Pneumatic Modular System as Adaptive Skin to Enhance Daylighting and energy efficiency in Workspace

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Abstract

Global warming and climate change are bringing disasters to mankind according to all the recent studies. The office building sector is a great contributor to energy consumption and greenhouse gas emissions which makes it a crucial matter to consider energy efficiency related to the building sector. Considering energy efficiency in buildings and sustainability factors will result in significant energy reduction, environmental savings and greenhouse gas emissions reduction. The building envelope influences the building energy demand greatly, windows are important components of any building envelope contributing to daylighting mainly and thermal transfer partially.The research focuses on the office building design fascade with a pneumatic modular system as adaptive to enhance daylighting and energy consumption by putting guidelines to the designer to use this system well in the office building, the research focuses to analyse two case studies with three stages to achieve the effect of pneumatic modular fascade in the office building.

Keyword's pneumatic structure, adaptive façade, daylighting, energy saving, workspace.

1. Introduction

The pneumatic system in architecture was used in the early stage as a structural element to make portable inflatable homes or workspaces after natural disasters or any festival in the city. But nowadays the pneumatic modular system is used as an adaptive modular system to cover the outer façade to make a shade system in the inner space to enhance daylighting and energy efficiency, so the architect in the projects used to make double skin with double glass or triple and put dynamic louvres as a shading system tracking the environment and sun path but this system needs more efforts and complicated installation than the pneumatic façade that need only structure system and membrane sheets fill of air or gas to make the system run well.

pneumatic modular system envelope systems are tensile structures, based on the use of membrane skins, which are stabilized by the differential pressure between their

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inner and outer sides; to acquire enough stiffness to maintain an equilibrium position and to be able to support external loads.[1]

The paper *(PNEUMA-TECHNICS // METHODS FOR SOFT ADAPTIVE ENVIRONMENTS)* which publish at ACADIA 2015 | COMPUTATIONAL ECOLOGIES advance a developing typology of responsive systems: a breathing architecture that is sensitive to its changing environment. Pneuma-Technics is actuated breath in the building and they make a prototype to prove that pneumatic actuation effects in the adaptive facade, but they didn't mention the design or applying the pneumatic cushions as a shading tool instead of the traditional shading technics.

Also the paper *(Pneumatic skins in architecture. Sustainable trends in low positive pressure inflatable systems)* which publish at the 2011 International Conference on Green Buildings and Sustainable Cities focused on the review and critical analysis of the architectural low positive pressure inflatable systems, from the first patents to the most recent trends. So the paper didn't show the analysis project of the pneumatic fascade and the effect of the design on the daylighting factor.

Most of the research papers revolve around a superficial study of the pneumatic from point of view of the shape not in detail with the parameters of the effect in design and daylighting relation.

The paper *(The Adaptive Solar Facade: From concept to prototypes)* which publish at *(Frontiers of architectural research(2016) 5, 143–156*) focused on the study of Bipv using actuation of the pneumatic arm to track the sun path to collect solar energy and st the same time used as a shading device, so the pneumatic role in the actuating arm not affect in the adaptive façade directly and design pneumatic modular system.

There are many design stages in the field of architectural facades depending on the type of building, its function, working hours, as well as the direction of each of its facades, so the design is linked to the simulation stages to reach the optimal design appropriate for the interior workspace. Pneumatic modular system facades are one of the first solutions used to reduce direct natural lighting that causes glare and increases the rise in temperatures inside the space, so it is necessary to use them in the facades most exposed to the sun throughout the year and work on studying the pneumatic modular system in the destinations before implementation, as well as it consists of inflated cushions, including the two or three layers according to the amount of insulation required, and also the internal blowing of it is either by air or by any inert gas that helps reduce heat transfer This is what we will review by researching the way to link the design of pneumatic modular system facades and their impact on natural lighting and energy saving within the work environment. (Auther)

This research focuses on the relationship between three axes of study, first the design of the fascade with a pneumatic modular system, second the daylighting on the workspace reaches the allowable amount that comforts the user and third the energy consumption in the building which makes the efficient. This study will be supported by analytical examples and comparisons to reach the best results.

2. Research problem

Reducing energy consumption, reaching the optimum daylighting distribution by using traditional shading systems such as wood panel curtains or dynamic aluminium louvres or double glass with isolated gas didn't reach the optimum level of daylighting or energy consumption, on the other hand using pneumatic modular façade system with different membrane material could enhance the indoor daylighting in the workspace.

3. Research Aims

The study aims to analyse and define the types of using pneumatic modular system façade to make the relation between pneumatic system and comfort zone in the workspace by:

- Define the role of the pneumatic modular system in enhancing the daylight in the workspace
- Illustrating the case studies that show the different types of pneumatic modular façade systems and the suitable façade direction that can use it.
- Clarifying the different membrane material used in a pneumatic system and how it affects lighting distribution.
- Prove that a pneumatic facade has a vital role in promoting daylighting inner the workspace.
- Explore the technical usage of a pneumatic modular fascade instead of any shading system.
- Extract the parameters of the design stages using the pneumatic modular system.

4. Research Methodology

For attaining the research aims, the methodology was divided into two parts; ***First,*** investigate the pneumatic modular façade and the different types and techniques. ***Second,*** analyze several architectural projects that effectively optimize their environmental performance by using a pneumatic façade as a shading tool to enhance daylighting and avoid the glare inner the workspace. ***Finally*** compare with the case studies and ut out the guideline for using pneumatic façade in different cases and techniques.

4.1 Pneumatic envelope definitions

Pneumatic envelope systems are tensile structures, based on the use of membrane skins, which are stabilized by the differential pressure between their inner and outer sides; to acquire enough stiffness to maintain an equilibrium position and to be able to support external loads.

There are different typologies of pneumatic systems, and the most common classifications have been made according to their type of pressure and their morphological properties. The most developed systems are stabilized with positive pressure (air-supported and inflated), while negative pressure systems (vacuumatics) are still in the emerging research period.

