Integration of Active and Passive Systems in Glass Façades

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ABSTRACT: In this paper, we explore an integrated approach blending active, mechanical systems in whole, comprehensive façade systems. To do so, we draw a state of the art of these technologies and analyze their performance in several cases of study built in Germany the last years. We conclude outlining the key elements an integrated façade should consider, emphasizing the complementation with passive systems and the architectural consequences and requirements of such a trend.

Keywords: integration, passive systems, mechanical systems, glass façades

1. INTRODUCTION

Two main approaches can be recognized regarding architecture and energy. On the one hand a mechanical, energy intensive approach based on building services, here called “active”: complex networks of heating, ventilation and air conditioning that supply comfort conditions in spite of variable weather conditions. These are internal ducting and piping, seldom visible, supporting the building operation “from the inside”. On the other hand passive, low-energy strategies claim for an architecture that is climate-responsive and environmentally responsible. This approach is mostly based on a careful adaptation of the building envelope, mediator between inside controlled comfort conditions and outside weather variations.

However, these seemingly irreconcilable positions and practices have been showing signs of coming to terms with each other. In a number of recent designs, particularly in Germany, the choice has been made for a compromise that brings together in a new blend these traditionally opposed strategies, with surprising results. Façades are increasingly integrating not only sophisticated sun protection and other passive devices, but also active systems, such as electric wiring and light, decentralized HVAC, PV’s, etc.

Integrating active building systems to the façades offer a number of potential advantages, such as sparing space in ducts and big central units, allowing discreptional decision making closer to user needs, and simplifying the system by using smaller, standardized machines are also promoted by the producers. As a result, façades are increasingly being reconsidered by designers as potentially integrating active systems. These emerging alternatives gain relevance both in research and practice, and challenge designers to further develop the role of façades in the environmental performance of the buildings.

2. INNOVATION TOWARDS SYSTEM INTEGRATION IN FAÇADES

Glazed façade designs have undergone in the last decades substantial innovation by integrating specific elements to adapt the mediation of the outside conditions and user requirements, both in the quality of materials and components and in the overall conception and design of the façade system. These improvements include passive measures, such as multi layered glazing, sun
protections, ventilations, etc. and are articulated in as double-layered façades, ventilated façades or protected façades. The literature has come to a number of definitions for these, among which, a comprehensive one was proposed already in 1999 by Compagno [1], naming them “intelligent glass façades”. However an area undergoing dynamic innovation, a number of earlier, less sophisticated systems still hold valid, when considered from the perspective of their current use in the construction market worldwide.

Curtain walls were first understood in environmental terms as “an environmental filter, a membrane mediating between desired interior conditions and variable exterior circumstances” [2] in the 1950s. This definition, including the environmental performance, is hardly representative of mainstream, energy supported glazed architecture, prevailing all over the world since then and hardly conceived or designed as an “environmental membrane”.

Starting the 1990s, a new generation of glazed facades can be identified that do undertake the mediation of climate conditions and comfort requirements, many of them still under development and study.

The most usual definitions include:

Double Façades (DF), which are façades adding a second layer to the façade, usually glass, in order to improve some of the properties of the façade, most notably, noise reduction.

Double Skin Façades (DSF), consist of an exterior and interior glazing, with varying insulation, ventilation and access strategies [3].

Integrated Responsive Façades (IRF) are defined by Wigginton [4] by recognizing characteristics and features present in a number of examples, such as responsive artificial lighting; daylight and sun control; occupant control; ventilation, heating and temperature controllers; electricity generators; and the double skin among others, and emphasizing control and management strategies.

Advanced Integrated Façades (AIF) include –usually in addition to DSFs- functions such as heating, cooling, ventilation, and also light-directing, shading, integration of artificial lighting and even energy generation with solar panels [5].

3. DEVELOPMENT TRENDS

Critical issues can be identified in the current literature for the further development of glazed façades and the improvement of their environmental performance. We underline here those more relevant, and include both the technological development of the facades and innovation in the design and the production process, which grows in importance as integration strategies develop:

3.1 Material technology research

Including the performance of glass, as in the late development of reflective, low-e, absorbent, etc. has had a relevant development in the last years, and it is likely to have an impact and further development as improved materials and construction systems become widespread. The trend towards nano-technologies is likely to continue innovating in construction materials and glass in particular.

3.2 Development of design and simulation software

To date, a strong development of Software has taken place, in areas such as environmental impact analysis, cost analysis, environmental simulation, and user behaviour simulation, which has led to a substantial development in the study and design of facades and their energy performance. However, there is still a need for developing software linking the simulation and the design process [6].
3.3 Implementation of operation control systems
Building automation systems will increasingly improve the façade and overall energy performance of the building by including improved and more affordable sensors, retrieving and conveying relevant climate and indoor conditions data; processing units modelling and defining the best measures to be taken by the system; and actuators performing in quick-response changes in the settings of the façade [7].

