Prototype of the New Lightweight Modular Facade FB720: Report on the Life Cycle Analysis of the Materials Used and their Effects. A Case Study

Gerardo Wadel, Pol Alonso, Architects
Societat Orgànica, Spain, gwadel@societatorganica.com, alonso.pol@gmail.com

Joan-Luis Zamora, Dr. Architect
Laboratori d'innovació i Tecnologia a l'Arquitectura (LiTA), Spain,
Universitat Politècnica de Catalunya (UPC) joan.lluis.zamora@upc.edu

Pablo Garrido, Architect
B720 arquitectos, Spain, pablogarrido@b720.com

Summary

The Façade FB720 project is the result of research funded by the Spanish Government's Centre for Industrial Technological Development (Centro para el Desarrollo Tecnológico Industrial, CDTI) (IDI-20090761). The aim of the project was to design and develop a lightweight, modular, unitized façade with low environmental impact and high energy efficiency, mainly for use in the Iberian Peninsula (temperate climates). The basic technical strategies to achieve this aim were as follows:

- Reduce the consumption of building materials
- Use renewable or recycled materials
- Optimize the façade structure and the transparent surfaces as elements to control solar radiation.

Keywords: prototype, lightweight modular façade, life cycle analysis, case study

1 Introduction

The architectural design of the façade is based on a proposal by the company b720 arquitectos, with the participation of various companies and technology centres acting as consultants. The Universitat Politècnica de Catalunya (UPC) provided advice on the life cycle analysis, in collaboration with the environmental consultancy Societat Orgànica. The consultancy JG Ingenieros was involved in the thermal and light evaluation. The characteristics of the new FB720 façade were verified by assessing their environmental impact in all the life cycle phases. This was achieved by means of energy simulations of the use phase and real trials carried out using several prototypes. While these processes were carried out, a series of rectifications and adaptations were made to optimize the design.

The results of the verification were validated by comparing the FB720 façade with a standard, lightweight, modular, quality façade. It was found that the energy consumption and the CO2 emissions due to the production of materials, transport, construction, maintenance and dismantling were substantially lower for the FB720 façade, with improvements of over 50% attained. With respect to the light and thermal evaluation, the energy saving in the areas of the building that are immediately next to the façade was approximately 34% in the most favourable cases. The project has not been published yet and was completed in December 2011.

Figure 1: Photographs of different prototypes that are versions of the FB720 façade system

2 Technical Characteristics

2.1 General Approach

FB720 is an innovative lightweight façade system of the modular "unitized" type. The aim was to benefit from the main advantages of this kind of systems – lightness, easy assembly and technical reliability – and improve the environmental and energy features. The system was developed using standard approaches to this kind of façade. Additionally, the following technological innovations were incorporated:

- The thickness of the façade itself was used as solar protection, by placing the strong substructure (uprights) towards the exterior.
- Alternative materials with less environmental impact were incorporated.
- A system of variable solar protection glass that has been developed specially for this project was incorporated.

The combination of these strategies provides an opportunity to increase the visibility of actions to improve sustainability that are promoted by architectural approaches. The final result is a building solution that is competitive due to its initial costs, which are appropriate for mid- to high-range projects; the impact of the built area, which is lower than that of other double skin façades; and the use of passive means of climate control.

2.2 Depth and Protection

One of the main characteristics of the FB720 system is that the uprights and crossbeams have been moved to the exterior. Although this approach was used in the first curtain walls, in contemporary systems the substructure has tended to be situated preferentially towards the inner face, to obtain better continuity of thermal protection and impermeability. Due to current technical requirements, the following design adaptations had to be made to recover the exterior position of the uprights:

- The assembly and replacement of glazing is expected to be carried out from the inside.
- Thermal break elements are positioned in alignment with the interior face of the frames.
- The joints between wider panels are on the inner face to enable anchor to be fastened on the central part of the frame.

The aim of moving the substructure frames to the exterior is to provide better solar protection for the façade, by taking advantage of the shadow that it casts on the plane of the wall. This is really a reinterpretation of a design that always been used in architecture: thick walls and deep openings. The result is a lightweight façade in which the main feature is depth and shadow, rather than glass and its reflections. Improved solar values can be obtained through an appropriate substructure design. For example, a façade located at latitude 41º (Barcelona), with uprights placed every 60 cm, the total incident radiation is reduced during the summer by approximately 53% if the façade is south facing, 38% if it is south-west or south-east facing and 27% if it is west facing.