According to their formal configuration; while air-supported systems are based on the use of unique membranes that surrounds the living space; inflatable systems are based on the use of closed structures made with a different number of layers and whose interior is pressurized and not accessible. Although the first ones experienced an important development in the sixties and seventies, the inflatable systems have been improved more in the last decade, allowing new sustainable strategies in climatic adaptive envelopes. [1]

As Ideas sketched out by Negroponte and Fisher in the 1970s have been experimented with in a contemporary context at Kas Oosterhuis' Hyperbody Research Group at Delft University. Projects such as E-motive House (2002), NSA Muscle (2003) and MuscleBody (2005) fuse the pneumatic ideas of the 1960s and 1970s with computer-controlled, interactive technologies that emerged in the 1990s. Oosterhuis draws parallels to Negroponte's Soft Architecture Machines when he characterizes the NSA Muscle project (Figure 1) as a 'paradigm of programming soft design machines.' Pointing to an architecture that not only uses the digital rhetoric of fluidity, adaptability and softness but embodies it. NSA Muscle consists of a soft, inflated envelope festooned in a series of artificial muscles that are computer-controlled and pneumatically activated. Oosterhuis notes that the project is a critique as well as a continuation of Ron Herron's 1964 Archigram project.

Figure 1 Kas Oosterhuis and Hyperbody Research Group. NSA Muscle. 2003.
The NSA Muscle prototype has been shown at the 2003 Non-Standard Architectures exhibition at the Centre Pompidou. The structure could change its shape based on sensor orchestration of individual muscle strands due to the proximity of visitors or be steered from a more traditional screen-based interface.

4.2 Pneumatics in architecture design stages

it was Frei Otto the first to undertake academic investigations, especially about the process of form finding. Through the IASS Pneumatic Colloquium (University of Stuttgart, 1967) and several publications and designs, Otto broadened the landscape, not only of pneumatics but of tension structures in general. Pneumatics were also part of the repertoire of Richard Buckminster Fuller. His proposal of a pneumatic dome to cover New York (1962) (Figure 2,3) is a famous example of Utopian pneumatic architecture. Realization of this project would require a radical environmental transformation, a sterilized enclosure without dust, pollution, exhaust gases and so.[2, p. 4]

Figure 2 Proposal of a pneumatic dome for New York City. B. Fuller, 1962.

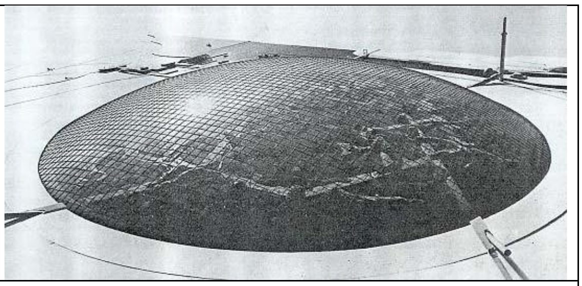


Figure 3 *The Artic City* of Frei Otto and Ewald Bubner, 1970. Plan, insufflating process and model.

This can be seen in early pneumatic architecture projects such as Oase No.7 (1972) by Haus-Rucker-Co in which "an inflatable structure emerged from the façade of an existing building creating a space for relaxation and play" (Figure 4). Other examples include the Fuji Group Pavilion (1970) designed by the architect Yutaka Murata, which consists of a series of air-inflated vinyl tubes attached to form a larger structure. The inflation of the membranes was achieved through a solution that "allowed a limited air exhaustion and kept a continual flow of air blown into the tubes at all times. This method maintained the air pressure at a constant level" (Figure 5).

Figure 4 Oase No.7, Hause-Rucker-Co, (Engelskirchen 1972)

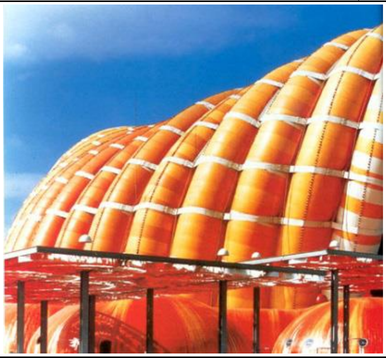


Figure 5 Fuji Group Pavilion, Yutaka Murata

In both examples, plastic and vinyl membranes are inflated to their maximum volume. The material was dependent upon a constant supply of air pressure to maintain its form and shape without collapsing. These projects demonstrate architectural solutions that are flexible and undergo transformations but are not reactive or adaptive.[3, p. 2]

In another example, a wall features individually motorized and sensor-equipped bricks that react independently to programmable environmental and use-related scenarios. Imagine the ensuing flux of continually adjusting patterns and adapting in real-time to anything from a shadow of a passing cloud outside to the presence of an occupant in need of privacy inside. In a Pneumatic Envelope, a system of inflatable pillows (Figure 6) embedded within a standard wall adjusts in real time the insulating capacity of the building envelope in reaction to environmental dynamics and response to user input. The possibility of modulating insulation vertically by differentiating between lower and higher sections of the wall would also aid in the circulation of the air within the room. [4, p. 325]

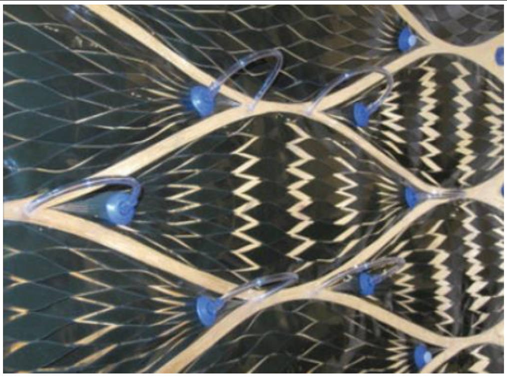


Figure 6 *Pneumatic Envelope*: each pillow inflates or deflates as necessary to provide local thermal comfort; a variation in insulation levels across the wall's vertical section allows for the generation of convective flows within a space, alleviating the problem of vertical heat entrapment.

