

Glass architecture: is it sustainable?

F.M. Butera

Politecnico di Milano, Italy

ABSTRACT

"Sustainable" and "ecological" are becoming fashionable words for advertising products: ecological car, ecological food, ecological bag, even ecological fuel. To claim that a product is sustainable or ecological helps to sell it. This trend applies also to buildings, and "sustainable architecture" and "sustainable design" is becoming a fashionable wording. Sustainable architecture has been, for decades, a small cultural niche ignored, sometimes ridiculed, by the official architectural culture, with very few exceptions. Nowadays, instead, also many famous architects, authors of the highest examples of modern architecture, start to include the word "sustainable" in the description of the main features of their projects. This is a very important and positive trend, since it is the most effective and powerful drive for, eventually, let sustainable architecture get out from the niche in which has been compelled up to now. The examples of sustainable architecture, published on the most important architectural journals and on large diffusion magazines, are the best mean to diffuse culture of sustainability and induce a replication process also in the far wider field of everyday architecture, the one represented by thousand of more or less obscure professional that are the real actors of the development of the building stock.

In the last century, and especially in the last few decades, the architectural language has given more and more emphasis to the "lightness" and the "transparency" of buildings, pushing towards fully glazed envelopes. A brief history of the irresistible rise of glass envelopes in architecture is recalled for putting the problem in its appropriate cultural framework.

The question then posed is: to which extent fully glazed buildings, especially those designed by famous architects claiming themselves as environment concerned, are actually sustainable? This is not a minor question, given their role of model examples of the rising new culture of sustainable building design.

The effectiveness of envelope technologies largely used such as all glazed curtain wall and double skin is discussed, taking into account luminous, thermal and acoustic comfort with its connection to energy use, on the basis of the most recent findings available in specialised literature.

1. HISTORICAL BACKGROUND

According to the Webster Dictionary of the English Language the word 'window' derives from the Icelandic 'vindauga', that literally means 'wind eye'. This is not surprising, since for millennia, up to the Renaissance, windows were not provided with glass panes. Even if occasionally present in Roman *Thermae* and in a few rich Roman houses, glass panes started to appear in the mansions of the wealthiest inhabitants of Florence, Venice, Genoa at the end of XIII century. The diffusion process was very slow, and only at the beginning of XIX century in the main European cities all the windows were glazed, except the ones of the poorest people (Butera, 2004).

The glass pane has been, after the fire, the most important technological innovation in the history of mankind, in relation to comfort in enclosed spaces.

With glass panes windows ceased to be 'wind eyes' and it become possible to have at

the same time natural light and warm air. Before, in the Middle Ages, people sitting or standing by the large fireplace was not very comfortable: they were chilled in the back and roasted in the front. This was due to the fact that a cold draft entered through an open door or a window, being this draft necessary in order to let the fire burn properly, and to avoid to fill the room with smoke.

Glazed windows made possible a technological innovation that represented a tremendous improvement of indoor thermal comfort: the stove. In a room provided with glazed windows and a stove it was eventually possible to enjoy natural lighting in a uniformly warm environment (air and surfaces), since it was no longer necessary to introduce a large and cold air flow to keep the fire going. Moreover, glass was capable to trap solar radiation in the room, and in winter sunny days indoor thermal comfort was improved even without a heating source.

In the second half of XIX century new heating technologies started to diffuse, first in commercial buildings: central heating systems with radiators and hot air systems. The revolution induced by glass panes was then complete: we become able to create an artificial micro-environment, our home, our office, etc., where we could enjoy sunlight and a comfortable temperature even in the coldest winter day.

2. GLASS AND ARCHITECTURE

From then onwards the history of glass starts to interlace with history of architecture.

In 1914 a sort of manifesto in favour of the use of glass was published in Germany by the utopian poet and science fiction writer Paul Scheerbarth, in which its author sets his vision of a future "Glass Architecture which will let the sunlight and the light of the moon and stars shine into the room, not through a couple of windows but, as nearly as possible through whole walls, of coloured glass" (quoted in Frampton, 1992).

The book mirrors an architectural trend that is fascinated by the new materials available: concrete, steel and, especially, glass, that starts to be an important component of the architectural language. Entirely glazed facades were possible only thanks to the developments of heating and cooling systems, otherwise the

building would have been uninhabitable. As a consequence architects felt themselves freed from any kind environmental constraint in the design of buildings and "it fell to another body of men to assume responsibility for the maintenance of decent environmental conditions: everybody from plumbers to consulting engineers. They represented "another culture", so alien that most architects held it beneath contempt, and still do") (Banham, 1984).

