Innovative Building Skins: Double Glass Wall Ventilated Façade

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Contents

Introduction

Let's talk about skin. Skin is a protective membrane. Skin is the interface between organism and environment. People have skin, buildings have skin, and even our planet Earth has a skin. Skin regulates temperature and moisture, it protects from the outer elements (or the vacuum of outer space); it allows the internal system to function in a regulated environment.

Preceding the advent of Carrier's air conditioning, building skin was crucial in providing a well-ventilated, thermally-regulated environment. The skin insulated and ventilated. Following the integration of air conditioning into buildings, this protective membrane ceased to provide such services. Our reliance on the mechanized environment led us astray from passive strategies used for reducing heating and cooling loads, as well as for ventilating and lighting the interior.

Mechanical heating and cooling of the building's interior meant the skin had to be sealed tight to keep in all that valuable thermal comfort. Therefore, ventilation had to be mechanized as well. As inhabitants and designers of these buildings, we are just now realizing that strict reliance on mechanical equipment comes at a high cost: more energy to operate and maintain all this machinery, and worse health due to poorly ventilated interiors and invariable temperatures.

This new realization, which comes as part of the Green Revolution, forces us to look at building skins in a new way. We could revert back to techniques and materials used by builders of the 19th century, but instead, there is great evidence of people looking ahead. New technologies in building skins are abound. Building-integrated Photovoltaics are making an impact. Intelligent skins, like the one used in the Caltrans 7 building in California, mechanically respond to environmental conditions via a central monitoring system. This 'robo-skin' shades and ventilates automatically on demand when appropriate. One of the most promising, and most aesthetically suitable innovations is the double glass wall ventilated facade.

Scratching the Surface of Building Skin: Development of the Ventilated Double Facade

The European *BestFacade* report claims that the Steiff Factory in Germany, still in use today, as well as Otto Wagner's Post Office Savings Bank in Austria, used the double façade method in 1903. In 1930's France, Corbusier was designing his "Mur Neralistant", where an air cavity was meant to neutralize the external climate. High first-cost kept this idea from being realized (Li, 2001). Following the 1970's energy crisis the Hooker Building (now called the Occidental Chemical Center), with its 'buffer' double glass façade, was the first of its kind seen in North America.

Up until now, however, we have had no real need to alter the function of the building skin. In 2007, with Global Warming no longer a debate but a stormy reality, and the rising global tensions over precious oil escalating with every dollar per barrel, energy efficiency has become a primary focus. Research and development in the field of sustainable design has led to advancement in products and methods used in double glass facades, and holistic analysis of building physics using computer modeling proves that integrated design can maximize energy efficiency. The subject of computer modeling, as well as building management systems (another major factor in the development of double glass façades) will be discussed in following sections.

Christian Schittich, in his book, *Building Skins* (Schittich, 2003), demands that we treat cladding as a responsive skin, not ornamental packaging. Werner Lang suggests, in the same book, that since the building skin fulfills a multitude of vital functions, it is the principle factor in the energy consumption of the building. Perhaps we should treat the façade not as a skin at all, but as system to be integrated with the entire building.

Sara Hart, in her article on Façade Engineering, explains that, "The evolution of the building envelope from static wrapper to a complex, active building system has been partly motivated by the economics of energy consumption and the promise of sustainability. The proliferation of private and public research and development has produced a juggernaut of products and processes." (Hart, 2002, "Façade…").

Another factor in the development of the building skin, and thus the double glass wall façade, is the impact of Biomimicry on the design industry. Biomimetic buildings apply this innovative design model most successfully to the building skin. Examples can be seen in the self-cleaning Lotus-Effect paint used in Germany, the transpiring Stomatex cladding, and the passive thermally-regulated 'Termite-Mound' building in Zimbabwe.

With building skins becoming a major focus in the goal of reducing a building's energy load, we begin to see the role of the double glass façade in transforming the way we design buildings. As one writer expressed, the double glass façade can provide a "visual symbol of energy efficiency" (Streicher, p14). For both aesthetic and performative reasons, this innovation in façade engineering should be seen as an opportunity for efficiency and whole building integration.

As for the development of the ventilated double façade in particular, we see it as having been put into practice more in the temperate climates of Europe than the US. This contrast will be discussed at greater length in a following section, however it should be noted here that the development of 'integrated design' in architecture is a major determinant of whether a ventilated double façade will be used and ultimately if it will be successful, and that the EU has far surpassed the US in its application of integrated design in recent years.

Basic System Components of the Double Façade

Glass, cavity, shading and ventilation – these are the basic components of the double façade. However, a list of considerations from aesthetics to acoustics will produce a different combination of these basic elements within a complex, integrated environment.

To begin, we will overview a categorization of the types of double façade, followed by a brief description of the components.

Types of Double Façade Systems

System Type

The Belgian Building Research Institute, in their *Ventilated Double Facades* report of 2004 (Loncour, 2004), set three main criteria for distinguishing between types of double façade systems. The first distinction is between the types of ventilation. Natural ventilation relies primarily on stack effect for air movement, but also pressure differences created by wind. Since no mechanical systems are used to facilitate the air movement, the level of ventilation is dependant on exterior climate and the temperature of the air in the cavity. The termite-mound-inspired Eastgate Building in Zimbabwe relies solely on natural ventilation to regulate the interior from the excessive 100+ degree Fahrenheit exterior.

Double Façade Systems

Ventilation Types
- Natural
- Mechanical
- Hybrid

Cavity Partition Types
- Ventilated Window
- Ventilated Façade

Cavity Ventilation Types
- Outdoor Air Curtain
- Indoor Air Curtain
- Air Supply
- Air Exhaust
- Buffer Zone

Mechanical ventilation requires that the building envelope be carefully sealed and monitored. Being that energy conservation is a major reason for designing double facades, it seems counter-intuitive to rely solely on mechanical ventilation.