As an additional advantage, the external position of the substructure provides an exterior pre-environment that forms part of the thickness of the façade and could be used for various purposes. Thus, additional sheets could be installed over the frame to create ventilated air chambers in opaque modules or complementary solar control systems could be hung in front of the glazed areas. All of these would form part of the original thickness of the façade. Other technical devices could be incorporated, such as solar collections, photovoltaic panels, large format screens for transmitting information and even plant modules.

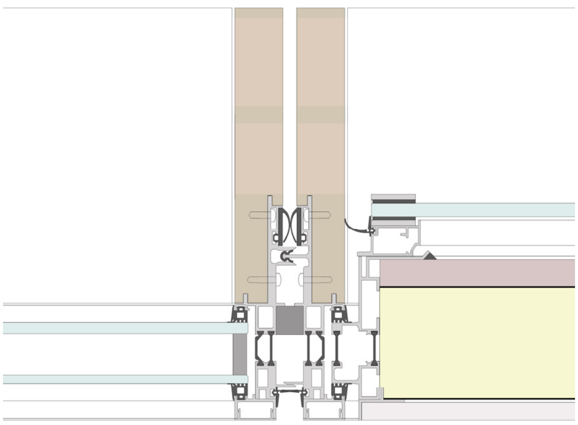
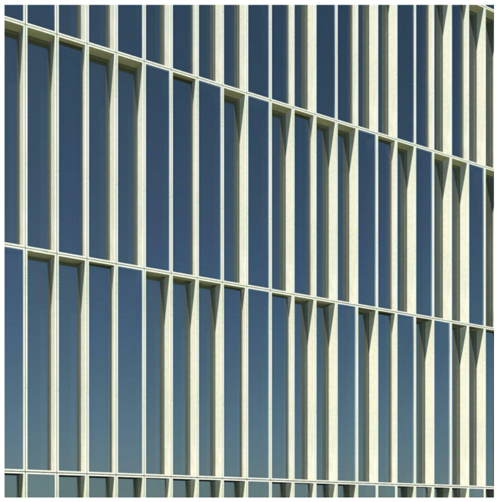



Figure 2: Detailed view of a horizontal cross-section and view in perspective of a possible architectural configuration of the entire FB720 façade system

2.3 Materials and Components

Three basic strategies were proposed to effectively reduce the environmental impact associated with the materials used in the façade system:

- Reduce the dimensions, by optimizing the aluminium frames.
- Use a high percentage of recycled materials in the aluminium frames.
- Design mixed components that enable the incorporation of alternative materials with less environmental impact.

The aim was to develop an alternative lightweight façade system that reduces the excessive reliance on the use of materials with a high environmental impact (aluminium, steel, polymers, etc.) and promotes the use of local materials that are renewable or recycled and industrial. The proposed substructure is made up of a framework with a small cross-section of aluminium bars that have a high proportion of accredited recycled material. These provide the basic specifications for assembly, mechanical work, water- and air-tightness. The load-bearing capacity is complemented by additional reinforcements that have no other purpose than to provide strength. Consequently, a wide-range of alternative materials can be used that are more environmentally friendly. Among those that have been tested are laminated wood, “technological wood” (composed of wood and plastic residues), recycled PVC and UHPC (ultra-high performance concrete that is reinforced with fibers).

Likewise, alternative materials can be incorporated into the infill panels in opaque modules to reduce the environmental impact. Examples of materials include: composites of natural fibres (sheep's wool, cotton), sheets of recycled textile waste, boards comprised of reused waste from carpets and laminated plasterboards containing recycled paper fibres. This range of alternative materials means that the FB720 construction system can be adapted to the financial, cultural and industrial context of each building design. Therefore, it is not a "closed" solution, but an approach that is open to the opportunities that arise in each case.

Figure 3: Photographs showing views of the various alternative materials tested

2.4 Variable Solar Protection Glass

To complement the basic solar protection system that takes advantage of the façade's own shadow, a new kind of glazing has been developed. This was designed to improve passive solar protection and has specifications that vary depending on the angle of incidence of the sun's rays. A design that is specifically adapted to the orientation of each façade and the latitude of each building can be obtained by combining several sheets of laminated glass with various superimposed layers of reflective, semi-transparent metal coatings. The special geometry of this glazing means that solar protection values are different in summer and winter, thus reducing the contribution from the sun's rays in the hot months and increasing it during the cold period.