3.4 Hybrid ventilation.
Hybrid ventilation combines features of both mechanical and natural ventilation. The latest definition of hybrid ventilation system was developed in EC projects in IEA Annex 35 (1999) hybrid ventilation system is defined as two-mode system that switching automatically from one mode to another in different time of the day, season or a year provides necessary indoor air quality in an energy-efficient way [8].

3.5 Integrated Building Concepts
The development of Responsive Building Elements, including Intelligent or Responsive Façades, Thermal Mass, Earth Coupling, Dynamic Insulation Walls and Phase Changing Materials, is proposed by the Annex 44 Group as an area of innovation leading to substantial change in building design from individual systems to integrated building concepts, allowing for best use of natural energy strategies as well as for the integration of renewable energies, including the research on the potential of technologies that promote the integration of active building elements and communication among building services [9].

3.6 Integration by Design
These trends suggest there is a broad range of alternatives for development ahead for façades to integrate both passive and active strategies for the mediation of climate and comfort conditions.

In the design of a building, the scattered decision making and contracting processes promote specialization and the separation of responsibilities, which is particularly critical in early stages. In order to cope with the increasing technical complexity and the growing interrelationship of the building components, it will be necessary to develop a substantial optimization and coordination of design specialists, focusing on the early incorporation of energy criteria. This underlines the relevance of an integrated design considering criteria for envelope integration at an early stage, that of the architectural design. This places architects in a critical situation for enabling and promoting such integration.

In the following, we identify and discuss AIF parameters relevant in the architectural design of façades, in order to outline early criteria promoting the successful integration and performance of the system and the architectural consequences and requirements of such a trend.

4. PASSIVE SYSTEMS INTEGRATION
Double façades with buffer spaces significantly improve the thermal insulation capacities of the glazed solutions. In the compared analysis of the U Values for several cases studied, it ranges between 1.42 W/m² K and 1.68 W/m² K. All of the cases studied used double and triple glazing systems, or a combination of double glazed façade and buffer chamber. In a reference analysis, the U-value jumps to 2.79 W/m² K, due to the combination of a façade completely covered with glass, and a double glazing solution without any buffer space.

4.1 Multiple layer envelopes and buffer spaces
The literature reports U-values of 1.2 W/m² K for the GSW Building in Berlin (Wigginton und Harris 2002, 51), and 1.0 to 1.2 W/m² K for the Stadttor in Düsseldorf, a double skin façade with mechanically
operated louvers [4]. Lower U-Values can be obtained by using high-quality profiles and glazing systems, reaching U-Values of up to 0.85 W/m² K. Still better values can be obtained with the use of one uses additionally high-quality multi-layered insulation glass, with U-Values of up to 0.7 W/m² K [1].

4.2 Light-shelves

Daylight systems can improve the performance of the day lighting significantly, but also the quality and the distribution of the natural light. The Photonics Centre in Berlin-Adlershof performs a quite good average Daylight factor of 13 to 14%. This is due to completely glazed façades that allow light to pour into the rooms. However, the distribution of the light inside the room tends not to be particularly good, but rather unevenly distributed, as it is usually the case in glazed façades.

![Figure 1: Lightshelves unfold on the façade. ZVK Verwaltungsgebäude in Wiesbaden, Arch. T. Herzog. Image: Herzog u. Partner](image)

In contrast, the also good in average Daylight Factor of ZVK Verwaltungsgebäude in Wiesbaden, 16,63%, is much more evenly distributed. This improved performance is obtained by dedicated light shelves, an adjustable system of sun protection with diffuse light passage, which reflect the incident light outside the building and conduct it also to the deeper areas of the room. Different types of steering light elements can be used, beyond light shelves, depending upon geographical adjustment, climatic region, day and yearly time.

4.3 Ventilated Double Skin Facades

One very representative case of DSFs is the GSW Headquarters, in Berlin, (Archs. Sauerbruch and Hutton). The building, completed in 1999, has been of big influence in the architecture milieu, because of its very strong and plastic image, and is one of the main responsible for the spread of DSFs among Architects.

The natural ventilation strategy is a central component of the energy strategy. Because of the low floor-to-floor height, predefined to 3.25 m by an existing tower, the thickness of the new building was limited for purposes of natural lighting, reaching 11 m in the deepest section. This narrow plan allowed cross ventilation, which was expected to allow reductions of 27°C indoors with 32°C outside, without refrigeration, using a “peak looping” system [4].

![Figure 2: Daylight Distribution Model. ZVK Verwaltungsgebäude, Wiesbaden. Arch. Thomas Herzog.](image)

The buoyancy in the chamber cross ventilates in complement with louvered operable elements in the east façade, and
with plenum floor and mechanical ventilation for extreme season situations.

**Figure 3:** Double Glass facade exterior view. GSW Headquarters, Berlin. Archs. Suerbruch and Hutton.

The system is centrally controlled with override allowance by the users. The natural ventilation DSFs in summer conditions and the insulating buffer in winter conditions are the main, alternating features that have turned them very used by architects.

However, it is not yet clearly defined if and how does the systems works in the summer, and further study is required to establish this for this and other DSF buildings.