Mixed-mode is most popular amongst the types listed in this report. This type requires a complex, centralized environmental management system which can switch the façade's components from natural mode to mechanical mode depending on climate and user need.

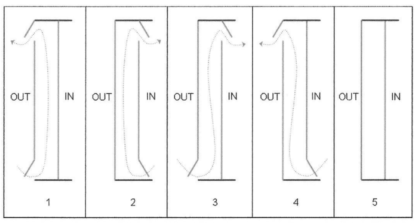
Partitioning

The next criterion is the partitioning of the façade, which is split in two. The partition creating the cavity can either isolate each individual window, or open the entire façade. Of the ventilated façade type, the system may be further partitioned either vertically by floor, or horizontally via a rising shaft. Or it may not be partitioned at all – but this multi-storey type of partitioning may lead to negative issues such as fire safety and inter-office noise pollution.

Ventilation

The final criterion is the mode of ventilation. The illustrations at right are taken from page 14 of the BBRI report (Loncour, 2004). In the 'curtain' modes, air is not exchanged between the inside and outside. The air exchange modes either take fresh

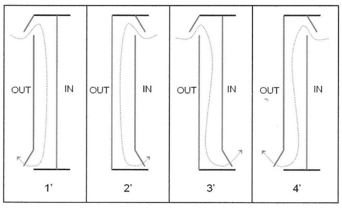
Main Modes of Ventilation
1. Outdoor Air Curtain
2. Indoor Air Curtain
3. Air Supply
4. Air Exhaust
5. Buffer Zone



Images taken from
http://www.bbri.be/activefacades/new/index.cfm
(see Loncour, 2004)

air from outside or exhaust indoor air to the outside. The buffer zone provides no ventilation, but is distinguished because it is still a double façade. The variants are simply a reversal of the air flow.

Variant Modes of Ventilation
(Air flow is reversed)



For Loyola University's Information Commons and Digital Library, Solomon Cordwell Buenz Architects developed the following strategies for using a double ventilated façade with radiant slabs and underfloor air distribution (refer to the images below). During natural ventilation, cool air from Lake Michigan enters the eastern façade (right) through open windows and travels across concrete slabs designed to accelerate and direct airflow. After cooling the interior, the used air exits through the double skin curtain wall. This strategy is for natural ventilation in Spring or Fall seasons.

During heating/cooling mode, the façade is sealed to the interior so the radiant slabs can temper the indoor environment. In cooling mode, operable shading minimizes solar gain, and the double façade portion evacuates hot air from the western and southern facades. Notice the bottom of the cavity is opened to allow air flow through to the top.

Images taken from
http://www.construction.com/CE/articles/0705edit-2.asp
(see Fortmeyer, 2007)

Glazing

Glazing must be split into inner and outer glazing. The air cavity provides insulation, and so, while one of the glazings is double glass, the other can be single pane. The consideration of spectrally selective or tinted glass must be countered with the possibility of other shading devices. Glazing can also be 'angularly selective'; this fritted glass appears in buildings where lighting is important, such as libraries or laboratories. The chosen angle of the textured glass allows maximum light while minimizing heat gain. Also, integrating photovoltaics into the external façade is becoming more popular, as it can provide many levels of transparency, shading and power production simultaneously.

Shading

Shading devices can be blinds or shades placed in the cavity, operated automatically, manually, or by a hybrid system. Solar heat transmitted into lowered shades or blinds will be absorbed into the air of the cavity and driven out through exterior vents via stack effect or mechanical ventilation. This constant air flow allows the cavity to perform as a natural buffer to the external climate. The shades must be placed close enough to the exterior to avoid transmittance to the interior glass, but far enough to allow proper airflow around both sides of the shade. External shading devices and light shelves can also be used to reduce solar gain while enhancing daylighting effects.

Shading is the façade component most easily controlled automatically. Aurora Place in London, by Renzo Piano and Hunter Douglas (a solar shading specialist) uses an automated shading system integrated into the building envelope and connected to the building management system. More about automated controls is written in the section: *Building Management Systems*.

Cavity

The cavity can vary in its size from a few inches to many feet (in the case of an atrium). This specification depends on maintenance accessibility, amongst others. The continuous air flow in the cavity, supplied by exhaust/room air, acts as an insulation barrier to the external environment.

Ventilation

Ventilation requirements depend on the necessary volume and velocity. For instance, lower velocity air requires more vent openings. The *BestFacade* report differentiates between 'high-draft mixing' and 'displacement ventilation'. Where occupants are not to be disturbed by air speed, displacement ventilation can change air volumes without strong wind currents by way of more vent openings. In conventional façade buildings, more vent openings means higher energy costs to temper the fresh air. In double glass façades, vents can be sealed to allow trapped air to be heated by the sun.

In an article from Architectural Record entitled "Using Multiple Glass Skins to Clad Buildings", Flack and Kurtz' NBBJ Office in Seattle is mentioned as surpassing the International Mechanical Code's requirements for fresh air. Montpellier, the mechanical engineer at the firm, suggests that occupant comfort is better achieved using 10% of wall space for operable windows per square foot floor space instead of the required 4% (Lang, 2000). Reiterated in the article is the basic design tactic of using shallow, open floor plates fifty feet wide, and a central atrium for increased air movement.

A unique component of the double façade that relates to ventilation is the ‘fish mouth’, used in the Commerzbank of Germany (see case study below for more info).