4.3 Stages of pneumatic in design stages

First: The predesign stage for the elevation
1. Design the concept of the elevations. 2. Wall window ratio (wwr) in all elevations depended on the direction of any elevation. 3. The solid and void massing in the elevation affects the self-shading on the elevation.
After that study the daylighting in the workspace with only glass curtainwall
Second: The daylighting study method in the workspace
1. The code of daylighting which is used to measure the comfort of daylighting in the workspace 2. The simulation programme is used to measure the concept of openings that the light gets throw 3. The percentage of glare and distribution of the lighting inner the workspace 4. The process of lighting design or evaluation is: Measurements – Calculation – methods Metrics – Criteria – Rating systems 5. The work plan illuminance the workspace to be comfortable at300 – 500 lux 6. Provide the energy target in the workspace by selecting the static and dynamic matrix simulating the optimum amount of daylighting
Third: The pneumatic modular system on the fascade as a double adaptive skin
1. Distribution of cushions on the critical elevation with the lowest environmental conditions (high daylighting radiation on the south and south-west elevation – high temperature on the outer skin – more glare on the work plan) 2. Choose the right fabric membrane such as ETFE with layers filled with air or any gas 3. Simulate the pneumatic elevation point in time and annually to choose the ideal case for providing the best daylight inner the workspace.
Table 1 This table adopted by the researcher

4.4 Types of pneumatic architecture

The pneumatic modular system is divided into two types;

4.4.1 High-profile and Low-profile designs

High-profile and low-profile designs are the two primary forms of air-supported structures, which refer to the height relative to the span. Low-profile designs span long distances, but high-profile designs incorporate air into more than just the roof structure.

Some commonly used fabrics used in pneumatic membranes are polyvinyl chloride coated (PVC) polyester fibres, Polytetrafluoroethylene (PTFE or Teflon) coated fibreglass or silicon coated fibreglass. These membranes are translucent but by no means transparent. On the other hand, Ethylene tetrafluoroethylene (ETFE or Tefzel) foils, nowadays commonly used as air cushions for facades and roofs in architecture, have very high transparency. [5]

Air supported	
Inflated with low positive pressure	200-300 Pa
Inflated with high positive pressure	Until 100.000 Pa

Table 2 Most common positive pressure pneumatic systems in architecture (pressure values in normal conditions) source:[6]

4.4.2 Pneumatic Actuation “modular façade with ETFE cushions”

The modular pneumatic facade is a branch from the kinetic architecture facade in the 21st century, it can be the main facade or double facade that is adapted to the building with the environment such as wind, sunbath, acoustics, pollution etc. (Auther)

The Media-TIC building in Barcelona, designed by Enric Ruiz-Geli of Cloud 9 and completed in 2011, features a dynamic façade made of lightweight ETFE air cushions that provide pneumatic sun shading (Figure 7).

Figure 7 the media-tic office building 2011 in Barcelona, by cloud9, features a dynamic facade made of “breathing” ETFE air cushions (source:[4])

The cushions consist of three layers of plastic with two air chambers between them that can be inflated or deflated as needed; the first layer is transparent; the second and third layers have a reverse pattern that creates shade when inflated and joined together (Figure 8). [4, p. 122]

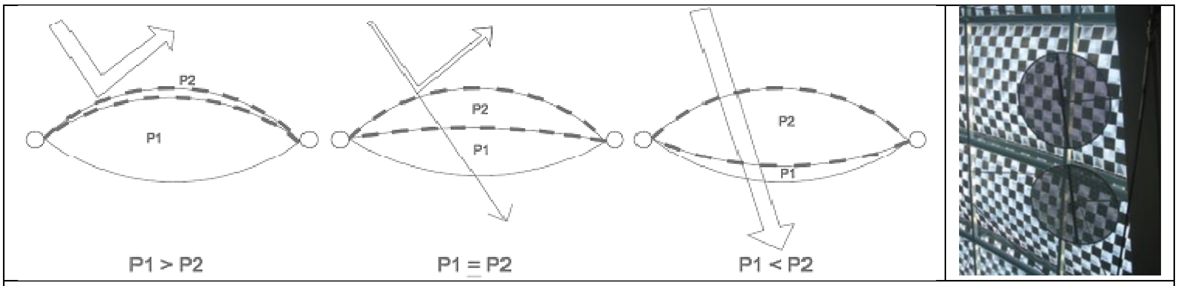


Figure 8 (a) active shading strategies. **-** (b) active shading inflatable envelope with 3 layers of plastic.

On the west side of the building, the ETFE air cushions are filled with nitrogen (mixed with tiny oil droplets) in the afternoon, transforming a transparent into a translucent façade that blocks 90 per cent of the sun's radiation, thus reducing substantially the building's heat gain. In addition, the building features many other control systems (based on over a hundred networked Arduino5 boards) that can sense various changes in the environment and then produce a corresponding reaction not only in shading but also in how the building is lit, etc. [4, p. 122]

ETFE cushions were previously used in the Eden Project, designed by Nicholas Grimshaw and completed in 2003 (Figure 10), and in the National Aquatics Center (the "Watercube") in Beijing, designed by PTW Architects from Sydney in collaboration with Arup, and completed in 2008 (Figure 14) for the Summer Olympic Games.