Unlike other products with similar specifications, the treatment applied to the glass can be customized and adapted precisely to each case and specific orientation of the façade. Thus, areas with greater visibility and different degrees of transparency can be incorporated into the same unit of glass. The formal result is a window of glass with a variable degree of reflection and transparency according to the interior and exterior environmental conditions in each case. As protection from the sun is incorporated in the glass itself, we eliminate the problems of durability and maintenance that are associated with standard elements of solar protection (blinds, awnings, slats, etc.). In addition, less material resources are needed to construct the façade. As this material is manufactured in the form of flat glass, it can be combined with other sheets of glass to provide, for example, units of insulating glazing with air chambers, low emissivity treatments or acoustic insulation. It can be used in any kind of wall or façade system

The solar protection values that are obtained depend on the final composition of the glass, the orientation of the façade, and the type of layer used in the treatment. For example, in the case of glass made up of an exterior sheet 4+4+3 mm with the variable protection treatment described above, an air chamber of 24 mm and a laminated interior sheet of 10 mm with a low emissivity treatment, the solar factor varies between 0.33 and 0.14 for incident angles of 25º and 72º respectively, which correspond to the incidence at midday (12 am) on the summer and winter solstices, with a south-facing façade at a latitude of 41º. This variable solar factor provides passive solar protection with seasonal differentiation, without requiring sophisticated operations to regulate it or depending on the uncertain management of the user. This leads to greater reliability in the final performance of the glazed wall, which is of particular interest in buildings with a high proportion of occasional users: for example, public buildings with administrative and residential uses.

3 Environmental Impact and References

3.1 Objective

Numerous variants of the FB720 façade can be constructed as a result of the combination of different materials, the types of glass, the proportion of transparent area and the distance between uprights. On the basis of a preliminary design created by the team of architects, the following questions were drawn up:

- Is it possible to carry out a summary LCA of different versions of the same development of a new curtain wall called FB720? The versions are based on different combinations of materials (exterior uprights, thermal insulation, interior walls, etc.), types of glass (clear, seasonal, low emissivity, etc.), proportions of the transparent part of the wall (75% and 37%) and separation between the axes of the uprights (60 cm and 120 cm), all for a 50-year life cycle.
- Which of the possible configurations of the FB720 façade leads to the greatest reduction in environmental impact?
- How does the LCA of the new FB720 façade compare with that of a standard modular curtain wall (MCW) and that of a standard traditional facade (TF)?

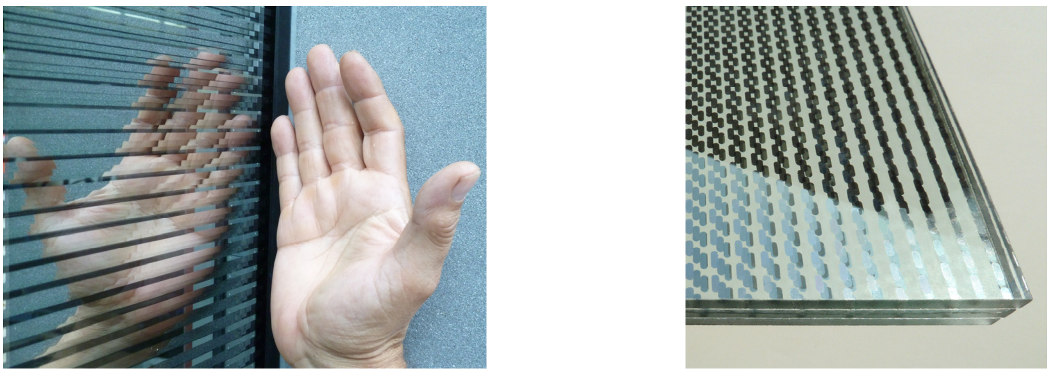
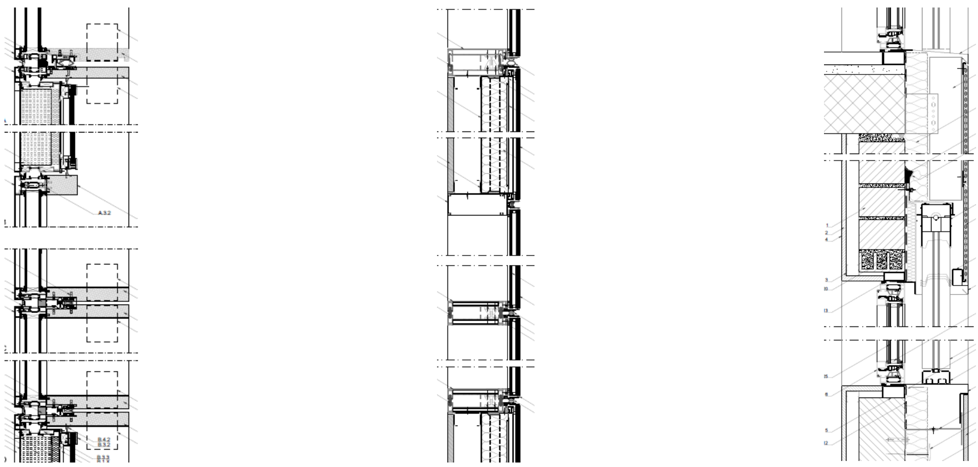