A Word About Unitization
To conclude this section on basic components and provide a transition into the following discussion of integrated components, mention should be made here of ‘unitization’. This refers to the method of producing basic components for the double facade, primarily the glazed portion, in a pre-fabricated process. In an article discussing technology transfer (Hart, 2002, “New Ways…”), the pressure-equalized, double glass façade is produced in unitized panels at the factory and installed on site, in the way that car parts are put together before being shipped to the final car manufacturing facility. This pre-fab construction offers a higher degree of quality and precision, thus further offsetting initial first-cost with better energy efficiency. An example of this unitized construction can be seen in Levine Hall of the UPenn building (listed in case study below); the glass façade has only four field joints. Arup’s façade engineers chose to have 5-foot façade modules shipped to the site where they were further assembled with solar blinds and catwalks before being installed.

Integrated Components of the Double Façade

Integrated Design

The ventilated double façade is surely an innovative method requiring vast technological development and support. In fact, the technology necessary to successfully implement such a method is not readily available in the US and only now becoming well-known in Europe. The main barrier the architect must overcome to implement this double façade is ‘integrated design’. Utilizing an interactive skin means designing with a higher level of communication between interior/exterior, and a more closely integrated combination of systems. It is noted in Michael Wigginton’s *Intelligent Skin* that the skin is the largest organ of the human body, fully integrated into the performance of every other organ. The comparison continues with the central ‘brain’, the building management system, its sensors, actuators and command wires connecting the skin to the rest of the building and its occupants (Wigginton, p. 27).

The main objective of integrated design is to initiate a dialogue between every discipline right from the outset of the project. Every specialist must add his two cents together to determine the most effective way of executing the proposed project. This front-end approach to the design process has even begun to change the specialties of the specialists. In Sara Hart’s article, “Born Again…”, she says that in order for building owners to determine the best course of action, “facade consulting is [becoming] a growing multidisciplinary specialty in the architecture profession” (Hart, 2005, “Born Again …”).

This section illustrates how multiple factors determine the effectiveness of the system. Without considering even one of the following integrated components, the system would fail to reach its full potential. Moreover, without careful collaboration between designers, engineers, manufacturers and contractors, the building owner will not get what he paid for.

Integrated Components

Building Orientation/ Surrounding Environment

Building orientation is the most important aspect of design when considering this technology. It determines which sides of the building will receive the double façade treatment. Typically, it is the south and perhaps either east or west. Solar radiation drives the ventilation process, and thus the thermal performance of the façade. Since the north façade (in the northern hemisphere) is in shade all day, it must be designed separately. In areas of stronger winds, however, it is the prevailing winds that drive the façade, and so architects must design according to the windward/leeward sides of the building (see UMNO building, Malaysia). In respect to both solar radiation and prevailing winds, solar and wind shadows created by nearby buildings or geographic features will also determine the design, perhaps even ruling out the use of the double façade altogether.

Building Management System (BMS)

Any well-integrated design requires communication between interior and exterior, and between building and user. This necessitates the incorporation of a BMS – a network of controls connected independently or centrally, operated automatically or manually, that measure and respond to both external and internal stimuli. Some systems can measure rainfall, wind speed, and occupancy density. Herzog's Design Centre in Linz, for instance, has ventilation valves controlled by an elaborate 'learning' computer system linked to 2500 sensors that initiate a response and provide feedback.

Cole Roberts, a senior consultant at Arup's San Francisco office explains the three basic ways a hybrid ventilation system can be managed: active, seasonal lockout, and informed occupancy (Solomon, 2007). Informed occupancy refers to cues or alerts that notify staff to make necessary changes. In the case of the Salt Lake City Library, librarians draw and pull back shades daily. In seasonal lockout, the custodial staff makes changes such as closing vents at the change of the seasons. Active control uses this BMS system to automatically respond to environmental conditions.

The human factor is of utmost importance when designing for comfort. An inspiring example of BMS is seen in the Biodesign Institute at Arizona State University (a conventional façade building). There the occupants can control shading louvers from their PC terminals.

The average building occupant, operator or manager often needs to be educated about how not to interfere with the system's proper function. Yet, secondary override controls allow individual control of motorized blinds. People know what they want more than a computer system, thus the necessity for such override controls. Solar control contractors

Hunter Douglas reference use of BMS in previous projects on their website. One of their strategies is to allow the system to update future advances in technology. A flexible BMS is a functional one.

Simulation Modeling Software/Computational Fluid Dynamics

Integrated systems such as the double façade require modeling software to assess their efficiency in real-world, building-specific simulations. The fluid dynamics of wind loads, pressure differentials, thermal transfer, and daylighting as they function on a daily and seasonal basis must be measured. The physics required to evaluate and engineer these systems can only be realistically measured using complex software that, unfortunately, is being developed mostly on a proprietary basis (Arup has in-house software developers). The Berkeley report (Lee, 2002) lists ten commercial software programs for energy simulation, daylighting, etc… (http://gaia.lbl.gov/hpbf/perfor_b.htm). Most effective simulation models that have been developed are so complex that they become inaccessible to anyone but their respective engineers. This makes collaboration difficult, but more importantly it reduces the confidence with which a designer can offer the energy-saving, comfort-raising benefits of the system to the building owner.

In any case, there are too many variables to consider in such a complex, integrated system in regards to micro/macro-climate. A mock-up is the only sure way to guarantee performance.

Open Plan

The performance of a double wall system is dependant on, among many other things, an open floor plan, higher ceilings with no plenum, and the right proportion of ceiling height to window opening. Concurrent innovations in under floor air distribution (UFAD) systems and daylighting work in tandem to make this component more popular with designers.

