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Intelligent and Adaptive Façade System – The Impact on the Performance and Energy Efficiency of Buildings

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Abstract—*Solar energy received annually at the envelope of a building can be sufficient enough to fulfil the need of the energy required to operate the building. With better utilisation of this received energy, one can potentially create buildings which are self-sufficient and self-sustained in terms of need of energy. Much interest has recently been focussed on intelligent facades or intelligent envelopes that by adaptive or responsive actions will make it possible to utilise more of this received energy for building operational purposes, such as heating, cooling, ventilation, and lighting. Double façade systems, dynamic façade systems can be quoted as basic examples of intelligent building envelope, which can incorporates natural ventilation system too. The term intelligent is, however, often used without any really deep understanding of the complexity required beyond common descriptions such as interactive, adaptive and responsive. It is easily understood that an intelligent envelope system can be dynamic, i.e. able to change its main functional parameters according to the dynamic demands of the changing situations, as well as stationary which can respond to varying conditions of surroundings and climate. In order to be truly intelligent, the system should learn from earlier experience and must use this knowledge to cope with new situations. The objective of this paper is to reduce the energy consumption with improved performance of the buildings through using new and more efficient technologies and to compare and analyse the results using various parameters to draw the conclusions. This paper summarizes research work within several areas related to the development of intelligent building envelopes. The intelligence concept specifically in relation to buildings has been studied in detail, and applied to various parameters affecting energy consumption and performance of building based on input from the external conditions and occupant preferences. System analysis has been performed for high latitude climates to develop a procedure for developing optimal design through analysis of prioritized optimization criteria.*

Keywords*: Intelligent facades, Interactive, Adaptive, Responsive, Dynamic façade.*

1. INTRODUCTION

1.1 General

A new generation of high-performance envelopes has contributed to the emergence of sophisticated assemblies combining real-time environmental response, advanced materials, dynamic automation with embedded microprocessors, wireless sensors and actuators, and design-for-manufacture techniques. This practice has fundamentally transformed the way in which architects approach building design with a shift in emphasis from form to performance, from structure to envelope.

Building façades are increasingly developed as complex systems of material assemblies attuned to climate and energy optimization. An expanded understanding of building performance acknowledges that all forces acting on buildings (climate, energies, information, and Human agents) are not static and fixed, but rather mutable and transient.

Buildings able to adapt to changing climatic conditions are called intelligent buildings. Adaptation means that buildings and façades adapt to current weather conditions.

Instead of shutting the environment out, it makes more sense to make use of it since this will have a positive impact on the comfort level of the occupants as well as on the energy consumption.

The downsides of this construction method are high room temperatures during heat waves, susceptibility to wind damage to exterior sun protection (this is especially true for high-rise buildings or in windy regions), draught caused by natural ventilation in winter, and reduced daylight with limited transparency when the sun protection is in use.

Adaptive façade helps to minimise at least some of these disadvantages so that a high comfort level can usually be achieved even without air-conditioning. In so-called hybrid buildings the comfort level can be further increased by integrating a supporting air-conditioning system for extreme climatic conditions.

2. EVOLUTION OF INTELLIGENT BUILDING ENVELOPE

Building's envelope can be considered quite literally as a complex membrane capable of energy, material and information exchanges. It can be designed to operate "as part of a holistic building metabolism and morphology, and will often is connected to other parts of the building, including sensors, actuators and command wires from the building management system" (M. Wigginton and J. Harris, 2009).

For example, the human skin works to protect the internal organs against the physical, chemical and bacterial threats. This example is a good representation to understand the behavioural function of the building's skin. It adapts to temperature and humidity, can feel the slight touches, and can repair itself. These reactions happen after an intelligent perception and movements of the skin's cells. The skin made up of many layers and contains enormous amount of elements that keeps the body free of any infections and many climatic conditions. Similarly building skin plays the same role in protecting and guarding the building against the environmental factors that threaten the internal space.

2.1 Intelligent Facades

The term intelligent building envelope has become a common denominator for a certain type of built form that uses artificial intelligence to provide the indoor environment with dynamic heating, cooling, lighting and air supply, aiming to procure optimal balance between occupant comfort and energy use. Building envelopes should potentially be able to give substantial reductions in energy use and peak power demand.

