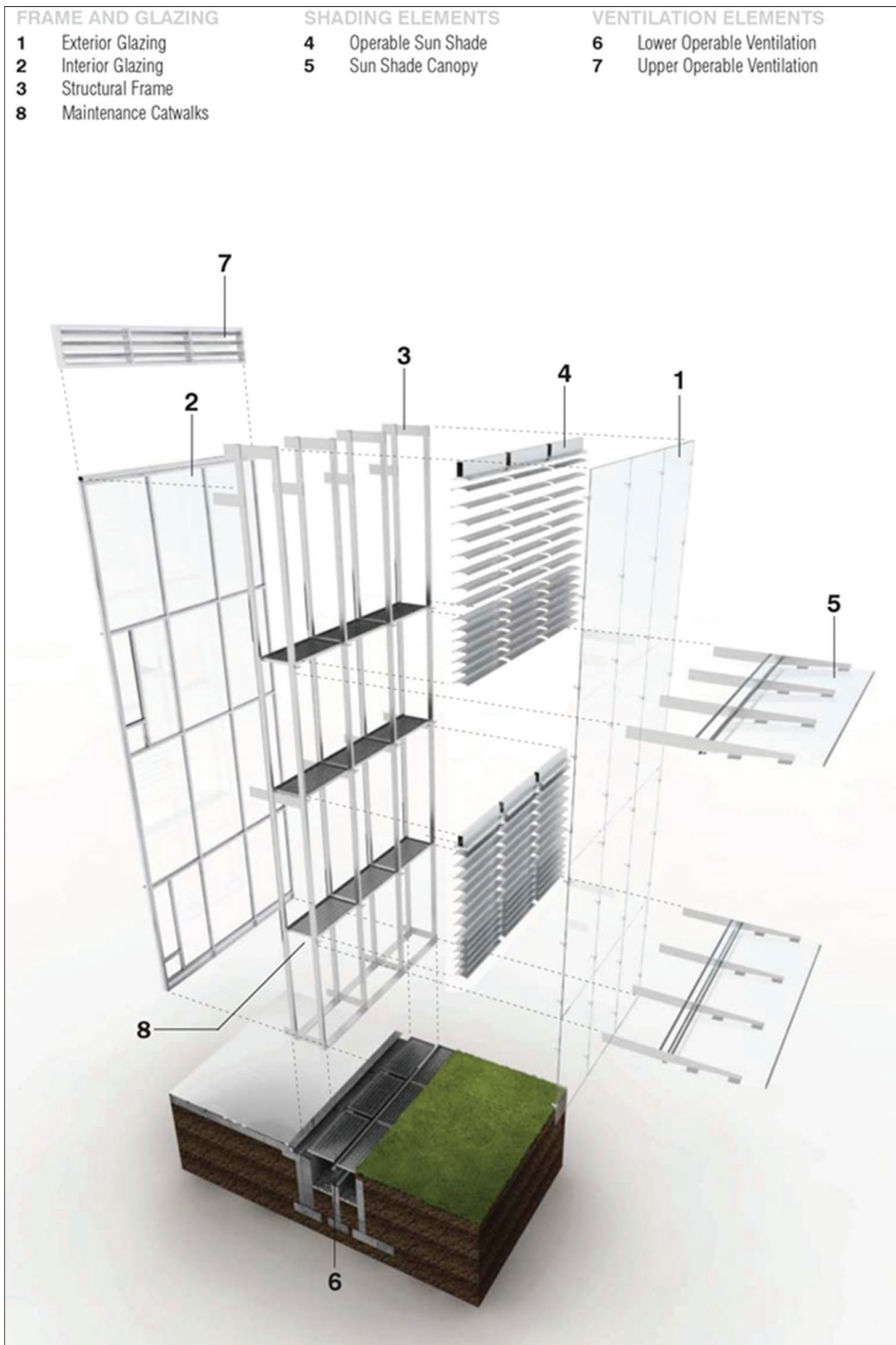


Figure 19: Main components of DSF



Structural ladder frame erection



Glass visor installation



Structural ladder frame



Inner glass skin installed



Structural ladder frame



Outer glass skin installed

Figure 20: Implementation of DSF





Figure 21: A view of indoor space of library

and as a result, more cooling. However, sun radiation can encompass only a part of building façade. In Council House 2 project in Melbourne Australia, the engineers found that to achieve optimization of energy consumption, along with enhancing comfort level of residents, every façade should be designed independently and same method can't be used for all types of façade. Using DSF plays key role in reducing energy consumption and improving building efficiency and the cost of the project can be returned and can be profitable over the time due its advantages. It should be noted that façade is inseparable component of building and should be integrated with the structure of building and to achieve favorable result, the advantages of each section should be used to meet hedges of the other part. However, it should be also noted that structure, components and materials used in DSF systems give special beauty to it and in addition to functional advantages of DSF and due to increasing use of this system in buildings, more efforts should be taken in field of designing and creating diversity in façade of buildings, so that façade uniformity is not observe in vast the sheer size of the buildings.

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