### 5. ACTIVE SYSTEMS INTEGRATION

Advanced Integrated Facades are at an early stage of development, with partial integration of specific systems being tested in laboratories for the most part, and seldom in buildings. In many cases, AIFs are seen as a natural development of DSFs, but they are substantially different, as they are based -at least in principle- in opposing approaches towards energy systems: while DSFs focus on passive energy systems, AIFs focus on the integration of passive strategies and mechanical building services.

The challenge of developing effective Integrated Façades means dealing with a very complex array of existing and developing technologies, involves a number of sophisticated specialties and specialists, while the scope of the task is likely to grow and eventually integrate the whole building.

#### 5.1 Decentralized Heating, Cooling and Mech. Ventilation

In the Post Bank Tower (Architects Murphy and Jahn) the air is tempered in the DSF cavity in the winter, or ventilated by buoyancy during the summer. Movable panes allow for additional air admission in the chamber, which is then more porous than typical DSFs, enhancing ventilation of the chamber.

**Figure 4:** Double Glass facade and ventilation inlets. Post Bank, Bonn. Archs. Murphy and Jahn. Image: www.trox.de

The building can be naturally ventilated mainly in Spring and Autumn, and the mechanical system operates primarily in extreme conditions of summer and winter. After being tempered in the intermediate buffer, the air is drawn into the decentralized air supply units (FSL, Fassaden System Lüftung, provided by Trox) are placed below floor level, taking air from the double façade chamber and injecting it into the work spaces. The exhaust air is conducted to the nine storey high “Sky gardens” where it is used for heating, and then exhausted centrally. In addition to ventilation, the decentralized units also regulate the temperature of the intake air.

Research conducted in generic mock-ups by the producer indicates that the cooling
loads and overall energy demand are roughly comparable to those of a central HVAC system. Advantages that continue to be mentioned are: lower energy requirements for distribution of the conditioned air mass; lower construction costs and simpler implementation and maintenance; individual control of the temperature and ventilation rates.

Figure 5: Detail of ventilation equipment. Post Bank, Bonn. Image: www.trox.de

The approach of the DSF in the Post Bank is then mixed, both in the side of the DSF, by including additional ventilation possibilities with the louvered outer skin, and in the side of the mechanical ventilation, by avoiding a centralized system, sparing the space for the central units and for the ductwork in every floor level.

5.2 Full Integration Prototype

The company WICONA-HYDRO, the Fachhochschule Biberach, and the Universität Dortmund have developed a façade prototype that includes a number of functions, including an optimized energy management, the automatic adjustment of heating and cooling needs, and the natural and mechanical ventilation. Also integrated in the façade are sun and glare shields, and it is also possible to regulate the daylight admission and artificial Lighting, as well as the colour of the light.


The main feature of the prototype is the integration of a vertical operable element in the façade that allows for natural ventilation and at the same time includes within the volume of the vertical louvered space to receive equipment that provides mechanical heating cooling and ventilation when needed. The box-cased double façade in the window element is the separated from the ventilation system, allowing for direct fresh air admission. Additional features are the deflection of natural light and the integration of artificial light in the module.

The module continues to be in a prototype phase, and has not been tested in real use conditions. In order to establish how much energy can be saved –in comparison with other façades types and technologies-, analyses and simulations were run by the authors in accordance with the bases of the EnEV 2006 including the energy requirement for heating, cooling and lighting. The results of these modelling indicate that with the multi-function façade
40 per cent savings of primary energy requirements can be obtained, compared with conventional façades, and a round a 35% reduction in CO2 emissions [11].

5.3 Integration and Control in practice

In the Capricorn Haus Düsseldorf (Arch. Gatermann – Schossig) an exterior façade with integrated active components, called i-Modul façade, was newly developed by the firm Trox and Schueco. The façade is composed of pre-assembled elements, 2.7 x 3.35 m. The perimeter grid modular size is 1.35 m. The design of the façade includes transparent and opaque components, combining visibility, natural light and reduction of solar gains, if compared to conventional curtain walls.

The units are centrally controlled, may be manually operated, and offer the alternative to operate in an asynchronous balanced mode, with regular rates of fresh air supply fixed at 60 m$^3$/h. However, they do not integrate natural ventilation in the design of the ventilation unit in the overhead system.
window pane, comprised in the iModul façade.

6. CONCLUSION

The opposition of passive v/s active methods is thought to be diverging, on either methodological or ideological grounds. However, the prevalence of HVAC and the trend to integrate elements in the façade and conceiving it as an integrated element of the building energetic dynamics, suggest that the integration of HVAC to the façade is a path worth studying.

By means of direct integration of building services in façades it is possible to spare expensive pits and channels and even technical storeys, with a better quality of the air supply, smaller energy consumption, smaller construction costs, and freeing useful space. Additionally, the decentralized supply of the buildings with air, heating and lighting, simplifies maintenance, and makes repairs easier and unobtrusive. The observed potential is that of complementing a non-homogeneous performance.

The complexity of such systems goes beyond the performance of specific systems, and requires an integrated analysis that can only be performed based on real study cases, as no separate analysis of specific elements accounts for the improved performance claimed for them.

REFERENCES


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