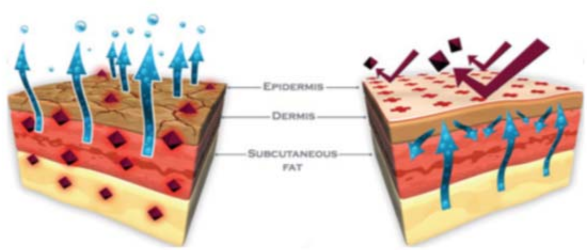


Fig. 1: A representation to show the intelligence in how human skin retain and protect the internal organs. Source: http://www.caecilian.org/wp-content/uploads/2010/04/skin-graphics.jpg

An intelligent building envelope's contribution to an indoor environment supportive of human needs can be analysed in five steps:

- Sensory perception
- Mental model
- Assessment of information and feedback
- Strategic thinking
- Implementation

An intelligent building envelope may be expected to fulfil three objectives: to cope with a variable environment, to cope with a conflictive environment, and to cope with human behaviour. An intelligent building envelope needs to solve problems that occur in its interaction with the environment; the task required of the envelope, may sometimes be conflicting. The envelope thus needs to make trade-offs according to a prevalent set of priorities, and find an optimal solution to all of the tasks.

2.2 Key Features of Intelligent Facades

The intelligent features in a façade require integration of responsive dynamic capabilities, which allow for changes in the façade's configuration based on daily and seasonal stimuli, and considering the surrounding environmental context in order to reduce the energy consumption and increase the building efficiency.

Fig. 2: The process of the adaptive feature and data flow through the intelligent façade.

Developing buildings with intelligent features should achieve better performance by implementing the following processes

a) Creation of a relationship between the occupants' behaviour and indoor space condition.

b) Provision of automatic adjustments in response to environmental changes and occupant's requirements.

c) Generation cost-effective modifications based on changes on tasks and users behaviour.

2.3 Intelligence in Architecture

Brian Atkin has identified three aspects that should be considered on intelligent buildings

- Building should know what is happening inside and immediately outside.
- Building should decide the most efficient way of providing a convenient, comfortable, and productive environment for the occupants.
- Building should respond quickly based on occupant's preferences

The new class of facades are as follows:

- Advanced facades (distinguished from conventional ones)

- High-performance facades (assuming conventional facades are low-performance)
- Innovative facades (conventional facades are per definition no innovations)

More in line with the dynamic character of such facades, these terms are commonly used:

- Smart facades (implying automated computer-based controls)
- Intelligent facades (normally understood as identical to “smart”)
- Active facades (which only means dynamic in character)
- Interactive facades (implying reactions to external situation and user demands)
- Responsive facades (normally understood as identical to “interactive”)

3. RESPONSIVE BUILDING ELEMENTS

This means that construction elements (like floors, walls, roofs, foundation etc.) are logically and rationally combined and integrated with service functions such as heating, cooling, ventilation and lightning.

3.1 Examples of Responsive Building Elements

Façades systems (ventilated facades, double skin facades, adaptable facades, dynamic insulation), foundations (earth coupling systems, embedded ducts), energy storages (active use of thermal mass, material - concrete, massive wood - core activation for cooling and heating, phase change materials), roof systems (green roof systems), active/passive solar systems, daylighting technologies, solar shading.

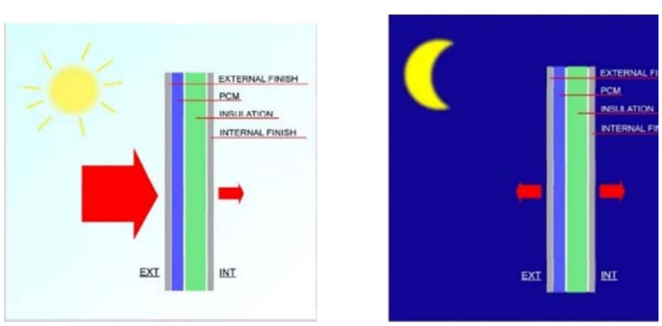


Fig. 3
Source:http://www.caecilian.org/wpcontent/uploads/2010/04/skin-graphics.jpg

Study will focus on the five specific responsive building elements which are

- Advanced Integrated Façade (AIF)
- Thermal Mass Activation (TMA)
- Earth Coupling (EC)
- Dynamic Insulation Systems (DIS)
- Phase Change Material (PCM)

4. DETAILED ANALYSIS OF DIFFERENT TYPES OF FACADES

4.1 Integrated Facades

Functions such as heating, cooling, ventilation as well as light-directing, shading, integration of artificial lighting and even energy generation with solar panels can all be realised in integrated façades.

On the one hand, the large number of decentralised air-conditioning units raises the maintenance requirements and increases the complexity of environmental control engineering.

On the other hand, cost savings are achieved through central environmental control units, shafts and ducting as well as lower storey heights because horizontal air flow is typically not required.