Figure 4: Photographs of the new glazing with variable solar protection

To answer these questions appropriately, an LCA advisory team was formed by the UPC's Architecture Technology and Innovation Laboratory (Laboratori d'innovació i Tecnología a l'Arquitectura, LiTA) and the Societat Orgànica consultancy company, which is made up of PhD graduates trained at the UPC. The environmental assessment that is presented here refers only to the environmental impacts of the cycle of materials during the useful life of the façade. The environmental analysis of the façade's thermal and light behaviour as the skin of the building was carried out by another technical team and is not described in this paper.



FB720 façade (ground plan) MCW (ground plan) TF (cross section)

Figure 5: Technical details of the different variants considered

3.2 Method

The method used in this case was a LCA with a shortened procedure, considering that the aim was to support the team in their decision making. The following considerations were taken into account:

- Functional unit: 1 m2 of façade, with a useful life of 50 years.
- Phases considered: production of materials [1], transport [2], construction [3], maintenance [4], demolition and final waste management [5].
- Impacts assessed: weight of materials [Kg/m2], energy consumption [MJ/m2], and CO2 emissions [KgCO2/m2]. In some phases, the following parameters were also included: solid waste [kg/m2], recycled or renewable material at the beginning of the life cycle [Kg/kg], recyclable or compostable material at the end of the life cycle [kg/kg] and environmental toxicity [ECA Kg/Kg].
- Assumptions and limits of the shortened procedure: phase [1] of the LCA summary includes all the operations of extraction and transport of raw materials to the factory where the building materials are manufactured. Transport from these factories to the curtain wall workshops, the manufacture of the walls and assembly of components are also assessed. The material intensity per service unit (MIPS) is excluded. In [2], the use of fuel in the modes of transport is included. The life cycle of vehicles and infrastructures is excluded. In [3], the energy consumption (electricity, diesel, etc.) of machinery is assessed. The energy costs of human activities and the depreciation of production tools are not taken into account. In [4], maintenance operations, partial and total replacement within 50 years are included. Phase [5] includes dismantling of the wall until its component materials have been separated and management of non-recyclable waste
- Tools and bases: almost all of the calculations were carried out with the help of standard spread sheets, but without the use of expert programs. The materials databases that we consulted were BEDEC PR/PCT of the ITeC, ICE of the University of Bath, EMPA of the Swiss Consortium of Public Universities, ELCD of the European Union and, in some cases, ECOINVENT and IVAM. Calculations were carried out with the SIMAPRO program (obtained from the Sustainable Building Initiatives Centre [Centro de Iniciativas de la Edificación Sostenible] research project) or we used our own calculations to determine the specific weight, volume and density of the materials used in the various building solutions. With respect to the operations of transport and loading, as well as waste generation, we consulted the PR/PCT bank, as well as information provided by manufacturers, other studies, calculations and our own estimations.

To express energy consumption (in electric KWh or litres of diesel) as CO2 emissions, we used the conversion factors established in the Spanish energy certification processes. In the case of recycled or renewable and recyclable or compostable materials, we used our own calculations as well as information provided by manufacturers or others.