Atrium

Many buildings that use the double façade have an atrium. This plant-filled atrium can act as a filter to ventilating air as it comes into the building. During colder temperatures, the atrium can add moisture to the air. For hot, dry climates, that added moisture can cool incoming air. In polluted urban environments, it can remove particulates. In humid climates, however, the atrium will add humidity to the air, increasing the cooling load.

Radiant Slab Cooling

Chilled copper tubes in overhead concrete slabs can prove a very effective means of cooling and it can be used for heating as well. Its use is not well known in North America. In fact, Geoff McDonell, in his article on high performance glazing cites the ICT Building at the University of Calgary, Alberta, to be the only facility in North America using a radiant slab for cooling as well as heating through the entire facility (McDonell, 2002). Radiant slab heating/cooling is known to be more comfortable than other techniques. Foster and Partners’ Philology Library of Berlin’s Free University has embedded water pipes in concrete which heats and cools recirculated air. The library is an example of how the double façade can be made more efficient with radiant slabs. Another German example of radiant slab use is the Commerzbank, also by Foster and Partners. There, the radiant slab ceilings are cooled by an absorptive chiller.

Underfloor Air Distribution (UFAD)

The double façade system necessitates the use of UFAD, another IAQ innovation. As mentioned earlier, successful natural ventilation requires higher ceilings. This can be provided with UFAD. Every double façade building uses this type of air distribution, though it is not always mentioned in literature focusing specifically on the ventilated façade.

Human Comfort

Buildings were made for people, and man is the measure of a building's comfort level, not a thermostat. This section examines how human comfort can be best satisfied when the architect mimics the natural environment indoors and when he allows occupants to control their environment. The double glass façade is an innovative method of incorporating a natural environment which mimics the exterior while allowing more sophisticated user controls. This makes it a smart choice for architects interested in human comfort.

Most contemporary buildings have sealed envelopes with HVAC systems engineered to deliver a constant, uniform environment. Not only is this method running up higher energy cost, it maintains very unnatural conditions. In Barbara Knecht and Sara Hart's article titled "Commercial Buildings Open Their Windows", David Bearg, an engineering consultant on IEQ states, "The more an indoor environment replicates the environment that humans evolved in [the exterior environment], the more comfortable people will find it" (Knecht, 2005). The miracle of modern HVAC is being misused. ASHRAE 55's all-purpose comfort zone is unreal. Humans need an environment in which the temperature, air velocity, and humidity fluctuate both daily and seasonally.

Even more important to occupants than environmental fluctuation is their ability to control the environment itself. James Steele devotes an entire chapter of his *Ecological Architecture* to natural ventilation and user control. Here he mentions the 'perception of control' as greatly influencing the user's 'perception' of comfort. He states that surveys show people who can control their environment by opening a window or adjusting a thermostat can tolerate an 18 degree change in temperature, as compared to mechanically ventilated building occupants, who will only tolerate a 7 degree change. An intelligent system combined with individualized localized override controls will provide the comfort that occupants prefer (Steele, 2005).

Productivity increase and energy cost decrease are the benefits of the sophisticated type of indoor environment that the double glass façade can offer. Take, for example, the Genzyme Corporation Headquarters in Cambridge, Mass. According to an *Architecture* magazine article, the building is estimated to see energy costs at 42% lower than similar buildings. More importantly stated in the article, Joan Wood, vice president of leadership and organization development at the headquarters claims a 5 percent lower sick rate and an 88 percent improved sense of well-being among employees (“Bright Green Machine”).

Providing a user’s manual which explains the role each occupant should play in controlling the function of the building, as McDonough and Partners did for an office project in Barcelona, might be taking the idea of ‘control’ a bit too far. Regardless, human comfort should be of utmost concern for the architect.

Use of Double Ventilated Façade in Europe vs. the United States

Upon researching the proliferation of double facade buildings one glaring pattern stands out – there are almost no successful examples of double facades in the US. Not only is there a lack of physical evidence, but the research on the subject, aside from one comprehensive report from Lawrence Berkeley National Laboratory (Lee, 2002), is all generated in the EU. There are four main reasons for this disproportion: the first is climate, next is energy cost, followed by experience with integrated design, and finally is the European communities’ demand for IEQ.

The Berkeley Lab report (Lee, 2002) states that it is dangerous to transfer a design solution from one climate to another without considering in detail how the system works. One must take note that although Europe has a similar latitude to the US, the seasonal temperature dynamics differ. Even near the lower latitudes of the Mediterranean, the summer temperatures are warm and dry at most. There are no humid climates in Europe as there are in the US. The cold extremes of Northern Europe can be dealt with quite effectively using double glass facades, but it is during the humid summers of the US that this form of natural ventilation fails to maintain our comfort. This single adversary – latent heat – is the most crucial of the double façade’s shortcomings. (Note that the prominent “high performance façade report” published in the US comes from Berkeley, California – one of the truly temperate climates in the US). It can be ameliorated, however, with intelligent, integrated use of mixed-mode HVAC, radiant slab cooling, and desiccant dehumidifiers, all of which are new to US architects and tradesmen.

The next most critical split between the EU and US is energy cost. Building owners want to see the bottom line, but are not willing to do the math required to prove the cost savings of integrated design and innovative energy efficient technologies. However, the newly-formed leverage used by proponents of sustainable building – first cost vs. operating cost – provides strong support for the use of expensive glazing and higher design fees.

Despite this total cost issue, quite an interesting flip-flop occurs between the EU and US regarding the design, construction and operation of double facades. An article by Lang and Herzog sheds light on this relationship, giving us a great explanation as to why double facades are more prevalent in Europe (despite the climate difference). The article states that in Europe, the double façade is twice the cost of a conventional curtain wall, but four to five times the cost in the US. This combined with US architect and contractor inexperience drives first cost upward. Consider now that energy cost in the EU is significantly higher than in the US. An energy efficient building's operating cost rings up more savings in less time. Thus, the double façade, or any new energy-efficient method, is much harder to justify here in the US where we burn kilowatts by the dime.