Actually, the issue is even more critical, since architects ceased to take into account some elementary physical principles in their design process, producing sometimes some unwanted monsters in terms of comfort and energy, even if beautiful as exterior aspect.

One of the first significant examples of such a case is the Cité de Refuge by Le Corbusier, documented by Banham (1984). The building, a large lightweight hostel for Salvation Army elderly people, had its south-west facing façade entirely glazed, according to Le Corbusier's ideal of de-materialising building skin by means of glass, the "minimum membrane" between indoors and outdoors.

In the Cité de Refuge, Le Corbusier introduced an innovation, that he calls "La respiration exacte", a technological system to put in action a philosophy that, unfortunately, has been very successful:

"Every nation builds houses for its own climate. At this time of international interpenetration of scientific techniques, I propose: one single building for all nations and climates, the house with respiration exacte...I make air at 18 °C and at humidity related to the state of the weather. A fan blows this air through judiciously disposed ducts, and diffusers have been created to prevent droughts" (Banham, 1984).

The sealed envelope as a consequence of the "respiration exacte", the south-west exposure of the main façade, the transparent glass membrane that, quoting Le Corbusier, permitted the "ineffable joy of full sunlight", and summer season combined together, made of the Cité de Refuge the first documented case of overheating with serious health consequences for the occupants.

The desperate need to reduce the overdose of *ineffable joy* led Le Corbusier to the development of a masterly invention: the brise-soleil, a very remarkable structural innovation, based on an external egg-crate of vertical and horizontal

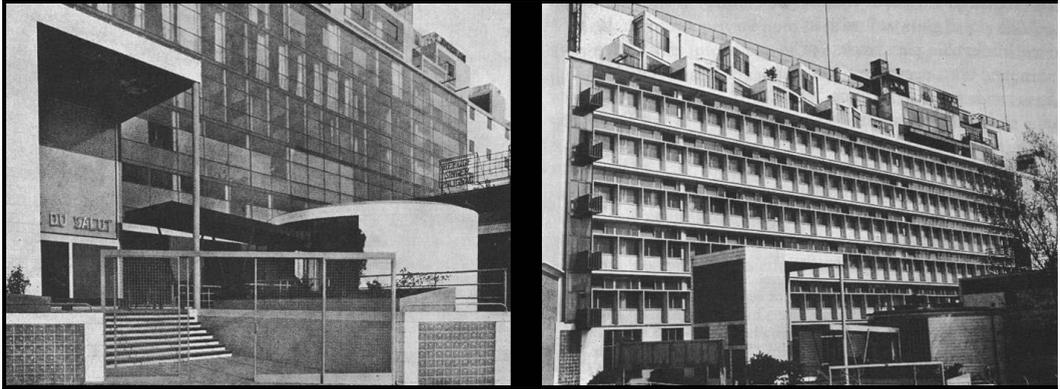


Figure 1: Le Corbusier's Cité de Refuge: original project (left) and with brise soleil (right).

shades, that was first applied as retrofit on the south façade of the Cité de Refuge (Fig. 1, Banham, 1984).

The creative fantasy of Le Corbusier for pushing the use of fully glazed envelopes and reducing their negative effects on occupants' comfort does not stop here. He claims to have invented the double envelope that he called "mur neutralisant" (neutralising wall), that is a wall "envisaged in glass, stone, or mixed forms, consisting of a double membrane with a space of few centimetres between them... In the narrow space between the membranes is blown scorching hot air, if in Moscow, iced air if in Dakar. Result, we control things so that the surface of the interior membrane holds 18 °C".

Le Corbusier was not the only great architect of that time fascinated by the glass envelope. Among the others Mies van der Rohe, with his project for an all glazed office building in Friedrichstrasse, in Berlin, for example, and Frank Lloyd Wright, who wrote: "Glass has now a perfect visibility, thin sheets of air crystallized to keep air currents outside or inside... Shadows were the 'brush work' of the ancient Architect. Let the modern now work with light..." (quoted in Frampton, 1992).

3. GLASS CURTAIN WALLS

The second world war is over, and architects operate up in a vital, dynamic context of turbulent technological change, with energy virtually at no cost, more and more effective HVAC systems and a new process for producing a more beautiful and cheap glass: the float glass. All

these factors, combined with their cultural heritage, led unavoidably to a further step in the successful march of glass as building envelope material in commercial buildings, in spite of its very poor thermal performance.