Figure 9 ETFE cushions used in the Eden Project

Figure 10 National Aquatics Center (the "Watercube")

ETFE is an incredibly lightweight, inexpensive and thermally effective building enclosure that weighs about 1 per cent of glass within the same area. Typically, the sheets of ETFE are precisely cut using CNC cutters, heat welded along the edges, and then inflated to create "cushions." The cushions need to be inflated continuously by air pumps, which consume energy and may require periodic maintenance. The cushions also require a separate support structure, which was given a honeycomb pattern on both Grimshaw's and Enric Geli's buildings; the Watercube in Beijing features hexagons and pentagons. ETFE is finding increasing use in all types of buildings, from school courtyards to football stadiums (such as Bayern's stadium in Munich, designed by Herzog and de Meuron). [4, p. 122]

4.5 Properties of Pneumatic Modular System

Table 3 shows the properties of the pneumatic modular system source: [7, p. 3]	
Lightweight	- The weight of the structure as compared to the area it covers is very less. - The weight of the membrane roof, even when it is stiffened by cables, is very small. - Low air pressure is sufficient to balance it. - Even with spans of more than 100 meters, the weight of the structure does not exceed 3kg/square meter.
Span	- For pneumatic membranes, there is no theoretical maximum span as determined by strength, elasticity, specific weight or any other property. - It is hardly possible to span a distance of over 36km. Steel cables would fail because of their inability to sustain their weight. But with pneumatics, such spans are quite possible.
Safety	- Pneumatic structures are safer than any other structure. Otherwise, proper care should be taken while establishing. - Accidental circumstances are avoided as they are very light. - Pneumatic structures cannot be destroyed by fire quickly and totally.
Quick erection and dismantling	- Suitable for temporary constructions because they are as easy to dismantle and establish. - 1 sq. km. of an area can be brought down in 6 hours and erected in less than 10 hours. The 4 hours difference is due to the establishment of pegs etc.
Economy	- First costs for a pneumatic structure always have compared favourably with those of conventional roof structures. On a cost-per-seat basis, the advantage is even more evident. The savings come from lower construction and supporting structure costs plus the overall economy of design. Architecturally, the design is very elegant and dramatic.
Good natural light	- Gives good natural light as translucent/transparent plastic sheets are used to cover airbags. We can even bring the whole sun inside. There is a lot of flexibility in getting sunlight (50%-80%).

4.6 ETFE materials for the pneumatic modular system as a shading system and the relation between daylighting and energy efficiency

According to its numerous remarkable properties, ETFE foils offer a valid alternative to glazing in building envelopes. The reduced self-weight is the most appreciated feature of ETFE structures. In comparison to equivalent glazing, pneumatic cushions achieve a comparable level of performance with less than 1% of the weight. This reduces the amount of secondary structure required to support the building envelope with consequent benefits on the primary structure and the foundations allowing unsupported spans up to 10m.

Furthermore, the high level of translucency over a wide spectrum represents the second main aspect which justifies the expectations placed in ETFE. The optical properties of ETFE foils are subjected to high variability from one producer to another due to the raw material used, the production process, the material colour and thickness. In addition, the optical behaviour in the UV spectral range, with a light transmission of around 70%, represents a significant benefit for a structure such as solaria, swimming pools and greenhouses where the natural bactericidal and fungicidal properties of UV light reduce the demand of chemical treatments.

The risk of an inadequate internal environment, due to incorrect solar control, can be addressed by using different printing patterns which reduce the danger of glare and overheating.[8]

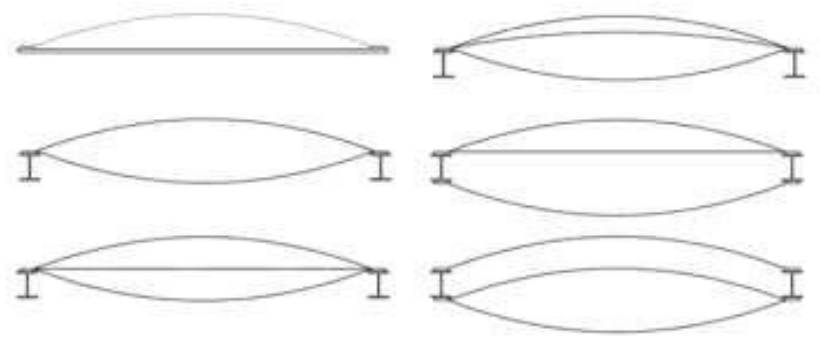


Figure 11 Common formation of ETFE layers in a foil cushion

Although the material ETFE does not offer exceptional thermal insulating properties, the use of multilayer solutions allows the achievement of considerable values of thermal insulation, comparable with those obtained using glazed envelopes, reducing overheating, internal condensation and the energy required for air conditioning, both during summer and winter. The environmental impacts of building systems based on ETFE foils represent one of the main interesting aspects in the comparison between different covering systems based on ETFE foils, PES/PVC and PVC Crystal foils, Polycarbonate panels and double glazing. Despite the absence of comprehensive studies in this field, recent research showed the potential LCA performance of lightweight envelopes which is mainly related to the overall covering system rather than the embodied energy of the raw material, expressed in GJ per ton of material. However, side effects due to the resource consumption/savings in use, such as the pressuring system, the artificial light or the use of detergents and water, play a crucial role.[9]

The load-bearing capacity of ETFE foils can be achieved through two different approaches, tensioned double-curved surfaces and pneumatic cushions. Although the increasing interest in single-layer envelopes, mainly due to the reduced maintenance costs, pneumatic cushions are the more common envelopes, especially for applications which require higher levels of thermal insulation or sun shading. The performance of the envelope can be improved by increasing the number of layers and internal chambers and combining the reflectance properties of different frit patterns printed on the layers which can be moved by changing the air pressure of the chambers. This solution becomes unavoidable for applications in the Mediterranean area where printed ETFE foils are necessary to reduce sun irradiation and air-conditioning loads. The high percentage of area covered with frit patterns, which increases with the amount of solar energy which has to be reflected, opens interesting prospects of applying flexible photovoltaic cells instead of reflecting patterns.[9]
In 2000 Festo Technology developed an interesting solution to control the daylight conditions in an architectural space enclosed by an ETFE cushion system. As shown in (Figure 12,13), a variable skin has been created by printing overlapping gestalt graphics on multiple layers, integrating the cushions with sophisticated pneumatics, and finally by moving the different graphics together and apart from each other.
Two main production techniques obtain flat and blown ETFE foils: the blown film extrusion, in which the melted mass comes out of the extruder and is formed by a ring die into a tube which is expanded by blowing in the air. And flat extrusion is in which the film in a roll form comes flat from the extrusion. The extruded product, passing between rollers, is a 0,05-0,3mm thick and 150-220cm wide film. Then it is ready to be rolled up into cardboard tubes for storage and transportation to the cushion fabricators. This part of the process, the lamination, is carried out using techniques with several aspects in common.[9]

