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Authors:	Marc Zobec, Permasteelisa Group Massimo Colomban, Permasteelisa Group Mikkel Kragh, Dow Corning Corporation
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BUILDING SERVICE SYSTEMS

An Integrated Design Approach to the Environmental Performance of Buildings

M. Colomban, M. Zobec and M. Kragh

1.1 ABSTRACT

The present paper deals with the complex relationship between architectural intensions, indoor environment, building envelope and environmental systems, energy performance and design process. The development of architecture and the construction industry is discussed with focus on the way design used to be adapted to, and responsive to, local climatic conditions and later on, with commercialisation neglected these aspects and relied on mechanical systems for fully air conditioned buildings. This development resulted in energy consuming buildings with poor occupant comfort. The paper introduces Blue Technology, which is based on integrated design of building envelope and environmental systems, facilitating design of buildings with high levels of occupant comfort and reduced energy usage. Problems and solutions pertaining to transparent building envelopes and the need for integrated design are discussed. Moreover, the financial incentives in terms of tax legislation and potentially increasing productivity are introduced, supplementing the performance related aspects. At the Permasteelisa Headquarters in Italy, a series of full-scale test rooms have been set up in order to test and demonstrate different combinations of façade and environmental system technology. The test room activities are described and a case study is presented as an example of innovative thinking and the potential of an integrated design approach. Finally the recently established architectural Internet portal BuildingEnvelopes.org is introduced. In recognition of the need for dissemination of knowledge and guidance, the portal is dedicated to building envelopes and environmental systems and will constitute an important point of reference for the future.

1.2 BACKGROUND

The first American house built in war-time Java completely bewildered natives there. Instead of building walls of local bamboo, which is closely spaced to keep out rain while admitting light and air, the white man put up solid walls to keep out light and air, and then cut windows in the walls to admit the light and air. Next, he put glass panes in the windows to admit light but keep out the air. Then, he covered the panes with blinds and curtains to keep out the light too (Moore, 1993, adopted from Ken Kerr, 1978).

1.2.1 Building Form and Function

Throughout history, the building envelope of monumental structures has attempted to embody the complex relationships between functional and cultural elements. The history of the building envelope can be described as constant research and development of the following functions:

- Protection: *rain, cold, heat, solar radiation and intrusions*
- Prestige and identity: *dimension, materials and decorations*
- Comfort: *light, ventilation, insulation, perception*

In modern times, buildings have come to represent both corporate and individual identity (much like the palaces and temples of the past). Throughout history; up until the early post WWII years, architectural response to the climate was an integral part of professional architectural education. Unfortunately from the 1960's to the present day, the principles of designing with the climate; or using bio-climatic principles, was almost negated. Architectural institutions no longer focused on teaching fundamentals of building physics and the design of the mechanical system was focused on the suppliers of the mechanical plant. With the advent of mechanical air conditioning, building designers were free to pursue and give precedence to purity of form over human comfort. It was by no coincidence that the suppliers developed most of the HVAC design standards, manuals and software packages used by HVAC engineers. Whilst the research undertaken to develop such standards and systems has facilitated quick development of design, there has been a clear demarcation between the services engineers and architect regarding design responsibility. The inside of the office building became a deep-plan space, artificially both illuminated and ventilated throughout the day. The sealed concrete/steel and glass box was the only option. In urban environments, this of course has some justification due to land prices being at a premium as well as shielding occupants from noise and pollution.

At the same time as the 'sealed glass box' came into popularity, the face of the construction market also changed considerably. Unlike monuments of the past, which were occupied by the owners, buildings began to be seen by owners as a source of financial investment. Construction was beginning to be driven by fundamental market forces and a great deal was undertaken by speculators and developers, who had no intention of occupying the building, but rather saw three fundamental obstacles regarding the façade: cost, timing and warranty. Returns on investments and 'maximum nett lettable area' took preference over occupant comfort.