With any innovative technology, lack of experience keeps most designers reluctant. The demand for double façade technology is not strong enough for our designers to pay for the learning curve. Inexperienced workers who can not properly integrate and install the system cause poor efficiency rates (see 'unitization' in *Basic Components* section). Various published documents throughout Europe based on real buildings, and a strong public demand from European office workers for better IEQ informs and motivates architects to find cheaper, faster ways of implementing double facades. Organizations and universities then follow up to prove its effectiveness and generate awareness. In places like Germany, where healthy IEQ is the law, legislation mandates that every workstation in new commercial buildings be in direct sunlight (Slessor, 1997). There, architects must consider double facades.

Potentially Negative Issues Regarding Double Ventilated Façade

At this point, in both Europe and the US, poor performance of the double ventilated facade should be considered in the context of the individual building. So many variations exist, and the success is so inextricably dependant on integrated design and collaborative work efforts, that a general conclusion about the performance of the double ventilated facade system can not be made. That being said, some problems that have occurred will be listed here.

The issue that has the most potential for negative effect is the complexity of the system. There are so many components that must be integrated into a well-engineered whole, that most teams, especially the inexperienced, are not advanced enough to realize the full potential. The current lack of 'user-friendly' simulation modeling software in the public domain maintains poor assessment capabilities.

It is noted in an international conference on passive and low energy cooling for the built environment (Butera, 2005) that "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." (Butera, p. 166). Notice, however, he is talking about *fully glazed* buildings, when, of course, it was mentioned in the previous section that the Bestfacade study cites only the South and East facades as acceptable for ventilated double façade. To assume that a ventilated double façade is a *fully glazed* building is to be misinformed of its true purpose and potential. Surely as any well-studied sustainable architect should know, no two facades, even of the same building, should be the same.

Other negative issues include reduced floor space due to the cavity between facades. Fire safety can pose a threat if there is no partition between floors in the cavity. Also, firefighters have to break through two layers of glass to enter the building. Construction weight is increased. People sitting next to the window may be warm in summer when hot air is flowing through the cavity. When windows are open, noise pollution may proliferate through the cavity making its way from one room to another or from floor to floor. Cost is always brought up as a possible disadvantage, but any sustainable system must be viewed as a long term investment where first cost is negated by operating cost over a number of years. (As energy prices become more expensive, the negation of first cost will accelerate).

The previous issues are minor, meaning they can be solved with minimal alterations to the technology. The most worthy opponent of the ventilated double glass wall façade system at this time, however, is humidity. Solar gain can be removed by air flow in the façade cavity, but in climates where high numbers of cooling degree days are caused by humidity (New York City, Washington, D.C.), any natural ventilation brings with it moisture that puts heavy demand on the cooling system. Desiccant dehumidifiers, which draw moisture from the air, may become an added integrated component to this system.

Here it should be mentioned that with distinction to the double glass façade is another type of double façade where the outer skin is not transparent. This type can be applied in hotter climates. One example is the CalTrans 7 Building in Los Angeles, California, by Morphosis Architects, where the intelligent second skin blocks solar gain and opens when in shade. Also, Foreign Office Architects of London wrapped 98 units of a Madrid housing project in folding bamboo screens, allowing individual occupants to manually adjust their solar gain/daylighting.

Being the oldest double façade building in North America, the Occidental Chemical Building, originally known as the Hooker Building, provides real data on the performance and longevity of a double façade system. A report coming from the University of Waterloo School of Architecture (Harrison, 2007) provides the following information. Excavation due to new construction in front of the building increased the amount of dirt accumulating in the wall cavity, and so the intake grilles at grade had to be covered with plywood. Air was then no longer drawn through the cavity, and upper floors became too hot. Also, the louvers ceased to function and were never fixed, allowing excessive solar gain to enter. Occupants tried to mitigate the extra heat with vertical blinds. Clouding has formed on the inside of the exterior glass.

The author makes note that a failed buffer facade system leaves this building in a very inflexible position. The skin is sealed shut, whereas in other more dynamic systems the skin may still open to allow fresh air. Also, mechanical dependence of operating vents, dampers and louvers makes them susceptible to inevitable complications. Maintenance of this kind is a cost rarely mentioned in double facade research.

Case Study Surveys

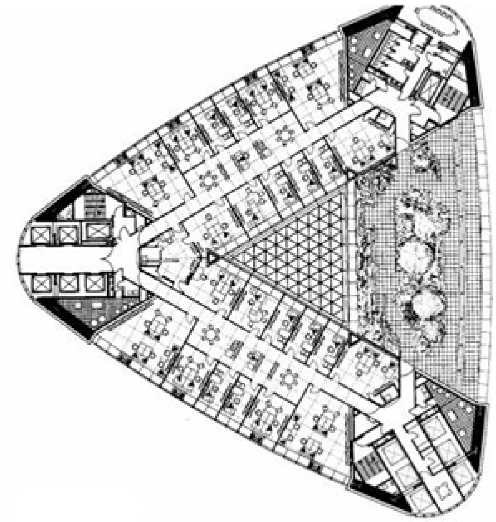
Every building is different. Thus, every example of double façade changes from one building to the next. Following is a list of examples researched on the Web, showing a variety of possible configurations. Post-occupancy data at this time, both in Europe and the US, is lacking. Germany stands out ahead of the rest of Europe, however, and there is more data available for their buildings. Another exception in terms of post occupancy data is the Hooker Building/Occidental Chemical Center in Niagara Falls, NY (This data was mentioned above in the *Negative Issues* section. The objective of this brief case study is simply to show the variety of possible applications for the double façade.