Individually-adjustable room environment and air quality present additional benefits because they increase the comfort level.

The worst-case scenario of a double skin façade is a hot summer afternoon with low sun-angle at the west oriented façade of the building when outside temperatures are high. This extreme situation can be solved by means of a high reflecting sunshade, a double coated, low emission heat protection glass in the primary façade, which reduces the radiated heat flux from the gap to the room significantly.

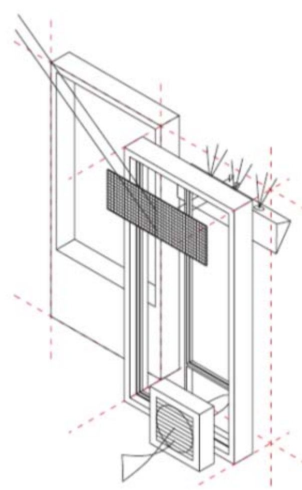
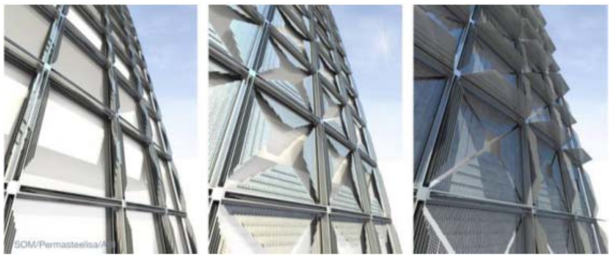


Fig. 4: The integrated façade of the Capricorn House comprises integrated air-conditioning units behind the opaque areas of the façade, allowing for individual adjustment of the room environment
Source: Adaptive Facades

4.2 Intelligent Facades

The ability for a building envelope to change and adapt its configuration relative to the sun (either by blocking its rays to prevent overheating and/or glare, or by allowing them to penetrate for passive heat gain and/or daylighting), has been a primary source of formal and technological innovations in intelligent building skins.



4.3 Smart Facades

Doris Sung, principle of *DO|SU Studio Architecture* and faculty member at the University of Southern California, is experimenting with the use of thermo bi-metals for creating self-supporting building skins that are able to open their pores to self-ventilate without the use of external energy sources. Laminated metals with differential thermal coefficients deform unevenly when exposed to temperature set points, inducing tension and causing movement in the thermo bi-metal. When the heat source is removed, the bi-metal returns to its original shape.

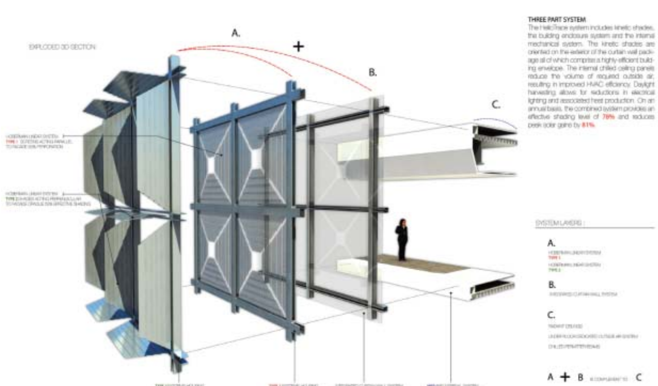


Fig. 5: Smart Thermobimetal Self- Ventilating Skin: installation of prototype and details of skin performance under different temperatures, 2010

Source Responsive Building Envelopes: Characteristics and Evolving Paradigms

4.4 Responsive Facades

The use of electro active polymers for kinetic skins is also at the forefront of research in the field, given their speed of response, large potential for active deformation and resilience. Manuel Kretzer and students from the ETH in Zurich have developed a prototype dynamic skin called "Shape Shift"; a layered, self-supporting unit made of elastomeric films which deforms when electrically charged.

Architects Soo-in Yang and David Benjamin are developing a new smart material called "Living Glass" which is comprised of arrays of polymer "gills" interfaced with sensors. The system opens and closes as a function of both human presence and carbon dioxide levels and is designed to control the air quality of a room.

4.5 Adaptive Facades

Engineering firm Buro Happold, in collaboration with deployable structures innovator Chuck Hoberman, have established an intelligent surfaces unit called the Adaptive Buildings Initiative (ABI). This design unit has developed a number of kinetic shading and cladding systems, including the Strata™ System, which consists of automated modular kinetic units that can retract into a slender profile. The system is designed to significantly increase daylighting while reducing solar heat gain effects for building occupants up to 81% annually.