The designers of HVAC plant are usually commissioned far earlier in the design process than the façade contractor. HVAC designs are therefore carried out based on assumed façade performance parameters rather than adopting an integrated design approach or using what is termed *Blue Technology.*

1.2.2 The Philosophy behind Blue Technology

With the current boom in information systems, the word technology usually conjures up images of technical complexity such as computer chips. On the contrary, *Blue Technology is the understanding of fundamental building physics principles applied in a manner, which enables HVAC and façade to be designed as an integrated, synergetic system rather than individual components.*

Normal glass is almost completely transparent to short wave solar radiation (visible and near infra red) but is a barrier to long wave radiation. As solar radiation strikes the façade, the solar energy passing through the glazing tends to warm up the various internal surfaces by absorption, and these internal surfaces become heat radiators. However, the re-emitted heat is long wave radiation to which glass behaves as a barrier causing the building temperature to rise. This effect is commonly referred to as the 'Greenhouse' effect. Once heat is trapped inside a room, it can be removed by:

- Natural ventilation
- Mechanical ventilation
- Full air conditioning
- Radiant cooling by chilled surfaces and/or building thermal mass

The development of high performance solar coatings on glass has made significant improvements in reducing heat gains yet there is still a down side. In recent years, transparency in architecture has become most desirable. In architectural terms transparency is most associated with maximum natural daylighting. Since more than half of solar radiation is visible light, with high performance glazing, reductions in heat gains result in reductions in natural daylight. Most HVAC systems are also designed on the basis of short duration peak cooling loads and therefore in order to reduce heat gains for a brief peak loads, transparency or the use of natural daylight is limited or even sacrificed.

The problem remains to optimise transparency whilst minimising heat gains and achieving buildings with optimal internal comfort. It is important to note that it is not possible to air condition against direct solar heat gains. Current full air HVAC systems only treat the problem of building conditioning and do little towards preventing the primary problem associated with cooling loads … solar heat gains. Many alternatives to full air conditioning systems exist (i.e. chilled ceilings), but since the capacities of such systems are limited, reductions in cooling loads must be possible. The obvious solution is not to treat but prevent the problem altogether, starting at the source … the façade. By excluding or reducing solar gains, the internal environment can be significantly improved and capital, maintenance and operational costs can be reduced.

The main obstacle is not a matter of available technology, but reluctance due to a combination of problems. Research endeavours aim at resolving these as indicated in the following table:

Table 1.1 Transparent building envelopes – problems and solutions

Problems	Solutions
• Clear demarcation between the architect and building services designers. • Conventional building 'practices' in obtaining the expertise of the façade and services engineers at different stages of the project development. • Misunderstanding of building physics principles. • Over reliance on proprietary software, which may not allow the input of parameters other than those related to conventional full air systems. • Lack of adequate design tools, details and cases studies of completed projects	• Promoting an integrated approach to the design of the façade and the environmental system. • Undertaking an R&D test program, which verifies and quantifies the performance of alternate simpler integrated façade and HVAC systems. • Documenting case studies of completed buildings and their performances. • Developing a series of inexpensive design tools, which enable building designers to undertake simple preliminary simulations. • Effectively disseminating and sharing experiences within a global information medium available to the global construction community.

There is a pronounced need for a common language in order to characterise and communicate the performance of innovative systems such as the mechanically ventilated façades

1.3 INTEGRATED BUILDING ENVELOPE AND ENVIRONMENTAL SYSTEM DESIGN

1.3.1 Transparent Building Envelopes

Transparency in architecture has always been desirable and the problem has always been to realise a transparent building envelope without compromising energy performance and indoor climate. For years the development of advanced façade and environmental systems has aimed at creating fully glazed buildings with low energy consumption and high levels of occupant comfort. Ventilated double skin façades reducing solar gains in summer and providing thermal insulation in winter is an example of a technology, which is becoming still more common.

1.3.2 Integrated Design

Intelligent application of advanced façade technology in conjunction with innovative environmental systems results in significant energy savings and – at the same time – improvement of indoor comfort. It has been shown that, when designed carefully, innovative systems do not represent additional initial costs, running costs are lower and energy costs can be reduced by approximately 30 per cent compared with conventional solutions.

> *Successful application of these systems depends closely on the adoption of an integrated design approach from the early, schematic phases of a given project*

Too often the façade design is developed when fundamental decisions, for instance pertaining to the layout of the ventilation system, have already been taken. At this point it can be too late to benefit fully from application of advanced façade solutions. If façade and environmental system are engineered as two parts of the same solution, not only will the performance most likely be superior – both initial and running costs may moreover be reduced significantly.

To this end, there is a need for a change of approach bringing together façade- and M&E engineers during the early design phases. Moreover – and this is a problem we experience frequently these days – there is a pronounced need for a common language in order to characterise and communicate the performance of innovative systems such as the mechanically ventilated façades. For instance, quantities such as U-value and solar factor are not readily applicable when the façade interacts with the ventilation system, and traditional ways of designing HVAC systems may not be adequate when assessing possible application of innovative solutions such as soft-cooling.