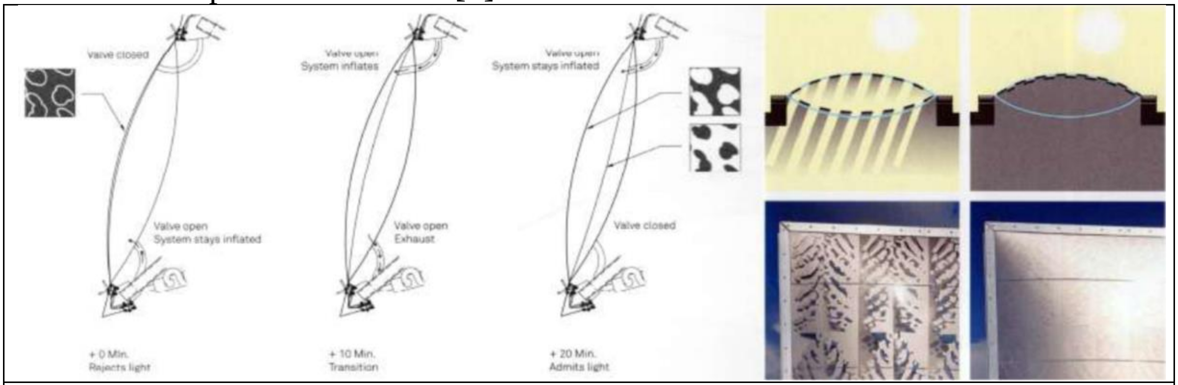


Figure 12, Figure 13 Membrane cushion movements, Atelier Brückner& Festo Technology, Cyclebowl, 2000, Hannover

A variety of different environmental control strategies have been developed for multilayer ETFE constructions (Figure 14). But very few systems have been tested so far in commercial buildings. (Figure 15) show the mechanism of etfe printed sheets works as a shading device on the commercial building.

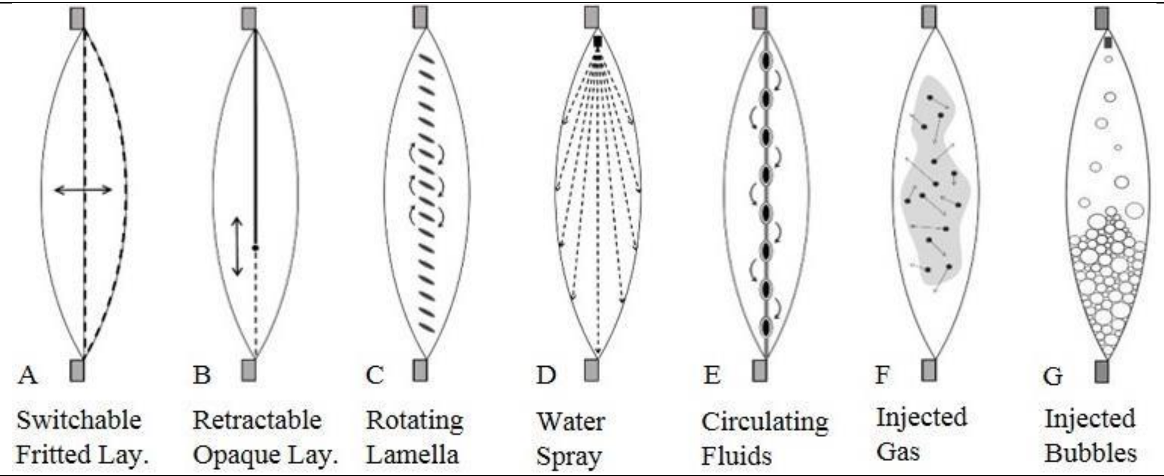


Figure 14 Environmental control mechanisms for multilayer ETFE constructions Source:[10]

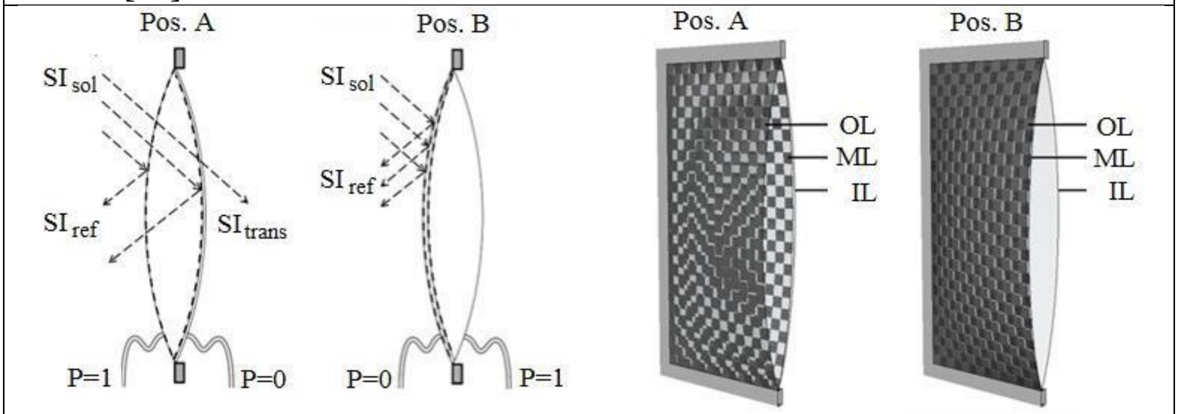


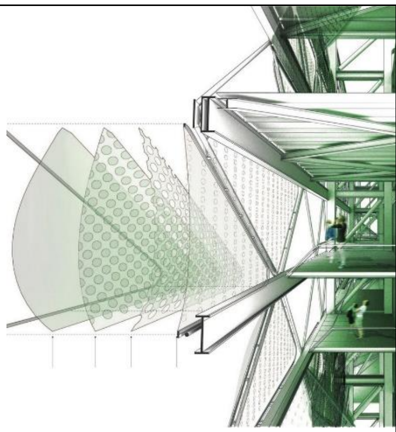
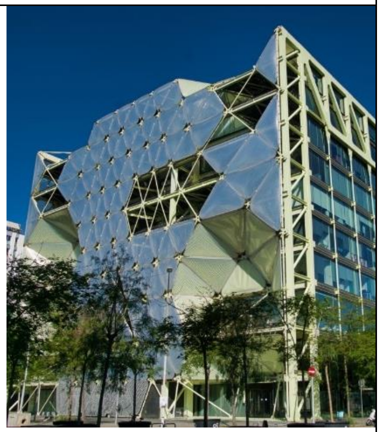
Figure 15 Dynamic triple-layer shading mechanism for pneumatic foil constructions, functional diagram and rendering of the section in perspective view. Source:[10]