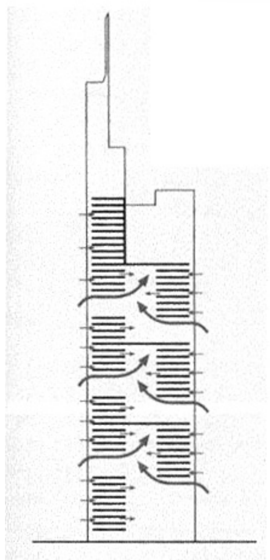
Note should be made here that despite the variety of architects listed, Arup associates almost always has some hand in the design of these buildings, usually as the structural engineer. Their advanced proprietary software enables them to deliver cutting edge, thoroughly modeled technologies. Also, in most of the projects listed here, a façade engineer has been a crucial person in the successful design of the double ventilated façade.

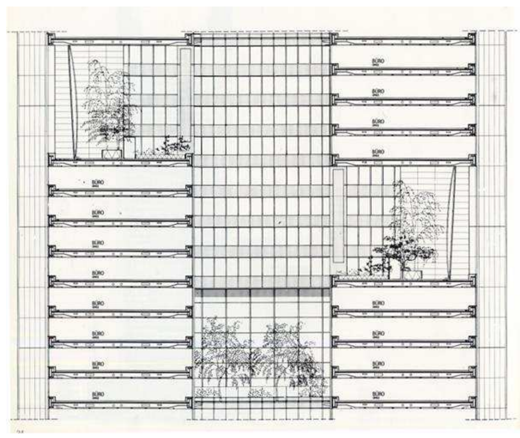
Commerzbank Headquarters
Foster and Partners
Frankfurt, Germany
1997

Germany sets the benchmark for double ventilated facades. The Commerzbank is claimed to be the world's first ecological high-rise tower. Consequently, post occupancy data is more available in Germany than anywhere else, giving us rich data regarding energy efficiency and occupant satisfaction. For instance, Dr. Horst Gruneis, director of Commerzbank's Central Building Department, reports on an MIT webpage that "We are given lots of praise when our office workers leave at night and tell us that they don't feel tired – this means that their productivity increases. This is more important to me than great architecture or sky gardens" (Commerzbank, 2007).

The success of the double ventilated façade here is a direct result of intelligent, integrated design, starting at the overall building design level. In section, the building is a triangle with a full height atrium in the center (see image below). Four-story 'Sky Gardens', atriums placed in between the inner and outer layer of the glass façade, are placed on each side every eight floors. This smart design allows every floor access to the massive atrium across the triangle (see sections illustrated below). As stated earlier in the 'Building Components' section of this report, atriums provide pollutant removal and humidification in dry winter weather when used in conjunction with the double façade system. Absorption refrigeration running on municipal steam chills the ceiling slabs on hot days.







images taken from
http://web.mit.edu/meelena/www/urban-nature/template-mainframe-commerzbank.html

If climatic conditions shift abruptly or are ignored, pressure differences, high temperatures, or condensation can occur. Thus, while the operable windows on the inner façade are individually controlled, the central BMS will override if necessary.

As mentioned, post occupancy data is readily available, uncovering problematic features of the design. Not only acoustical noise, but also smells from the cafeteria travel freely throughout the integrated network of atriums. Regardless, the building was measured to use 30% less energy than other German office buildings (Commerzbank, 2007).

Commerzbank. Accessed December 1, 2007:
http://web.mit.edu/meelena/www/urban-nature/template-mainframe-commerzbank.html

RWE Tower
Ingenhoven, Overdieck, Kahlen & Partners
Essen, Germany
1996

Touted as the first contemporary high-rise to be naturally ventilated, the RWE Tower is very special in the study of double ventilated facades because of its use of a biomimetic technology, the ‘fish-mouth’ (they look like mouths only in profile, see images below).

These ‘fish mouth’ openings on the exterior regulate airflow depending on wind speed and prevent rain from entering. German curtain-wall manufacturer Josef Gartner and Company developed the “fish mouths” according to Computational Fluid Dynamics (CFD) analysis. Analysis caused them to vary the size of the fish mouths above the sixteenth floor due to different wind velocities. Careful planning was made in regards to building aerodynamics and wind pressure reduction. Besides regulating airflow, the curved design of the fish mouth reflects sunlight to the interior.