1.3.3 Financial Implications of Blue Technology

The emphasis that clients require in particular is the achievement of BEST VALUE.

Value management of the building envelope

In the UK, Government initiatives to secure best value have lead to changes from normal development, making ‘cost in use’ a key factor in the design. Local authorities must obtain best value when procuring goods and services and must comply with a rigorous regime of performance indicators and efficiency measures. The Authorities need to take into account whole life costing of the service or element.

Both central and local government is thus undergoing significant change. Similar strategic changes are also taking place in the private sector. The purchase decision is moving away from the lowest tendered costs with the focus being more on the cost in use benefits whoever the tenant is going to be. This issue is particularly relevant in the selection of an appropriate façade design.

Tax laws – the UK situation

The tax laws in the United Kingdom are uniquely favourable to technical development in environmental engineering generally and active façades in particular.

UK tax relief is given by way of capital allowance on plant and machinery that writes off the capital value effectively within 8–9 years. It covers for example all heating, ventilation and air conditioning systems, most and in some cases all electrical installations.

The stage is wide open to propose that active façades, which carry air as part of the air conditioning/environmental control system, should be treated as an air duct to the perimeter of the building. This of course will depend on the design of the wall itself (Glanville, 2000).

1.3.4 Comfort and Productivity

Energy-efficient building and office design offers the possibility of significantly increased worker productivity. By improving lighting, heating, and cooling, workers can be made more comfortable and productive. An increase of 1 per cent in productivity can provide savings to a company that exceed its entire energy bill (Romm and Browning, 1998). Efficient design practices are cost-effective just from their energy savings; the resulting productivity gains make them indispensable.

There has always been a consensus that the comfort of the occupants affected their productivity, but until now the hard data proving this have been lacking. The Rocky Mountain Institute (Romm and Browning, 1998) carried out a series of case studies of both new buildings and retrofits of existing ones, all demonstrating correlation between occupant comfort and productivity. The following are examples of the findings:

- Lockheed's engineering development and design facility, which saved nearly US$500,000 a year on energy bills and gained 15 per cent in productivity with a 15 per cent drop in absenteeism.
- West Bend Mutual Insurance's new building, which yielded a 40 per cent reduction in energy consumption per square foot and a 16 per cent increase in claim-processing activity.
- ING Bank's new headquarters, which used one-tenth the energy per square foot of its predecessor, created a positive new image for the bank, and lowered absenteeism by 15 per cent.

However attractive the gains in terms energy-efficiency retrofits for existing buildings, and new buildings designed for energy-efficient performance these gains are tiny compared with the cost of employees, which is greater than the total energy and operating costs of a building. Based on a 1990 US survey of large office buildings, as summarised in the graph below, electricity typically costs US$1.53 per square foot and accounts for 85 per cent of the total energy bill, while repairs and maintenance typically add another US$1.37 per square foot; both contribute to the gross office-space rent of US$21 per square foot. In comparison, office workers cost US$130 per square foot – 72 times as much as the energy costs. Thus an increase of 1 per cent in productivity can nearly offset a company's entire energy cost.

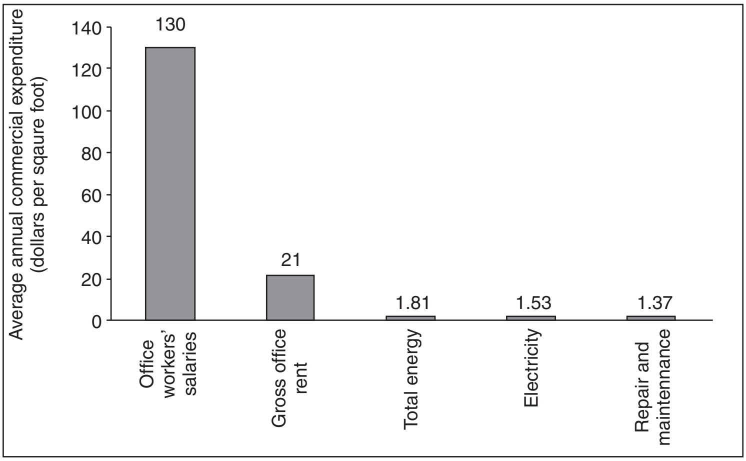

Figure 1.1 Data from Building Owners and Managers Association; Electric Power Research Institute; Statistical Abstract of the United Stated 1991 [Romm and Browning, 1998].

Productivity is measured here in terms of production rate, quality of production, and changes in absenteeism. This can be improved by fewer distractions from eye-strain or poor thermal comfort, and similar factors.