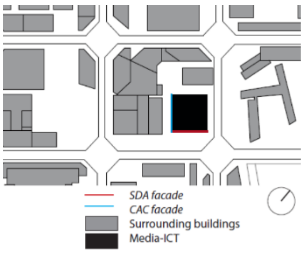
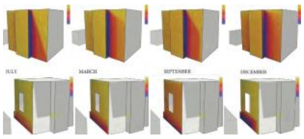
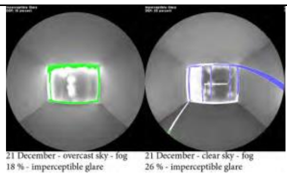
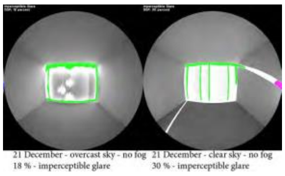
5. Case studies using a pneumatic modular system and the criteria of enhancing daylighting and energy efficiency using some techniques

Some tools of the parametric modular system and the relation between the design stage and daylighting will affect a measure of the applied case study and will discuss in chosen case studies (Author):

The type of pneumatic modular system.
The type of pneumatic modular system.
The type of fabric material.
The position of the shading device of fabric material used in the building (façade, skylight, roof).
The climate of the urban context.

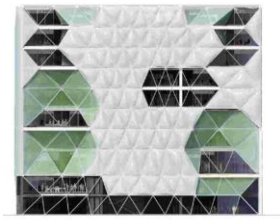
The direction of the pneumatic shading device on the façade (north, south, east, west).
The time frame will measure in between adaptive along the day, month and year.
The sun radiation study.
The glare studies.
Room geometry.
The temperature of the room and the effect of the material which it uses.
The type of gas in the cushions.
The no. layer of the fabric material is a shading device.
The no. layer of the glazing material if it uses inner the space.
The shape of the modular cushions on the façade.
The state of cushions (active – semi-active-passive).
The type of sensor that moderates the pneumatic cushions system on the façade.
The layers of the pneumatic skin (fabric material only for whole the skin or glazed layer indoor and fabric material outdoor).
The energy efficiency affected elements (lighting-cooling-pump and auxiliary-fans-heating).
The colour of the fabric material.
The type of building and the relation between the design of modular pneumatic façade and the size of cushions along the outer façade.

<table>
<tr><th colspan="2">Tools of the parametric modular system and the relation between the design stage and daylighting</th><th>Media-ICT</th></tr>
<tr><td rowspan="2">Info</td><td colspan="2">The MEDIA-TIC building, promoted by the Consorci de la Zona Franca and the company 22@Barcelona, is located in the 22@Barcelona district at the intersection of Carrer Roc Boronat and Carrer Sancho de Ávila, near the Parc Barcelona Media.
The Media-ICT is an element of 40x40x40 meters, “not a cube but a byte of information” (Albiñana, Marta et al. nd). The architects studied the programme needed and they entered the data in Excel, which created this efficient parametric architecture building by using a pneumatic fascade as a shading device and controlling the interior temperature achieving the comfort zone area.</td></tr>
<tr><td colspan="2">  </td></tr>
<tr><td>First: The predesign stage for the elevation</td><td>1- The designer makes the concept of the elevation as a breathing modular unit, solid and void double skin in the Southeast façade and one sheet in the Southwest façade that because of the organic shape make different opportunities for more self-shading.
2- Wall window ratio the designer depends on the parametric generative according to the sun path
3- The solid and void on the two elevations are different; one on the direct sun radiation is more solid and void than the other to make more efficacy in daylighting and maximize the temperature resistance.</td><td></td></tr>
</table>

Second: The daylighting study method in the workspace	1- The designer used the iesna code for daylighting standards and make the orientation of the building adapted to study the two elevations SDA, and CAC fascade. 2- They used the grasshopper programme ladybug plugin to simulate the building to choose the specific type of pneumatic fascade 3- The study begins with a solar radiation analysis of the facades, which confirms the need for sun shading systems in both the Southeast and Southwest facades, which receive between 800 and 2000 [Wh] in the winter and around 6000 [Wh] in the summer, while the other two facades perform well only with the glass walls.	 
	4- There is a glare study in the indoor environments created by these two facades that are comfortable for the individuals that use the structures. The findings suggest that the glaring percentage on the CAC facade ranges between about 20% and 30% in the winter and between 25% and 30% in the summer, which is imperceptible to the naked eye. In addition, the proportion on the SDA facade varies between 20% and 30% in the winter and 25% to 30% in the summer. 5- The energy efficiency simulation before putting the pneumatic modular system shows the high use of artificial light in the workspace instead of daylight.	 
Third: The pneumatic modular system on the fascade as a double	1- The design proposal for the southwest and southeast are the two that have higher sunlight exposure and want to convert them into adaptive skin by using a parametric pneumatic ETFE membrane for reducing the temperature and avoiding glare in the workspace. 2- The Southwest facade receives 6 hours of solar light each day, thus it filters it through a screen of vertical cushioned panels (2 ETFE layers) holding nitrogen and oil, which combine to form a 'cloud' sunscreen. It takes the density of the air and increases it in the interior packed with nitrogen, lowering the solar factor from 0.45 to 0.10. (four times smaller). This facade has an on/off switch, so it may be filled with fog or not.	 