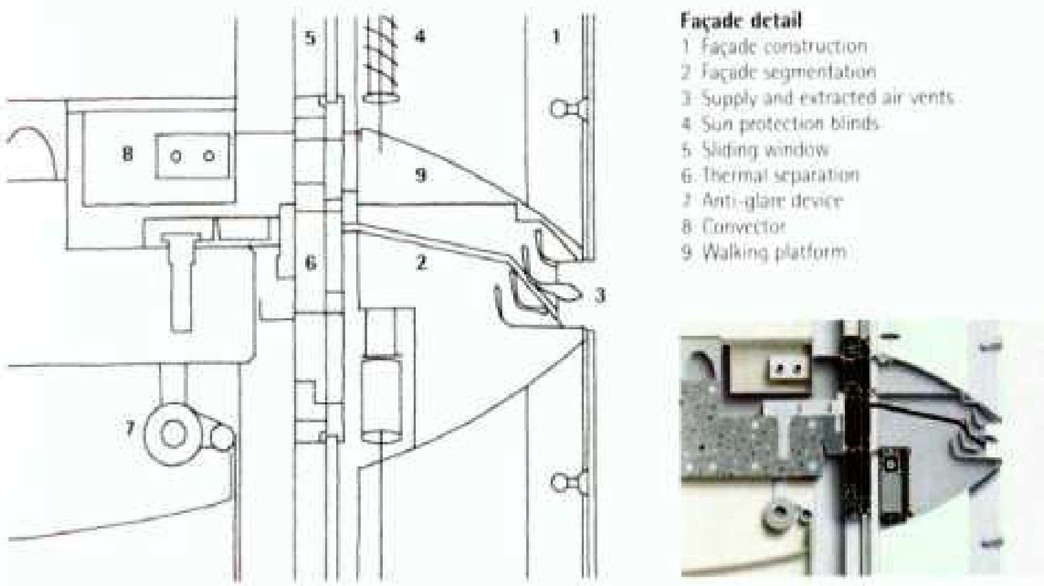
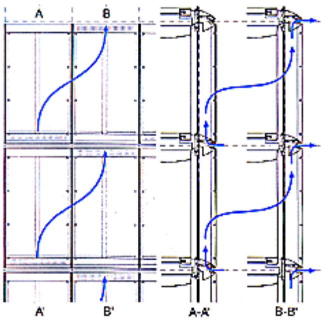
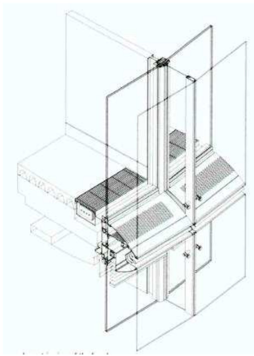


Image taken from
http://www.hku.hk/mech/sbe/case_study/case/ger/RWE_Tower/facade_detail.jpg

Images taken from
http://space-modulator.jp/sm81~90/sm86_contents/sm86_e_2skin4_txt.html





Images taken from
http://www.hku.hk/mech/sbe/case_study/case/ger/RWE_Tower/facade_axo.jpg

The BMS was designed to work in conjunction with the natural system, shutting off, for example, when it detects that someone has opened a window within a zone. It is also designed to monitor outside wind speeds and to sound a warning when they exceed certain limits.

Architects of RWE considered fire safety into the design by allowing the fish mouths to 'exhale' smoke. The pressurized space of the emergency stairs and corridors keep smoke from entering.

The cost of the façade for the RWE Tower ran 30% of the total construction cost, the typical cost in Germany for such buildings being 20-24%. Energy reductions are expected to offset this cost, but no post-occupancy energy data has been posted as of yet.

A life-size model was constructed to analyze the increasing force of the ventilating stack effect created by hot air between facades.

A water-flushed pipework system integrated into the concrete ceiling soffits cools the building during hot weather. On the Southwest façade, temperatures above 86 degrees F were found for 10-70 hours on the box-type windows, and 10-40 hours for the perimeter. Temperatures above 79 F, however, were found for 85-180 hours on the box windows, and 85-125 hours on the perimeter. In-depth analysis of summer conditions can be found at the following website:
http://www.hku.hk/mech/sbe/case_study/case/ger/RWE_Tower/rwe_index.html#3.4.

RWE Tower: A New Phase of Ecological and High-tech, *Space Modulator*, n.86, 1999. Accessed December 1, 2007:
http://space-modulator.jp/sm81~90/sm86_contents/sm86_e_index.html

Swiss Re Building
Foster and Partners
London, England
2006

Said to be London's first environmental skyscraper, this double ventilated façade is a symbol of the green future for most Londoners. Though the building is reported use 50% less energy than a traditional contemporary, no post occupancy data verifies that claim.

The most evident of the building's integrated components related to the double facade is its shape. The aerodynamic, curved shape minimizes wind loads and maximizes natural ventilation. The atrium is its most identifying interior characteristic. A spiral atrium where each floor is rotated 5° from the plan of the floor below facilitates ventilation. The atrium here is interrupted every six floors by air-purifying gardens that also act as fire-safety partitions.

The double-wall cavity is ventilated by exhaust air from the offices.

The detail photo below, taken from www.art-andersen.dk , shows fixed solar blinds installed between two glass layers.

An automatic window-opening system supplements the air conditioning with natural ventilation. Here is another example of a BMS linked to exterior weather stations reading temperature and wind speeds. When the weather is right, almost 800 windows swing open to let in the outside air.

According to an article on emporis.com, the Swiss Re Building experienced a slight malfunction when one window pane fell from the 28th floor. The hole is covered with a wood panel, and is only one of many that perforate the smooth, glazed façade.

30 St Mary Axe. Accessed December 1, 2007:
http://www.emporis.com/en/wm/bu/?id=100089

Barker, Don. Swiss Re Tower by Foster and Partners, *ArchitectureWeek*, n. 238, May 2005, pD1.1. Accessed on December 1, 2007:
http://www.architectureweek.com/2005/0504/today.html

Compton, Tristran. News: Glass Falls From Tower, <emporis.com>, Apr. 2005. Accessed on December 1, 2007:
http://www.emporis.com/en/bu/nc/ne/?id=101346

Swiss Re Tower Tests 'Green' Windows. Jun. 2006. Accessed on December 1, 2007:
http://www.propertyweek.com/story.asp?storyCode=3060792

London's City Hall
Foster and Partners
London, England
2002

Another curved form using the ventilated double façade comes from London. Once again, the building shape is of great importance to the performance of the building, so much that the glazing on the southern façade is unshaded. This modified sphere is designed so that on the southern façade each floor is shaded by the one above.

In the image below one can look up through the atrium. In the only thorough article referenced on this building, found in *ArchitectureWeek*, no mention was made of how this atrium was partitioned for fire safety.