Will just any energy retrofit produce gains in productivity? No, only those designs and actions that improve visual acuity and thermal comfort seem to result in these gains. This speaks directly to the need for good design, a total-quality approach that seeks to improve energy efficiency and improve the quality of workplaces by focusing on the end user – the employee. This is a point that seems to have been forgotten by many designers and building owners (Romm and Browning, 1998).

1.4 PERMASTEELISA'S TEST ACTIVITIES

1.4.1 Test Room Monitoring

At the Permasteelisa Headquarters in Italy, a series of advanced façade solutions have been realised in conjunction with innovative environmental systems. Currently, a total of 10 full-scale test rooms are being continuously monitored in terms of energy consumption and indoor environment and another 4 rooms are in progress. The measurements will enable a direct comparison between different solutions exposed to identical climatic conditions and provide a basis for validation of both simplified and detailed engineering tools.

The building envelope configurations comprise double skin walls (naturally ventilated, mechanically ventilated indoor-indoor and outdoor-outdoor) demonstrating stand-alone systems as well as integration between façade and environmental system. Examples are the Active Wall, a double skin façade ventilated with room return air and the Interactive Wall, a double skin façade, mechanically ventilated with outdoor air by means of micro fans incorporated in the spandrel area. The environmental systems comprise variations of radiant systems as well as displacement ventilation.

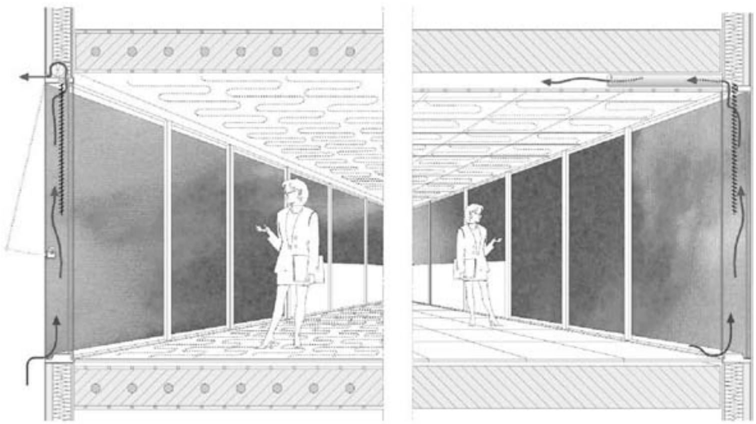

Figure 1.2 Schematic of the Interactive Wall (left) and the Active Wall (right).

For comparison, the innovative systems are installed side-by-side with conventional systems adopting high performance glazing and fancoil cooling and heating.

Figure 1.3 External view of the Permasteelisa test room facilities.

Initially the test rooms are not occupied and no internal loads are simulated. They are all kept at the same set point temperature and ventilation air is supplied at a rate corresponding to 2 air changes per hour. The rooms, which have radiant systems are being conditioned mainly by means of these, but the air volume is increased if the capacity of the radiant systems is not adequate, for example during peak load periods. It is important to note that the objective is to monitor combinations of façade and environmental system technology rather than one of the two.

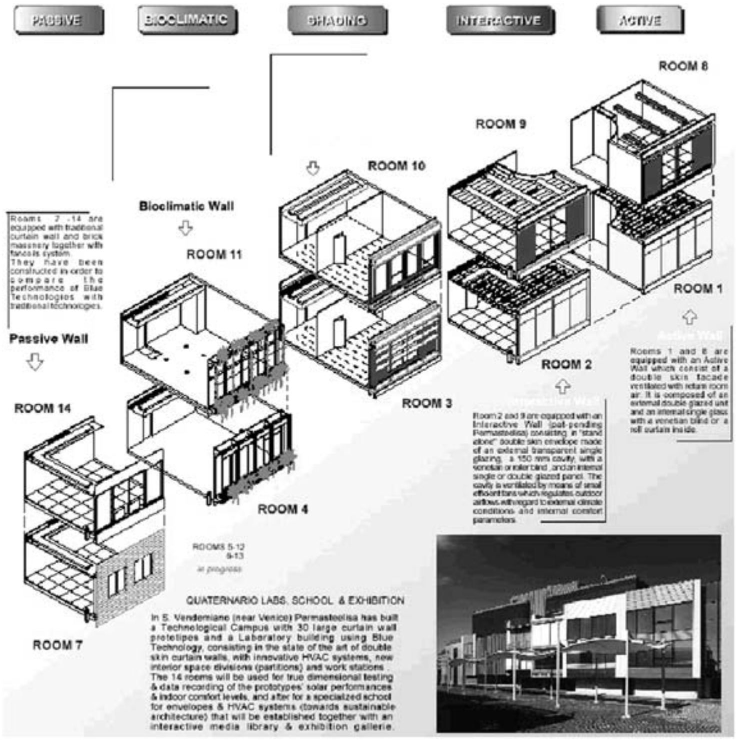

Figure 1.4 Schematic representation of the 10 operating test rooms.