3- There are 4 types of cushions on the Southeast facade:

- Type A: three-layer cushions with pneumatic sun shading, allowing to adjust of solar transmittance to either 65 or 45%.
- Type B: two-layer cushions. Exterior layer print of silver circles, interior layer green-tinted ETFE foil, Solar transmittance approx.55%.
- Type C: Exterior layer transparent, interior layer green-tinted ETFE foil, Solar transmittance approx. 65 %.
- Type D: two-layer cushions. The exterior layer is transparent, the interior layer is printed with negative silver circles, and Solar transmittance is approx. 50%.



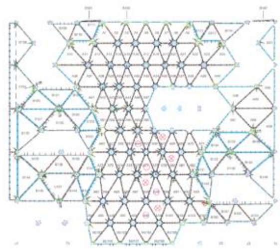
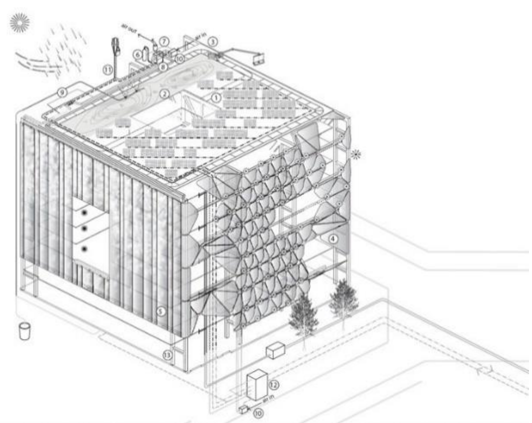
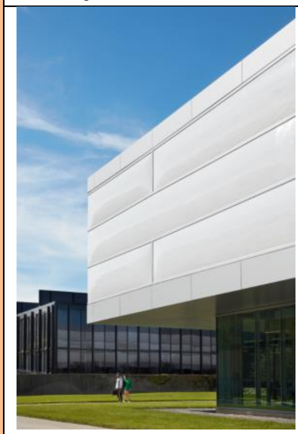
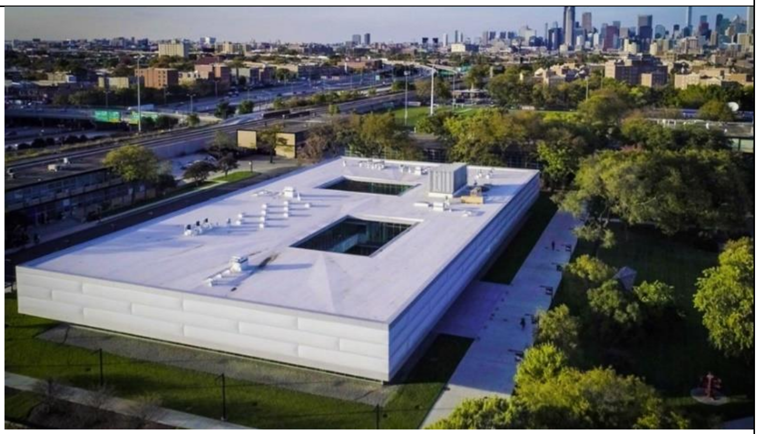
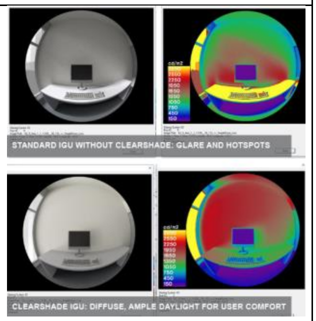
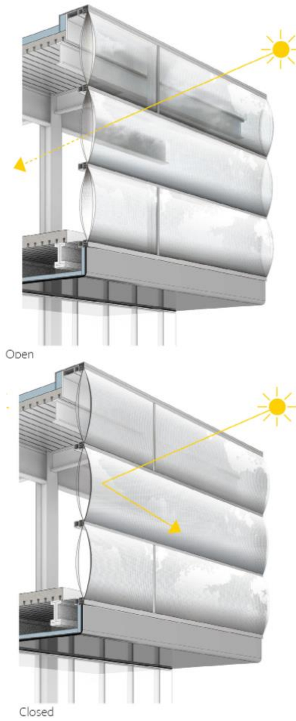


Table 4 analyse the three stages of how we can put the pneumatic modular system in the elevations after the simulation of the building in two cases after and before applying ETFE material and the size of the cushions.source: (Author)

Figure 16 show the study of direct heating and cooling, ETFE fascades and the positions of the sensors for all the building**.**
Source:[11]

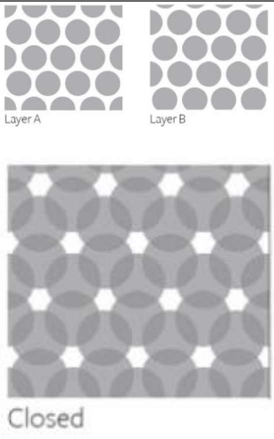


<table>
<tr><th colspan="2">Tools of the parametric modular system and the relation between the design stage and daylighting</th><th>Ed Kaplan Family Institute for Innovation and Tech Entrepreneurship(on the campus of the Illinois Institute of Technology (IIT))</th></tr>
<tr><td rowspan="2">Info</td><td colspan="2">Chicago Illinois The Ed Kaplan Family Institute for Innovation and Tech Entrepreneurship at the Illinois Institute of Technology is dedicated to stimulating cooperation, innovation, and entrepreneurship among IIT students, faculty, alumni, and partners. The structure is organised around two open-air courtyards via which guests enter; circulation inside the building is indirect and dispersed, facilitating collaboration and contact. The structure provides versatile space that may be quickly altered to suit a variety of needs. [12]</td></tr>
<tr><td></td><td></td></tr>
<tr><td>First: The predesign stage for the elevation</td><td>1- The designer makes the concept of the elevation in the campus as the four elevations covered with curtain wall glass to make an open view to the garden but it's the problem that the glare and exposure are more than usual.
2- Wall window ratio the designer makes the curtain wall glazing cover all the elevation to make an open view of the campus.
3- The solid and void on all elevations are the same, no solid just all void and open view to the garden. this technique makes more daylighting but high glare and temperature inner the space.</td><td></td></tr>
</table>