After the oil shock in 1973 there is a change of attitude towards energy wastes, and new building regulations are enforced for energy conservation. Glass industry is ready to react: not only tinted or reflecting float glass is available, but also double and even triple glazing. A few years later low-e glazing will be developed. So, the triumphal march of glazed envelopes is not affected at all by energy concerns, nor by law, nor by culture.

What's wrong with it? No doubt that glass architecture is light and transparent in architectural terms. The fact is that it is light and transparent also in physical terms, affecting thermal losses and gains and thermal inertia. But it is not the only problem. Let's analyse how these full glazed envelopes were and are used, and their effect on energy consumption and comfort.

3.1 Tinted glass

Since part of the solar spectrum is absorbed, in sunny summer days the glass warms up to 30-40°C, and the infrared radiation emitted makes uncomfortable the surroundings. On the other hand, during cloudy days or by night in winter the glass is cold, and for this reason all the area close to the glazed surface is uncomfortable. In most cases this undesired effect is reduced or eliminated by blowing a jet of cold (in summer) or hot (in winter) air parallel to the glazed surface, whose temperature becomes closer to the

room air temperature. In this way the comfort is improved, but at expenses of higher heat losses.

There is another environmental drawback deriving by the use of tinted glass facades, especially if the colour is blue-green, the most appreciated and used by architects. The drawback is evident having a look to such buildings during clear days in winter or in summer: in spite of the brilliant sun shining and the flood of natural light available, artificial lighting is on. The reason is that even if the illumination level in the office rooms reaches or is above the required value, the light coming from the fenestration is too "cold" (i.e. too high colour temperature), due to the colour of the glass, and – as it is well known since more than 60 years – the occupants feel the luminous environment uncomfortable; as a result, they switch on artificial light, warmer, that compensates the cold natural lighting: more energy is wasted.

3.2 Clear glass

Is it clear glass better? In winter it behaves exactly like the tinted glass, therefore an hot air stream for heating the glass surface is often used; glass heating in summer sunny days is less critical than in tinted glass, but still significant.

The real problem of a clear glass wall, however, is glare. The benefit of a large aperture that lets come in a flood of natural light is entirely cancelled by the effect of glare on occupants' behaviour: they restore their visual comfort by obscuring the glass surface with curtains, venetian blinds or whatever it is available. The struggle for survival of the unfortunate occupants is clearly expressed in innumerable buildings of famous architects as Oscar Niemeyer (Fig. 2) or Mies van der Rohe (Fig. 3, from Wiggington, 1996).

The final result on the energy balance of the building is easy to evaluate: high thermal losses



Figure 2: Esplanade of Ministries, Brasilia.



Figure 3: 860-880 Lake Shore Drive, Chicago.

through the façade, uncontrolled solar gains in winter and in summer (the curtains inside, even if white, absorb solar energy that is transferred to the room) and lights always on. Little difference, then, with a tinted glass building envelope, on the environmental point of view.

To temperate this undesirable effect in more recent times some leading architects use to protect the large glazed curtain walls with external shades, as in Renzo Piano's Il Sole 24 Ore Headquarters in Milan (Fig. 4). It seems a good idea, but unfortunately with glare also light and outside vision is cut off, and artificial lighting must be on all the time.

It wasn't the glass curtain wall thought to give natural light inside and an ample vision of the outside landscape?

4. DOUBLE SKIN FAÇADE SYSTEMS

The double skin façade is essentially a pair of glass "skins" separated by an air corridor. Sun-shading devices are often located between the two skins.

One of the most common type of double skin façade consists of a main double-glazed skin of insulating glass with a second single-glazed skin placed outside (or viceversa). The air space between the two layers of glazing becomes part of the HVAC system. The heated "used" air be-



Figure 4: Il Sole 24 Ore Headquarters, Milan.

tween the glazing layers is extracted through the cavity with the use of fans and thereby tempers the inner layer of glazing while the outer layer of glass reduces heat transmission losses. Shading devices are mounted within the cavity. Windows on the interior façade can sometimes be opened, while ventilation openings in the outer skin moderate temperature extremes within the façade.

This kind of envelope is becoming more and more popular, especially in Europe, due also to the imitation effect deriving by the fact that it has been adopted in some milestones of most modern architecture, such as Richard Roger's Lloyd's Building in London and Norman Foster's Business Promotion Centre in Duisburg, Germany.