1.4.2 Measured Parameters

Generally speaking, all of the rooms are continuously monitored in terms of energy consumption, ambient temperatures and humidity as well as surface temperatures across the façade (and cavity air temperatures when applicable) and solar radiation transmitted through the façade. Moreover, mobile instruments are available for series of daylight measurements. A meteorological station records the climatic conditions from the roof of the building.

Apart from providing a basis for assessment of system performance and a direct comparison between different solutions exposed to identical climatic conditions, the measurements will yield a basis for validation of simulation tools. The data will prove useful for validation of both existing and future software tools.

1.4.3 Publication of Results

The monitoring/control system has been operating since the summer of year 2000. Preliminary results yield trends, while the system is continuously being modified and improved in terms of both control and monitoring. Since the seasonal variations play an important part in the assessment of façade/HVAC performance, long-term measurement is essential. However, already now, studies of specific climatic situations and pertinent system performance are being carried out in collaboration with the MIT and the results will be published. Apart from publications in journals and at conferences and seminars, the results will be published through the architectural Internet portal www.BuildingEnvelopes.org, which is dedicated to building envelopes and environmental systems.

1.4.4 Preliminary Results

The following graphs show examples of the monitoring output. The specific case is a hot, clear summer day in August and the energy consumption for cooling is compared for two test rooms, both with fully glazed curtain wall: (a) conventional curtain wall and fancoil units (b) Interactive Wall and dynamic beams (cooling/heating by convection and radiation).

The outdoor climate is registered from a meteorological station at the roof of the building. The graph below shows the variation of drybulb temperature, relative humidity, solar irradiance on vertical and illuminance on vertical. The selected day is characterised by outdoor drybulb temperatures between 30 and 35°C and a maximum solar irradiance of 680 W/m2 (on vertical).

These extreme environmental conditions yield a good basis for comparison of two fundamentally different solutions. The following graphs show the cooling energy consumption as recorded for the two rooms. The difference in cooling consumption is due to both façade type and HVAC system.

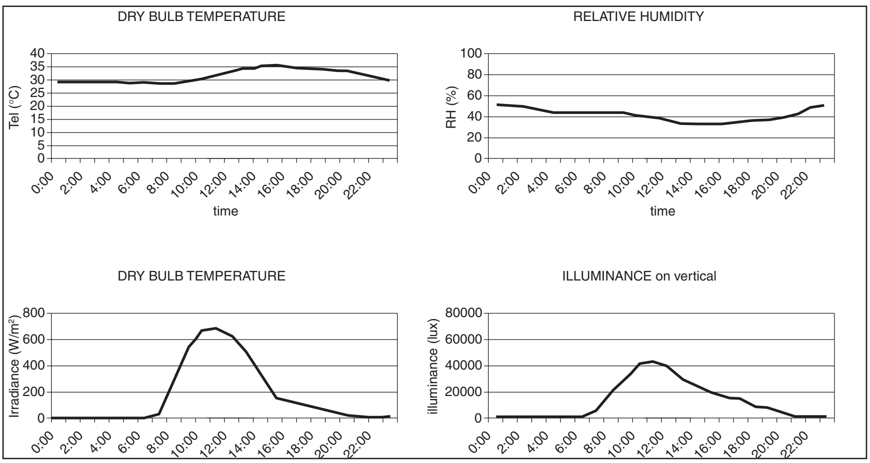

Figure 1.5 Example: hot summer day – outdoor climatic conditions.

Both rooms are conditioned mainly by means of water, with additional background cooling provided by the fresh air supply (two air changes per hour). The room with the Interactive Wall and dynamic beams is consuming between 1400 W and 1750 W, whereas the room with conventional curtain wall and fancoil units is consuming between 1900 W and 2800 W.