4.6 Bioclimatic Self Active Skins

Self *Active Bioclimatic Strategy (SABS)* has to be intelligent like human skin is. For example, in summer time with hot weather our inner temperature increases and our skin reacts to reduce it. Opening its pores and sweating the skin refreshes its external layer aiming to maintain constant the temperature of the body. Similarly, an efficient SABS should be smart enough to know what, when, and how to react to changing external inputs to held inside temperature stable.

According to Active and Passive strategies SABS must include:

- Opaque panels (shading devices)
- Transparent panels represented through the bio reactor panels (heat trap system sand natural light)
- Controlled opening systems (ventilation)
- Responsive material combination that will monitor the kinetic feature of the skin.

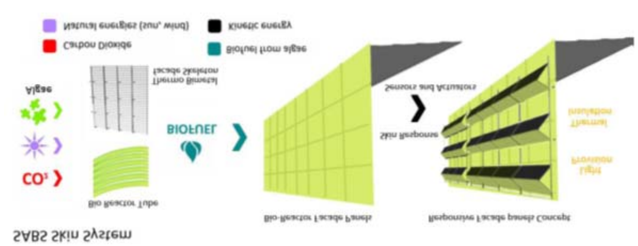
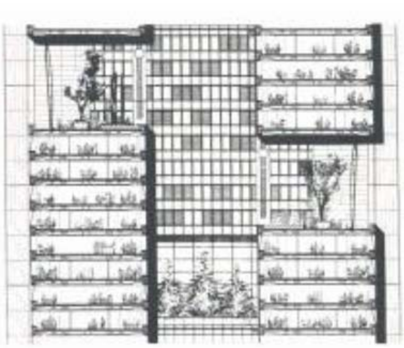


Fig. 6: Basic components of SABS skin System

Source Responsive Building Envelopes: Characteristics and Evolving Paradigms

5. CASE STUDIES

5.1 Commerzbank Headquarters, Germany



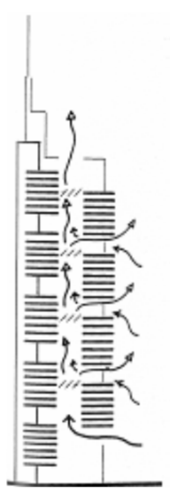

Net conditioned area: 100 000m2, 53 stories

Total energy use: Naturally ventilated 70% of the year (monitored)

Climate, site and context

The climate in Frankfurt am Main is temperate. The area around the skyscraper is pretty open. It is, however, situated in the inner city area of Frankfurt am Main in a high density urban area with high levels of noise and air pollution from traffic.

Design concept is a reliance on natural systems of lighting and ventilation. Every office in the tower is daylit and has openable windows, allowing occupants to control their own environment, and resulting in energy consumption levels equivalent to half those of conventional office towers. Four-storey gardens are set at different levels on each side of the tower, forming a spiral of landscaping around the building, and visually establishing a social focus for village-like offices clusters. These gardens play an ecological role, bringing daylight and fresh air into the central atrium, which acts as a natural ventilation chimney for the inward-facing offices. Responsive building elements that have been applied are: Double skin façade, shading, vegetation atrium, hybrid ventilation, daylight, passive solar heat.



Heating system

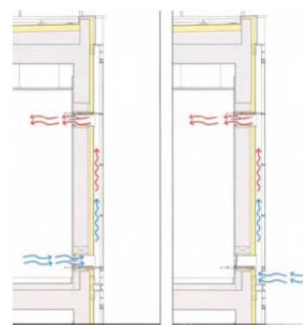
Ventilation air is preheated in the double skin façade and in the winter gardens. In seasons where the natural ventilation will result in increased energy consumption, the offices are ventilated mechanically with preheated air.

Cooling system

Night cooling and evaporation via the winter gardens help to keep the summer temperatures down. If this is insufficient the building is cooled via mechanical ventilation.

Ventilation system

The interior zones of the building are mechanically ventilated with the minimum air-change rates required for hygiene, while a perimeter heating installation and chilled ceilings regulate the room temperatures. The mechanical ventilation is supported by natural ventilation, and the user of the different offices can regulate the degree of mechanical ventilation by pushing a button or opening a window. The atrium works as a chimney for the ventilation air. The winter-gardens also work as a thermal buffer during the winter and summer season.



The Double skin façade enables the ventilation of the offices and at the same time it provides external shading. The system consists of a ventilated cavity between a one layer waterproof glass wall, a climatic buffer and an internal double glass wall which is insulated for thermal bridges. The Winter garden provides green islands in the high-rise building office landscape. The vegetation is used to produce purer air furthermore it reduces the dust in the in-let air and helps to cool down the building in summertime (ADA 1997).