Compared to glass curtain wall, the main advantages claimed about double skin envelopes are: high energy saving, excellent thermal comfort, high acoustic performance, natural ventilation and low environmental impact, keeping the architectural value of a light and transparent envelope. The problem is that many of these advantages are controversial, sometimes in conflict each other and in any case lacking of scien-

tific documentation (Selkowitz, 2001; Harrison, 2003; Poirazis, 2004). Let's analyse them one by one.

4.1 Energy saving

No doubt that in sunny winter hours exhaust air is heated when passing through the cavity, if blinds are lowered (and they have to be lowered to prevent glare). No doubt, also, that there is no energy advantage during the hours without sun: in this case the exhaust air is cooled, and the energy recovered in the HVAC system is less than the recoverable. But this inefficiency is necessary for maintaining the wide inner glass at a reasonable temperature, for thermal comfort.

The poor winter performance of a double skin façade was measured in a building in Turin (Perino and Serra, 2004). Long term measurements showed that preheating efficiency was lower than 50% for most of the time and, however, the equivalent thermal transmittance of the double skin ($2.0 \text{ W/m}^2 \text{ K}$) resulted to be lower than a conventional double glazing with low-E coating. This result is not surprising nor unique: in the best conditions, i.e. with still air in the cavity, when a single layer of glazing is added to a double low-E glazing in a double skin façade construction the reduction in heat loss expressed by the U-value is modest (<20%) (Oestler et al., 2001).

In summer, on the other hand, solar energy absorbed by the lowered blinds is extracted by the air flow, that becomes warmer, so increasing the indirect gains. In other words *a rather inefficient manner compared to preventing the solar energy to penetrate the building by exterior shading devices* (IEA, 2000). These almost obvious considerations are confirmed by the measurements made in summer in previously mentioned double skin building in Turin. In a typical summer clear day at 3 p.m. the air temperature in the gap between the blinds and the inner glass reached $32 \text{ }^\circ\text{C}$, while glass temperature was almost $38 \text{ }^\circ\text{C}$, because of the infrared radiation emitted by the blinds at $52 \text{ }^\circ\text{C}$. The overall effect was a significant heat input through the inner glass, higher than that of a single leaf glazed facade protected with external sun shades.

To all this there is to add the energy waste deriving by the use of artificial lighting even in the most luminous days, as a combined result of

physiological needs (eliminate glare) and behavioural aspects (blinds lowered by occupants all the time, as it was experienced during all the measurement campaign in Turin and as it is the current occupant's behaviour in all glazed buildings).

Same problem as in fully glazed single leaf façades.

4.2 Comfort

As far as thermal comfort is concerned, double skin façade systems have an indubitably good performance in winter, since the inner glass is warmer than it would be without the outer. The opposite may happen in summer, since the high glass temperature may cause discomfort especially to people close to the glass surfaces, as it has been documented for the building in Turin and unofficially admitted in other double skin buildings.

Also acoustic performances need to be carefully evaluated since if it is indubitable that the second skin is a good sound screen for the noise coming from outside, it is also evident that during the periods in which natural ventilation is used and the windows of the inner skin are open, room to room or floor to floor sound transmission will take place enhanced by the cavity (IEA, 2000).

One of the main advantages claimed about of the double skin façade system is that can allow natural or fan supported ventilation. This possibility may have some impact on energy savings during mid seasons and in summer in those climates where external air temperature keeps well lower than 26 °C most of the time, allowing for the extraction of the heat produced by internal loads and solar gains. In climates with hot summers the advantage of natural or forced ventilation is negligible.

4.3 Critical issues

Other disadvantages that have been mentioned are related to the higher construction costs (twice as much as a conventional curtain wall in Europe, four times in US (Lang and Herzog, 2000), to fire protection, because of the possible room to room transmission of smoke in case of fire, to the reduction of rentable office space, because of the thickness of the cavity, to the additional maintenance and operational costs, to the increased construction weight (Poirazis,

2004).

Double skin façade systems are a very complex innovation, characterised by a tight dynamic interaction between the HVAC system and the building cladding. For this reason it is recognised that to succeed with these buildings a holistic approach has to be applied, a close co-operation between architects and technical consultants. In fact, it is very difficult to predict the performance of such a complex system. New simulation and evaluation tools need to be developed, often tailored to the specific building and capable to perform fluid dynamics simulations in the cavity.