Second: The daylighting study method in the workspace	1- The designer used the iesna code for daylighting standards and make the orientation of the building adapted to the study of the building in the urban context. 2- They used the grasshopper programme ladybug plugin to simulate the building to choose the specific type of pneumatic fascade 3- The study begins with a solar radiation analysis of the facades, which confirms the need for sun shading systems in all facades, which receive between 1000 and 1500 [Wh] in the winter and around 5000 [Wh] in the summer.	
	4- There is a glare study in the indoor environments created by south and east facades that are comfortable for the individuals that use the structures. The findings suggest that the glaring percentage on the south facade ranges between about 18% and 25% in the winter and between 26% and 30% in the summer, which is imperceptible to the naked eye. In addition, the proportion on the east facade varies between 18% and 28% in the winter and 24% to 29% in the summer.	
Third: The pneumatic modular system on the fascade as a double adaptive skin	1- The façade is made up of four layers of ETFE foil that combine to form three air chambers within the façade assembly. The two outside layers of ETFE are fritted with staggered dot patterns offset from one another; the inner layer may be pneumatically pushed back and forth, bringing it together and apart from the outer fritted layer to control the quantity of incoming solar energy. This movement is accomplished by admitting air into one chamber and removing it from the adjacent chamber, causing the fritted inner layer to be relocated. 2- The dot patterns overlap when the inner layer is pressed against the fritted outer layer, reducing light transmission. When the inner layer is shifted away from the outer layer, light transmittance increases. The dynamic façade, which may be controlled by automated building system controls or overridden manually, can adapt throughout the day to changing weather and sunshine conditions in real-time to decrease energy usage and increase daylighting potential.	

	Closed position			Open position		
	UV	Visible light	Solar light	UV	Visible light	Solar light
Transmission	0.08	0.24	0.26	0.10	0.27	0.28
Reflectance	0.21	0.49	0.43	0.16	0.46	0.41
absorption	0.70	0.27	0.31	0.74	0.26	0.31
Shading coefficient		0.34			0.47	
G-value=SHGC		0.30			0.41	
SHGC range					0.13	

Table 5 show the comparison between the closed&open pneumatic ETFE shade with the factor of UV, visible light, solar light.
Source:[12]



3- To heat and cool the building, a "radiant deck" system is used: water-filled tubing inserted in a concrete-filled metal deck floor structure converts the metal decking into a radiant heating and cooling surface. As a result, the building structure serves as both a heating and cooling system. This radiant deck system "talks" to the dynamic façade via a Building Automation System, and the two work together like an organism to save energy and control the amount of heating and cooling required in real-time based on weather (via a weather station positioned on the building's roof). This radiant deck heating and cooling system are more comfortable and healthier than typical forced air systems.

Table 6 analyse the three stages of how we can put the pneumatic modular system in the elevations after the simulation of the building in two cases after and before applying ETFE material and the size of the cushions.source: (Author)

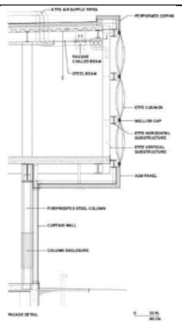


Figure 17 shows the details of the ETFE fascade and how to construct it.
Source:[13]

6. Results and discussion

The analyse of the two case studies used three stages before applying the pneumatic modular system to make a more accurate decision of where the adaptive fascade was put on and the material used. The design first stage is the important one which is the main point the designer makes the opening and wwr adapting to the usage of the building after that study of the sun path make the opportunity to select the types of shading devices that enhance the daylighting and thermal resistance on the space, then the pneumatic system with different types Switchable fritted Layer (Retractable Opaque Layer - Rotating Lamella - water spray - circulating fluids - Injected Gas - injected bubbles) the designer after simulation choose the specific on to apply on the fascade and make comparisons between the case after and before the pneumatic fascade

By applying two case studies shown (fascade design – daylighting simulation – pneumatic modular system – energy efficacy) the result is :

- The solid and void on the fascade is more efficient to make self-shading and ease in reducing the direct daylighting making the glare inner the space.
- The optimum daylighting used in the workspace average from 300-500 lux so the high cause more glare for the users.
- The material ETFE used in the pneumatic modular system contains at least two or three layers with a dotted pattern to make on and off the system when it pillow with air or other gas.
- The daylighting in the inner workspace after applying the pneumatic system raise from 25% to 45% because ETFE makes the description of the light to the deepest point of the space.
- The temperature in the inner workspace after applying the pneumatic system deduce from 75% to 55%.
- The energy efficiency of the pneumatic system saves artificial light by more than 60% and this is because the adaptive pneumatic system controlled the daylighting and temperature inner the space.

7. Conclusion

Accordingly, from the theoretical and analytical study of applying the pneumatic modular system on the office building facade, some points were concluded followed by some recommendations.

The present analyses study determined the effect of the three stages on the fascade design, results have shown that;

1- The three stages (elevation design – daylighting simulation – pneumatic and its energy efficiency effect) are used effectively for enhancing the daylighting inner the workspace and reducing energy consumption in the building.
2- Both the types and materials of the pneumatic system affect the efficiency result and obtaining the building study.
3- The pneumatic system makes the fascade adaptable by sensors on the outer screen and this allows the building to contact the environment.

4- Parametric design has great potential to generate different opportunities for solutions in the fascade to reach the optimum design enhancing daylighting and reducing energy consumption.

8. Recommendations and future work

1- Future studies in this field explore the role of the pneumatic system in integrating the interior design solution with the best exterior case.
2- Studying more stages that affect the pneumatic system
3- Make more tests in a different material than ETFE and compare with us.
4- Architecture students must apply the pneumatic modular system in their advanced environmental projects to raise their ability in the new system and have a great role in increasing their creativity, abilities, and skills.

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