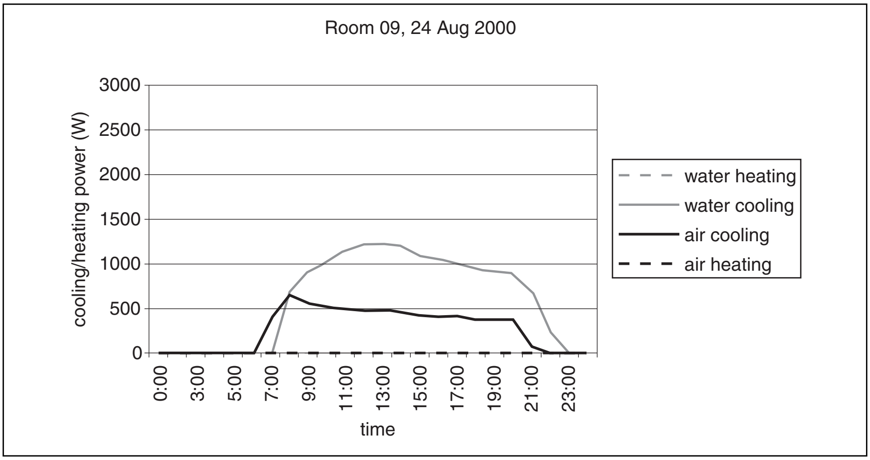

Figure 1.6 Example: hot summer day – Interactive Wall and dynamic beams.

The case demonstrates significant differences in consumption. At peak load, the room with the conventional curtain wall with high performance glazing and internal roller blinds is consuming approximately 60 per cent more than the room with the Interactive Wall.

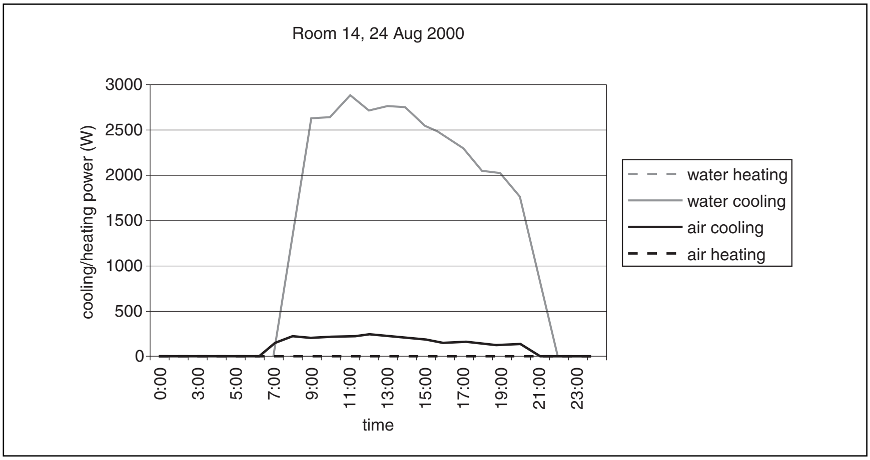

Figure 1.7 Example: hot summer day – conventional curtain wall and fancoil units.

The rooms are being studied in terms of both energy consumption and internal environment. In this regard, it should be noted that with radiant systems the same level of perceived comfort can be obtained with higher ambient temperatures (summer) as long as the operative temperature is acceptable.

1.5 CASE STUDY: THE UCB CENTER, BRUSSELS

1.5.1 Double Skin Façade in Conjunction with Chilled Ceilings

The following case study has been selected to illustrate the potential benefits of careful combination of advanced façade and HVAC technology. This particular case study describes the 'happy marriage' between a mechanically ventilated double skin façade and chilled ceilings as realised in the *UCB Center* by the architects *Assar* (Brussels) with the mechanical and structural engineers *Tractebel*. At a conference in the UCB Center, May 2000, the owner and the engineers involved presented both the initial analyses and the actual building performance the in terms of energy consumption and indoor environment.

Originally there was no intention to use double skin façades and chilled ceilings for the UCB Center. The project was proposed with conventional fancoil units. The directors of the UCB (Union Chimique Belge) wished to have transparent façades. Initially the chilled ceiling concept was considered, but rejected because of its limited capacity (soft-cooling) and the south exposure of the glazed main façade. Even with fancoil units, the thermal balance of the system would be at the limit. The architect's wish to increase the glazed area could not be met without introducing external solar shading, which would be in conflict with the whole design philosophy. These considerations lead to the idea of the double skin façade with solar shading positioned in the façade cavity. This type of façade poses an ideal compromise, offering a smooth, glazed external surface and, at the same time, providing the necessary solar protection. Mechanical ventilation was required in order to extract the solar heat from the façade cavity, but this was not a difficult problem to solve. Because of the solar protection provided by the ventilated double skin façade, the chilled ceiling (soft cooling) technology now became possible. A comparative cost analysis of the alternative solutions was carried out (Marcq & Roba, 2000). Both initial costs and expected running costs were compared. The conclusion of the study was that the solution with double skin/chilled ceiling resulted in better comfort and did not result in higher initial costs, compared with a solution based on conventional façade and fancoil units. The building has been in use for two years, and the expected advantages have all been confirmed (Vervaeck, 2000):