PERFORMANCE

During the design phase the double skin façade was analysed and it was concluded that it could provide natural ventilation about 60% of the year. Since the building has been put to use, the result has been that the building is naturally ventilated 70% of the time (Daniels 1997).

6. C0NCLUSIONS

6.1 Why Invest In Facades?

India is the world's fourth largest energy consumer (EIA, 2013) and fifth largest source of greenhouse gas emissions

(GOI, 2010). With the building sector contributing 35% of the total electricity consumption (Rawal et al, 2012), and a projected five-fold growth in the constructed area anticipated by 2030 - from a 21 billion square feet in 2005 to 104 billion square feet, building energy efficiency plays a major role in managing energy use in India (Seth, 2010). The rapid growth in Indian construction sector, the national government's efforts to improve energy-efficiency in buildings is based on significant reductions in air-conditioning, ventilation, lighting and plug loads.

Building façade design and engineering is critical to: air conditioning loads through solar heat control; to natural ventilation and night cooling; to effective daylighting; and even free passive solar heating in cooler climates.

High performance, climate responsive facades can significantly reduce both annual and peak electricity demand, and ensure "resiliency" in the face of power outages. Equally critical, high performance facades are critical to occupant health and productivity.

Triple Bottom Line arguments for five high performance façade measures can provide up to 25% total energy savings in typical Indian office buildings, reducing the cost of electricity and improving indoor environmental quality for human health and productivity.

Five strategies were selected to demonstrate the TBL cost benefit analyses that could be applied across all five climates - with climate specific variations:

- Invest in high visible transmission glass with climate appropriate shading coefficients.
- Invest in light shelves or light redirection louvers in clerestory glass areas.
- Invest in high performance ballasts with daylight sensors in perimeter office lighting.
- Invest in external overhangs or canvas awnings for summer shading.
- Invest in operable windows for natural ventilation and night cooling.

BIBLIOGRAPHY

[1] BIS (Bureau of Indian Standards). 2005 "National Building Code". New Delhi, India

[2] CBE. 2014. "Mixed Mode Building" .CBERD Task 3.1 Passive Design Report: UC Berkeley

[3] CBPD b. 2014. "Bio-Climatic Design Enclosure Guidelines for 5 Climate Zones in India". Master's Thesis for the Master of Sustainable Design program in the School of Architecture, Carnegie Mellon University.

[4] Energy Conservation Building Code (ECBC), Bureau of Energy Efficiency, 2008, "New Delhi. India

[5] EIA - Energy Information Administration. 2013. India – Country Analysis Brief,

[6] http://www.eia.gov/countries/analysisbriefs/India/india.pdf

[7] GOI – Ministry of Environment and Forests. 2010. India: Greenhouse Gas Emissions 2007

[8] Andresen, I. and Ø. Aschehoug: "System analysis of smart facades". Conference "Glass in Buildings", Bath (UK), 2005-04-07/08.

[9] Aschehoug, Ø, Hestnes, A.G., Matusiak, B., Lien, A.G., Stang, J. and D. Bell, (2000) "BP Amoco Solar Skin – A Double Façade With PV". Proceedings. Eurosun 2000, Copenhagen June 2000.

[10] Piaget, J (1967) 'The psychology of intelligence', Routledge & Kegan Paul Ltd, London.

[11] Wyckmans, A., Aschehoug, Ø. and A.G. Hestnes: "The intelligent building envelope - concept and qualifications". Conference "Glass in Buildings", Bath (UK), 2005-04-07/08.

[12] Addington and Schodek, (2009), *Smart Materials*, Berlin: Birkhauser *T.* press, p.22.

[13] D. K. Sung, (2010), *Skin Deep: Making Building Skins Breathe with Smart Thermo bimetals, Where Do You Stand?: Proceedings of the 2011 ACSA National Conference*, A. Perez-Gomez, A. Cormier, and A. Pedret eds., Washington, DC: ACSA Press, pp. 145–152.

[14] Hoberman Associates and B. Happold, (2010), *Adaptive Building Initiative*, Available at: www. adaptivebuildings.com, (Accessed 18 May 2013).

[15] Klooster, (2009), *Smart Surfaces and their Application in Architecture and Design*, Berlin: Birkhauser *T.* press, p.5.

[16] Wigginton, M and Harris, J, (2002), Intelligent *skins*, Elsevier, Oxford, UK.

[17] Responsive Building Envelopes ~ *Kathy Velikov and Geoffrey Thün*