It is evident, then, that such a kind of approach is hardly compatible with the demand of the present market for double skin façade systems: a market of very rich clients wanting a well visible and prestigious landmark as soon as possible. And a market of very busy famous architects.

It cannot be excluded, however, that a proper design of a double skin could lead to satisfactory energy performances, compared with the ones a single skin building. The problem is that any single leaf glass envelope is more energy wasting of any other kind of cladding, and does not provide higher comfort standard.

5. SUSTAINABLE BUILDINGS

When a building can be defined sustainable? There are many definitions of sustainability, but all of them agree on the fact that the minimum requirement is the minimum use of non renewable resources, compatible with the functions that the building has to provide and with economics. Of course this concept should be applied to all the life cycle of the building materials and to the building itself, i.e. the sustainability can be claimed only after a Life Cycle Assessment (IEA, 2000). So the designers of such buildings should be able to show that the embedded energy of a double or triple glass cladding with aluminium frames is lower than that of alternative envelope solutions, or that the energy saved in running the building is so large that the energy pay back time of the envelope is at least equal to the life of the building (a life that is shortening to 30-50 years, a cultural before than technical choice deriving by the present architectural trend for which buildings must

be light, transparent and, – consequently, even if unwanted – ephemeral).

To ask an architect all this is too much, even if in principle is correct. But at least a building explicitly claimed as sustainable or designed by an architect that depicts himself as an environment concerned architect (and the number of them is growing exponentially, given the demand of the market) should not show features that are clearly against sustainability or that are questionable, such as the use of the same type of envelope, the glass curtain wall, in Oslo and in Sydney, in London and in Singapore. And among the sustainability issues that are questionable there is to include the cost: is it sustainable a building whose cost is far higher than a "conventional" one with the same performances? Is not cost somehow a measure of the material (and immaterial) resources embedded in the artefact?

6. CONCLUSIONS

More and more often, in architectural magazines, "green" or "sustainable buildings", either residential and commercial, are presented; many of the latter are fully glazed buildings (single or double skin), whose main problem is cooling. In most cases a curious reader that goes through the article cannot find any concrete evidence that the building is sustainable, except for some new technology used in the HVAC system or for water recycling. He may find beautiful pictures of an empty building, with blinds up or down in such a way to create an attractive pattern in the façade, and so on; but he finds very little or no data at all that allows to assess the success of the design, i.e. the operational performances. Many times there are colourful sketches showing red and blue harrows showing air movements; sometimes very complicated and unlikely air movements: perhaps these green architects think that physics must obey to architecture's will; perhaps they think that as the drawing of a beam or of a window is then transformed in the actual beam and window (this is the sense of designing) also the drawings of the air movement will magically force air to do what expected (Croce, 2003).

The fact is that most of these 'sustainable' architectures "appear, more that a proved reality, an illustrated tale" (Filippi, 2003).

In a world based on publicity, on slogans, where appearance is all and in which what you communicate is more important than what you actually do, 'green', 'sustainable' are fashionable labels that give an extra bonus to a building.

The number of pretend-to-be sustainable buildings that deserve (or obtain) to be published in the architectural magazines or that are actually built is very limited, and represent a very tiny fraction of the building stock. So, why to worry about? The problem is that, especially if they have been designed by famous architects, become precursors, archetypes of a new generation of pretend-to-be sustainable buildings, replicated by thousand and thousand of more obscure but very active architects distributed all over the world. The environmental damage then would be other than negligible.

Fully glazed buildings are perhaps the most dangerous type of building from the point of view of a dull and uncritical replication: they are hardly sustainable if well designed, and they are definitively unsustainable if badly designed. Another danger, with a terrific energy waste and CO₂ emission potential that can be tempered only by appropriate building regulations, comes from the uncritical extension of the "fully glazed" concept to residential buildings.

Ferraris are beautiful cars, a perfect balance between advanced technology and beauty; but never they have been sold as ecological cars. The same should apply to fully glazed buildings: some of them are outstanding for beauty and for technological innovation; they are the Ferraris of modern architecture. But please, do not sell them as sustainable buildings.

The profession too must define an ethical stance. The requirement for architecture to contribute to social and environmental sustainability now charges architects with responsibilities that go beyond the limits of an autonomous brief. The status and power of the profession has declined under the weight of commercial pressure (Rogers, 1997). Beautiful, but architects speak with their buildings, not with their words.

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