- Transparency, better view to the exterior, which is particularly appreciable because of the nature surrounding the building.
- Thermal comfort, summer and winter, without draughts and fancoil noise.
- Virtually non-existent maintenance of the chilled ceilings.
- Reduction of energy consumption.

1.5.2 Technical Details and Performance

The double skin façade (Active Wall) of the UCB Center is composed of an external double glazed unit, a 143mm deep, mechanically ventilated cavity and a clear single layer internal glazing. Motorised blinds are positioned in the ventilated cavity and controlled depending on the solar irradiance. The airflow rate is 40m^3/h per module (width 1.5m).

Figure 1.8 The UCB Center, Brussels, Active Wall and chilled ceilings.

Heating is provided by the supply air, which results in lower installation costs, and means that the glazing can be continued down to floor level (no fancoil units). The ventilation air is re-circulated when the building is not occupied. The temperature of the inlet air is regulated depending on the solar irradiance.

Cooling is provided by means of chilled ceilings operating with water at temperatures between 15°C and 17°C(!). The chilled ceiling is a capillary type in polypropylene, incorporating thermal insulation. The acoustic barrier is horizontal. In order to avoid condensation problems, the ventilation air is dehumidified.

The UCB have reported savings between 12 and 30 per cent on gas and between 39 and 44 per cent on electricity (Caudron, 2000).

> *Energy savings have been significant. Up to 30 per cent savings on gas, and up to 44 per cent savings on electricity.*

The chilled ceiling technology is reducing air movement and increasing occupant comfort. The absence of fancoil units at the façade increases the usable floor area. Utilisation of a static system such as the chilled ceiling leads to better acoustic performance than the dynamic fancoils. Furthermore, the acoustic insulation of the façade is improved due to the extra layer of glazing.

It is important to note that the soft-cooling technology, which leads to energy savings, is enabled by the thermal and solar performance of the ventilated façade. The performance is due to the successful combination of these two elements. If the chilled ceiling is to maintain a comfortable indoor environment, the cooling load cannot exceed 70 W per m2 floor area. In zones with higher cooling loads, such as conference rooms, additional cooling capacity is required.

1.6 WWW.BUILDINGENVELOPES.ORG

1.6.1 Academic and Industry Collaboration

Research in academia has traditionally been focused on basic research, in an effort to lay the foundation for future developments. Apart from some notable exceptions, academic research has been typically government funded, resulting in the demand for tangible results being less than industry carried research that aimed in the development of products and services to reach the market at the shortest possible time. However, is there another role for academia in the new Internet economy?

A main characteristic of the new economy is that information can be disseminated fast and can originate from different sources. Creating an online resource would allow both universities and industry to work together in creating an aggregation of knowledge sharing among those involved in the building industry.