3.3 Results of the LCA Summary Procedure

The application of the environmental strategies for construction materials, defined in project FB720's method for the design of façade variants, led to considerably lower environmental impacts over a 50-year life cycle than the lightweight façade itself and the reference façades MCW (standard modular façade) and TF (standard traditional façade). Although improvements were also observed in the solid residues indicator, the evaluation of energy and CO2 emissions indicators is more suitable for analysing the complete life cycle, as it takes into account all of the phases. The following environmental strategies were applied in relation to the construction materials:

- Reduce the amount of material per unit of service.
- Replace the materials and systems that have the greatest associated impact.
- Use recycled industrial materials or renewable natural materials.
- Increase the reuse (of materials and components).
- Minimize waste generation and manage waste so that it is recycled.
- Increase durability and decrease maintenance.
- Use local materials and techniques.

The following environmental improvements were obtained using these strategies:

- Extraction and manufacture of materials. The study confirmed that the use of natural materials with few additional industrial processes is the option that leads to the lowest environmental impact. However, some factors, such as the distance between uprights (the further apart the better) and the full/empty ratio (the higher the better) are also essential to achieving the best environmental results. The materials used in all of the FB720 versions that have the greatest environmental impact, even in the best design options and taking into account that the amounts employed are significantly lower than in conventional façades, continue to be aluminium (even when 100% recycled aluminium is used), glass and synthetic materials (joints, spacers between glass sheets, etc.).
- Transport. The raw materials or materials that are already incorporated into the façade modules are transported over considerable distances and may even travel part of a route more than once. Therefore, it is essential to consider the flows of materials resulting from the location of prefabricated façade workshops, materials suppliers and the building sites. Another extremely important aspect is to optimize the load capacity of the mode of transport. For example, lorries are not always at full capacity on journeys between the warehouse and the building site. Finally, we should consider using modes of transport that are more efficient than road transport, taking into account the ratio between kg transported/energy consumed. One option is rail transport.
- Construction. The differences in the impacts of prefabricated and in situ systems are most evident in this phase. This is due to the fact that many operations are brought together and made efficient in prefabricated systems. As a result, there is less use of machinery in the workshop and on the building site, less direct consumption of materials (which does not mean that the total materials requirement, counted from the extraction of raw materials, is also lower) and less waste generation. In addition, waste that is generated in the workshop is easier to classify and consequently a higher proportion can be recycled. However, packaging materials (which become waste as soon as they reach a building site) also represent a considerable fraction of the energy and emissions cost of construction systems: up to 30% and 20% of the total in prefabricated systems (FB720 and MCW) and in situ (TF) respectively.
- Maintenance. In this 50-year phase (35 initial years of maintenance and a second period of 15 years, once the first period has been completed and the walls replaced), the differences between the façade systems are again notable. In other phases, the ranges of impact values enable us to group the performance of the prefabricated façades FB720 and MCW together, and place the in situ TF in another group. However, in the maintenance phase, the order of environmental performance, from best to worst, is FB720, followed by TF and finally by MCW. There were considerable gaps between the values for the first and second positions (1.8 and 2.6 times greater impacts) and between the first and third positions (between 1.9 and 3.5 times greater impacts). This is mainly due to the completely different strategies for the materials in each of the prefabricated options: natural renewable materials and recycled industrial materials that are separable and recoverable in the case of FB720, and industrial materials, few of which are recycled, that often cannot be separated or recovered in the case of MCW. As a result, the replacement of the wall at 35 years in the second case has an impact equivalent to the construction of a curtain wall for the first time.
- Demolition/dismantling. There are variations in the mechanical work required in the operations of demolition and dismantling. It is much more intensive in the first case, due to the force of striking and breaking the façade as well as the additional equipment required to move machines, workers and waste. In addition, each one of the façade systems differs in the amount of waste that is generated at the end of its life cycle. The dismantling of façade FB720 enables the separation of reusable or recyclable materials, as this was one of its design premises. In contrast, the dismantling of façade MCW and the demolition of the TF façade do not enable resources to be recovered in the same way, as they were not designed for this. Therefore, the loading, transport and final waste management operations that are needed for these two façades make their environmental impact higher than that of FB720.

3.4 Sensitivity Analysis: Improvement Hypothesis

As part of the process of developing the FB720 façade project, various ways of reducing the environmental impact were studied for implementation in each phase of the life cycle. Some of these alternatives were not included in the final design for several reasons: the technical difficulties involved (for example, the introduction of new materials that would have required the development of different manufacturing molds to those already in use); financial concerns (for example, the redesign of a product and the process of manufacturing a standard building component would have been a major expense); or practical considerations (for example, the location of factories for manufacturing the materials or products and the location of the curtain wall workshop). Below, in the same order as the phases of the life cycle analysis, we present five alternatives to reduce environmental impact parameters (energy, CO2 emissions, materials, waste, etc.). The alternatives are assessed in a simplified way using an energy consumption indicator. Finally, we assess the impact of incorporating all of these alternatives into the FB720 system.