Due to the use of the double façade, the building is expected to save 75% of its mechanical systems energy costs. When climatic conditions permit, the BMS deactivates that mechanical systems, and opens the exterior façade vents. Ventilation then enters the interior through the underfloor distribution system. During winter, heat and moisture are recovered from exhaust air.

To attack the problem of warm weather (notice that in London, it is 'warm' weather, as opposed to New York City's 'hot and humid'), cold water is raised from an aquifer 410 feet underground. The most interesting adaptation of this system is that certain horizontal members on the diagrid framing structure are hollow, allowing both cold and hot water to flow through them. This creates, as Don Barker in his ArchitectureWeek article calls it, "the largest radiator in London".

Barker, Don. Foster's New City Hall, *ArchitectureWeek*, n. 136, p. D1.1, Feb. 2006.
http://www.architectureweek.com/2003/0226/index.html

Salt Lake City Library
Salt Lake City, UT, USA
Moshe Safdie and Associates,
Valentiner Crane Brunjes Onyon Architects
2003

Images taken from:
http://www.architecture.uwaterloo.ca/faculty_projects/terri/steel/salt_library.html

The curved south side of the Salt Lake City Library has a five-story double glass façade acting as a thermal barrier while allowing in the maximum amount of daylight. Sunshades can be seen in the bottom of these photos. The small, possibly canvas, sheets must be opened and folded back manually by the librarians every day.

One of the key motivators for choosing this system may have been daylighting, as it is essential in a reading-intensive building. Note also, however, that a major problem inherent in libraries is mold. Being that the double façade does not, at this point, manage humidity well, it would not be a wise choice for a library in any other climate besides the dry desert of Utah. Regardless, the 100 degree summers there make the case for the double façade's ability to maintain comfortable temperatures in extreme heat.

Boake, Terri Meyer. *Salt Lake City Library*. University of Waterloo School of Architecture, updated May 14, 2006. http://www.architecture.uwaterloo.ca/faculty_projects/terri/steel/salt_library.html

Salt Lake City Library. Accessed December 1, 2007: http://archrecord.construction.com/projects/bts/archives/civic/04_SLCpubLibrary/specs.asp

Melvin J. and Claire Levine Hall,
School of Engineering and Applied Science,
University of Pennsylvania
Philadelphia, PA, USA
Kieran Timberlake Associates
2001

Mentioned previously for its use of unitized panels, Levine Hall uses an active, pressure-equalized, double-skin curtain wall. The mechanically ventilated cavity between two glass walls has an inlet at the base of each frame supplies the cavity with air from the interior rooms, while an outlet at the top draws tempered air back into the room.

Blinds located in the cavity absorb solar radiation, which is then exhausted by the ventilating cavity. This strategy leaves the surface of the inner glass within 1-2 degrees of the room temperature.

The unique feature of Levine Hall is its unitized custom aluminum frame – completely fabricated and glazed off-site. Its off-site fabrication allows fewer room for errors, leading to higher energy efficiency and tighter construction overall.

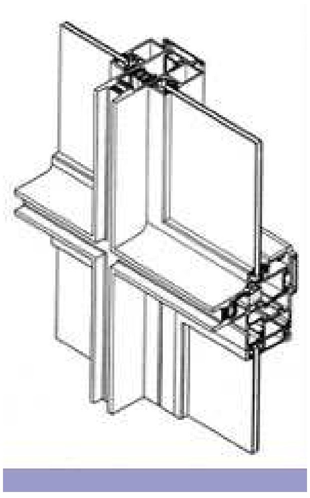


Image taken from:
http://www.kierantimberlake.com/research/curtain_wall_1.html

Images taken from:
http://www.kierantimberlake.com/pl_sustainability/levin_hall_1.html

Hart, Sara. Seeking Innovative Alternatives, *Architectural Record*. Accessed December 1, 2007:
http://archrecord.construction.com/innovation/2_Features/0310KieranTimberlake.asp

Levine Hall. Accessed December 1, 2007:
http://www.kierantimberlake.com

Seattle Justice Center
Seattle, WA, USA
NBBJ Seattle
2002

This LEED Silver, 9-storey high heat extraction double-skin façade uses automatically controlled louvers at roof level to release or retain heat gain. Interior lightshelves act as shading devices.

NBBJ Architect, Kerry Hegedus, cites very thorough research and development from Arup. He also mentions how Arup, with their vast experience in ventilated facades, helped to convince the client.

Hegedus, Kerry, NBBJ Architects. Convincing the Client: A Double-Envelope Façade at the Seattle Justice Center, Workshop Talks Given at Southern California Edison, April 30, 2001. Accessed December 1, 2007: http://gaia.lbl.gov/hpbf/design_g4.htm

Seattle Justice Center. Accessed December 1, 2007: http://leedcasestudies.usgbc.org/overview.cfm?ProjectID=225

Telus Building
Vancouver, BC, Canada
Busby, Perkins and Will
Original Construction: 1947
Renovation: 2000

The double glazed façade is suspended from the existing building face (making this a triple façade system). A sophisticated natural ventilation system run by electronic temperature sensors allows all perimeter windows to be operable. Fritted glass reduces higher angle solar gain. Photovoltaics power the vent fans.

Though this double façade was chosen to provide a 'futuristic' aesthetic for Vancouver's downtown, it still stands as a successful implementation of the system in North America.

Telus Building. Accessed December 1, 2007:
http://www.busby.ca/clients/9805telus/index.htm

http://buildingskins.blogspot.com/2007/10/double-skin-facades-canadian-examples.html

http://www.advancedbuildings.org/main_cs_bc_telus.htm

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http://archrecord.construction.com/features/green/archives/0509edit-1.asp

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"Double-skin facades and natural ventilation", p.18-28
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http://greensource.construction.com/tech/0707_Kirschcenter.asp

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