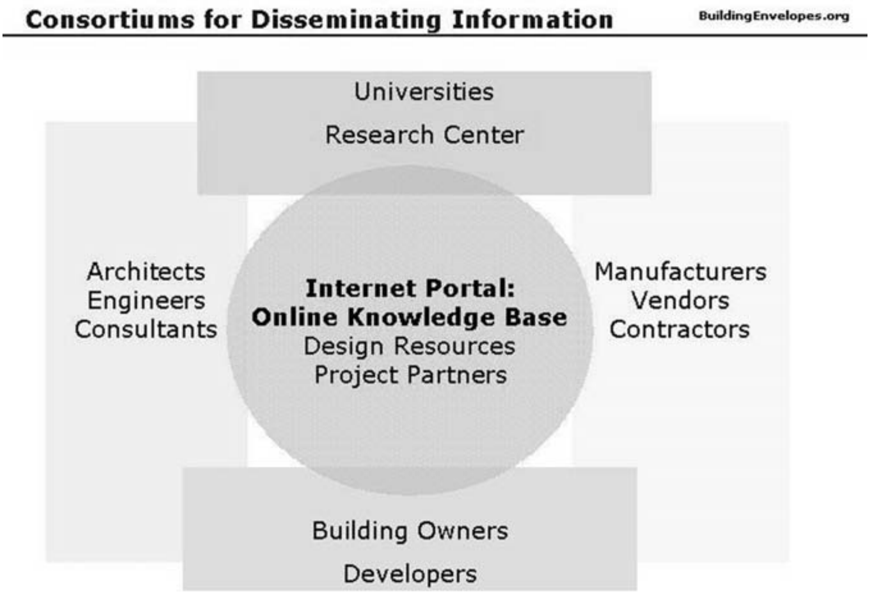

Figure 1.9 Internet portal consortium.

1.6.2 BuildingEnvelopes.org Portal

The result of this academic and industry collaboration is BuildingEnvelopes.org, an online knowledge base for the design and construction of innovative architectural envelopes and environmental control systems. An initial project archive was expanded to a portal because at the start of every new project, designers and owners are faced with two challenges: The *Design Challenge* and the *Information Challenge*. The Design Challenge continually grows as designers try to create state-of-the-art designs but are increasingly challenged by the rapid technical evolution that surpasses their know-how. This Design Challenge is exasperated because there is no single, reliable source of current information on the variety and number of products and systems available. These Design Challenges increase on international projects since local conditions, in terms of regulatory framework, climate conditions, or potential collaborators, are unknown. The second challenge, the Information Challenge, is created because suppliers and manufacturers are constantly challenged with keeping the designers informed about new systems and products. However, catalogues and brochures are unsatisfying because they can become outdated very quickly. This leads to the possibilities of integrating their products and services being limited when suppliers and manufacturers are involved late in the project development.

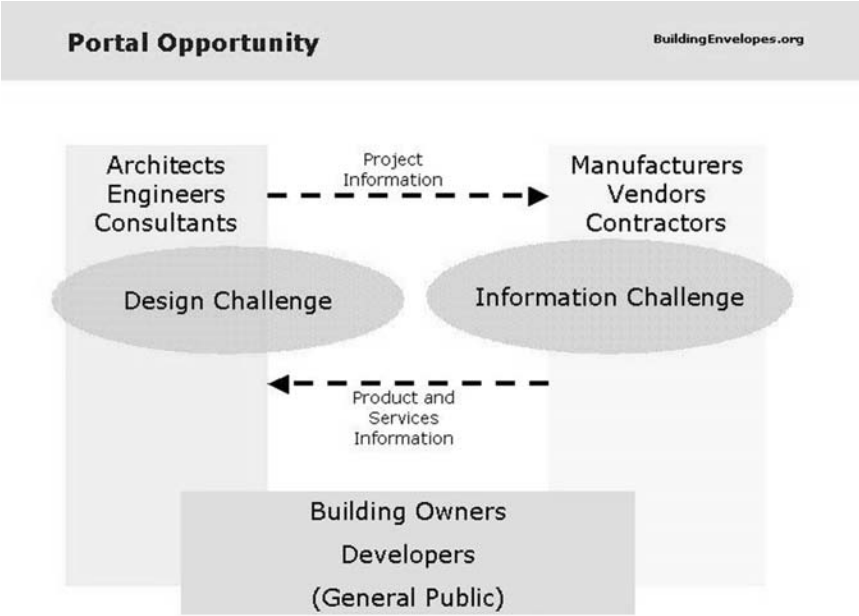

Figure 1.10 Internet portal opportunity.

BuildingEnvelopes.org fills this need by creating a dynamic, up-to-date resource for the building industry to gain knowledge on the most current technologies, products, designs, and methods. BuildingEnvelopes.org provides the framework for the building industry, academic institutions, and research centres to share knowledge and information. This knowledge is provided to owners and designers in order to expand their knowledge about new and innovative potential design solutions, thereby closing the information gap. After providing preliminary information, the portal then leads the owners and designer to the design or product specialists for further advice. It also provides new and inexperienced designers with a resource tool to answer practical, real-world questions.

Worldwide building industry organizations as well as research centres and universities provide information for the portal. Currently this collaboration is between Harvard Design School, ETH Zurich, Lawrence Berkeley National Laboratory, MIT Building Technology Group, the Polytechnic University of Milan, Solar Energy and Building Physics Laboratory (LESO-PB), the University of Michigan, VTT Finland and more than 15 building industry professionals, such as architects, engineers, manufacturers, and consultants.

Figure 1.11 BuildingEnvelopes.org home page.

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