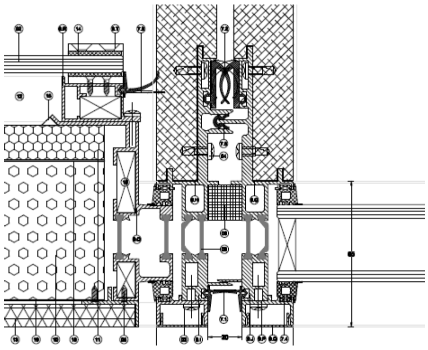



Figure 6: Technical details of the different improved versions considered

Extraction and manufacture of materials phase: the proposal was changing some of the 100% recycled aluminium frames for laminated wooden strips. The technical details were redefined (Fig. 6). We used as a hypothesis the A/II/37/120 configuration of the wall and proposed the replacement of up to 2.2 kg/m2 of aluminium with 3.07 kg/m2 of laminated wood. This resulted in a reduction in the energy used to produce the materials of 65 MJ/m2, compared to the original configuration. This represents 4.5% of the 1447.5 MJ/m2 of energy consumption of all the materials in the original configuration of this façade. This may appear to be a negligible energy saving, but it represents over 6 times the energy used in the construction and dismantling of the façade (between 11 and 12 MJ/m2).

Transport phase: the proposal was to situate the façade manufacture workshop as close as possible to the areas of large cities in which there is a potential demand for installing curtain walls in new buildings or in renovations. The aim of this measure is to reduce the fuel consumed by the lorries that travel between the factory and building sites. This would reduce the energy consumed and the associated CO2 emissions. We considered reducing the distances in the study (by moving the façade manufacture workshop from Olot, which is 750 km from the building site, to Madrid, where one of the hypothetical building sites is located). This is a reduction in the order of 10 to 1. In other words, the journey would be only 75 km if the manufacturing workshop was situated in Toledo and the building site in Madrid. The initial situation results in diesel consumption of 2.44 litres/m2 or 102.71 MJ/m2. If the journey from the workshop to the building site was 75 km instead of 751 km, the diesel consumption would be 0.74 litres/m2 or 31.31 MJ/m2. The energy reduction attained is 71.40 MJ m2, which is 69.5% of the total energy in the transport phase.

Left: Initial route: Olot – Madrid, 751 km

Right: Alternative route: Toledo – Madrid, 73 km

Figure 7: Planned route and proposed alternative route

Construction phase: the proposal was that the packaging materials should be reusable and 100% recyclable. The installation of the FB720 system hardly generates construction waste, as the building work only involves anchoring the wall to the structure of the building. Therefore, the main waste is the materials used to package the façade panels. These materials have two main impacts: during their production (extraction-manufacture) and their final management as waste (separation, loading, transport and final treatment). In terms of energy consumption, the production of the packaging materials that are used (mainly polythene, expanded polystyrene, wood and steel) represent 3.78 MJ/m2. The management of the waste generated by this disposable packaging has an energy impact of 0.51 MJ/m2. The energy saving brought about by employing a reusable, recyclable packaging system is estimated at 80% of this consumption, taking into account a minimum of five uses and complete recycling (which would avoid final waste management, but not the energy consumed loading and transport processes). Under the previous hypothesis, the energy consumption in this phase could be reduced to 0.78 MJ/m2.

Figure 8: Standard packaging procedures and the waste that is generated

Maintenance phase: the proposal was to increase the useful life of the entire façade from 35 to 50 years. In the initial hypothesis of this study and on the basis of existing market knowledge on the durability of curtain walls, we considered that almost the entire façade would need to be replaced at 35 years. This is the case of curtain walls constructed in the 1970s, whose main faults are a loss of water and air tightness due to the deterioration of joints, and little thermal insulation or solar protection. However, we still do not know the durability of recently manufactured curtain walls. They could be more durable if the flexible materials used in the joints are found to have a longer useful life. The total replacement of the FB720 façade (activities of removal, loading and transport, as well as identical operations for the new façade) represents an energy consumption of 442.91 MJ/m2 (if we assume that a certain proportion of materials are recovered and that only the part proportion to 15 years of useful life is affected, i.e. from year 35 to year 50 in this study). In contrast, if we manage to increase the useful life of the façade to 50 years (this durability is potentially attainable in all the materials except for the joints and the sealing chords) and resealing is planned at 15 years, which is taken into account in the calculation, and again at 30 years, the energy impact is just 0.027 MJ/m2 (taking into account the contribution of the sealing material and the additional construction equipment needed to apply this material up on the façade). Therefore, the energy saving could reach almost 100% of the impact of this phase.

Figure 9: Views of on-site usually procedures to replace sealing elements

Dismantling: the proposal was to redesign the glazed panels with air chambers in order to be completely disassembled and recycled. Currently, waste management is complex for various types of glass including glazing with air chambers, laminated glass, and printed, inked, coated and silk-screened glass. The composition and type of joints between the different types of glass that make up the panels are not reversible, which means that the original materials cannot be recovered in a state that enables them to be recycled in a technically and financially simple manner. Consequently, much of the glass that is used in construction is not recycled but downcycled (it is ground up and used as a component of lower quality compounds). The aim of the proposed measure is to avoid two environmental impacts: that due to downcycling (which could be avoided by dismantling and selective separation of the glass components) and that due to the production of new materials (which would be avoided if the existing glazing could be reused or recycled). Even when we take into account that most of the materials would be recovered to be reused or recycled, the environmental impact of disassembly in terms of energy is 10.99 MJ/m2. If we exclude the operations of disassembly, loading and transport to a recycling centre where the panels would be taken apart, the environmental impact that could be avoided with this measure is 0.15 MJ/m2 corresponding to waste management at a dump (the joints and the glass panels with an air chamber) and 0.25 MJ/m2 corresponding to transport from the site where the façade module is disassembled to the dump. In addition, up to 204.5 MJ/m2 would be saved due to the reuse of the glass (assuming 50% of the total is reused), as this would reduce the need to produce new material.

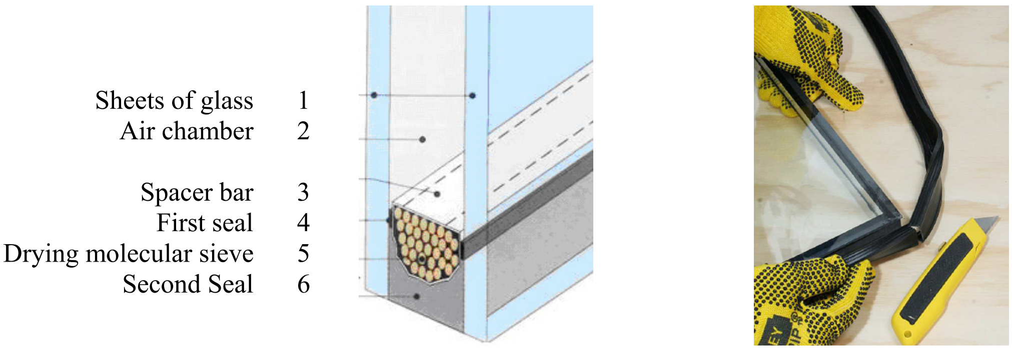


Figure 10: Detailed view of glazing with an air chamber and the process of removing a seal

Impact of the proposals to improve the life cycle: figure 11 shows the combined positive impacts of the different proposals to improve environmental performance, in absolute and relative terms (taking into account total energy consumption for the FB720 façade of 2,278.08 MJ/m2 throughout the entire life cycle).

Improvement measure	Savings (MJ/m^2)	Percentage of total savings
1. Replacement of aluminium frames with wood	65.00	2.85
2. Façade workshop close to the building site (75 km)	71.40	3.13
3. Reusable packaging and recyclable materials	3.43	0.15
4. Useful life of the joints extended to 50 years	442.91	19.44
5. Glass panels that can be totally disassembled	204.90	8.99
Totals	**787.64**	**34.57**

Figure 11: Table of the combined positive impacts of the various improvements proposed, in absolute and relative terms

Although the degree of difficulty in implementing the various proposed improvement measures varies (relocating a façade manufacturing workshop is not as complicated as developing new packaging), there are sufficient opportunities to make improvements that have a positive impact. When these measures are combined, they could lead to savings of up to a third of the total initial energy.

Barcelona, December 2011