

# Beyeler Foundation Museum, Riehen, Switzerland

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## Introduction

The Beyeler Foundation was set up to provide a permanent home for Hildy and Ernst Beyeler's modern art collection, which ranges widely from van Gogh and Monet to Picasso and Rothko, as well as including sculptures from Africa, Alaska, and Oceania. Its new museum stands in a park donated by the commune of Riehen, near Basle, and was designed by Renzo Piano, whose restrained, tranquil design was specifically intended 'to serve art, and not the other way round'.

The building is clad in red porphyry and comprises four monumental parallel walls, with glazed end walls and a glazed winter garden down the long west side giving views of the surrounding rural landscape. A single-storey basement houses plant, storage, and a small parking area, as well as temporary exhibition space accessed from the winter garden. The roof is multi-layered, consisting of (from the top down) inclined opaque white glass brises soleil; a flat, clear, double-glazed roof; operable louvres; a glass ceiling which defines a 1.5m loft space; and a perforated metal ceiling (Fig 2). These allow daylight to illuminate the art on average winter days and yet provide control of the sunlight levels on bright days.

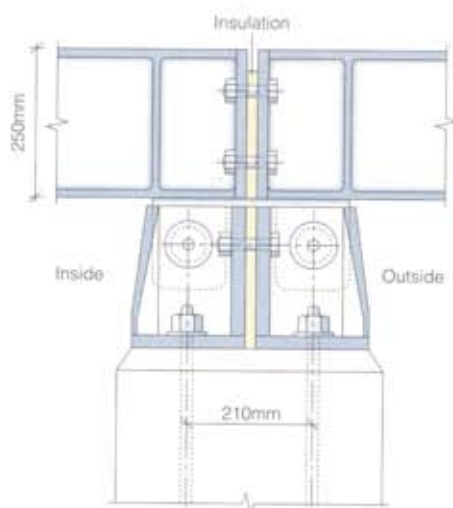
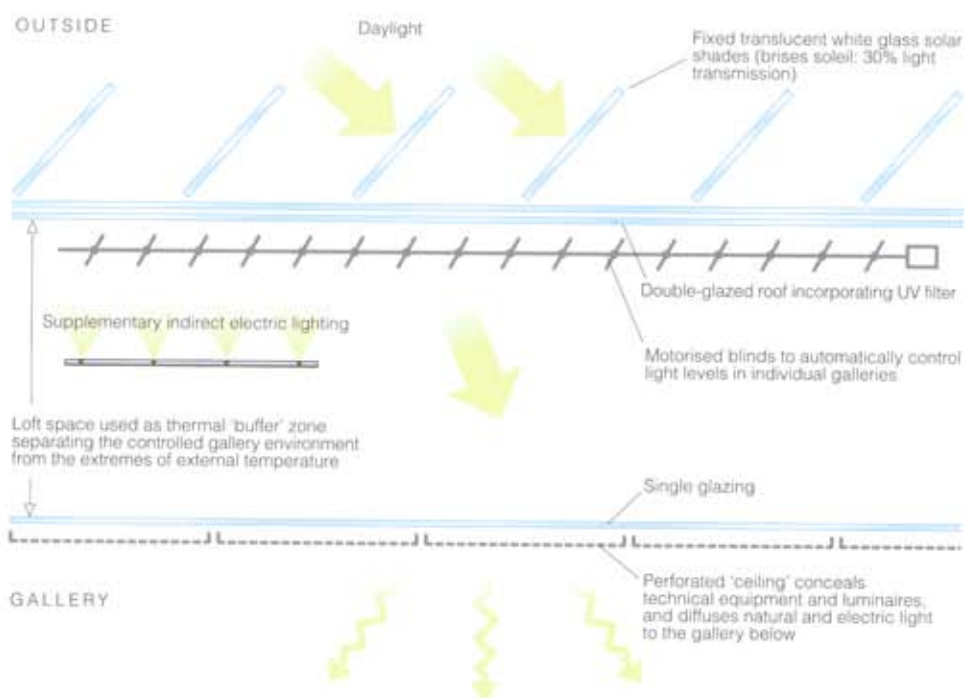
Renzo Piano was appointed architect in 1990 and Ove Arup & Partners as consulting engineers in 1992; over a considerable period the design went through several concept changes. Arups carried out the structural scheme design, the detailed roof design including the glazing, the services engineering with a detailed energy analysis, and the natural lighting design. Swiss consultants did the detailed design for the services and the concrete structure, and provided construction supervision.

## Structural engineering

The structure reflects the architect's desire for spaces between four long, massive walls with a light, crystalline roof structure - 28.3m by 127m on plan so that it overhangs all round - controlling the amount of natural light entering and also modifying the internal environment. The walls are 108m long, at 7.8m centres, and 6.05m high. The galleries are typically 6m x 7.8m, with larger exhibition spaces 7.8m x 12m, 7.8m x 18m and 15.6m x 18m.

The basement, at level -4.3m, and the ground floor structure are in reinforced concrete. Reinforced concrete columns stand at 6m centres within the long walls, and support the roof steelwork. Services run within the walls up to the loft space. The overhangs at the north and south ends are supported by stone-clad steel columns, while at the south end the ground slab extends to form a lily pond stretching into the landscape.

1. The west wall at night.   2 below: Section through roof build-up.



3. Detail of column/beam fixing.

The steel roof structure gives continuous support for the various roof layers in all situations: at the 2.5m cantilevered edges along the long sides, in the normal internal condition, and where parts of the long inner walls and their columns are removed to allow for the larger spaces. The roof supports the glass ceiling and internal louvres, the double-glazing, and the posts that carry the glass shading panels. Primary beams span continuously east/west, while secondary beams are arranged in pairs on either side of the columns spanning 6m typically north/south. In the larger exhibition spaces additional beams span 12m or 18m parallel to the secondaries, on the column lines.

To maintain a crisp appearance the 250mm deep beams, all lying in the same plane, are all fabricated using plates. The primaries have a box section with the flanges projecting outside the webs, so that their appearance is similar to that of the fabricated I-sections used for the secondaries. The beam/column connections were all made using steel castings and bolts. Joints, which can carry forces and moments, are provided where the steelwork passes from inside to outside the building, to minimise the effects of cold bridging (Fig 3).

The white glass brises-soleil are supported by numerous vertical posts composed of steel tubes and castings and bolted to the tops of the beams on site. The fixings for the glass were also made from steel castings, with adjustment for site tolerances provided by bolts. The top bolted connections allow glass to slide parallel to the glass, but take wind loads perpendicular to the glass so that differential deflections of the beams supporting the top and bottom of one plane of glass do not induce high stresses into it.

The structure was designed to Swiss codes. As well as accommodating reasonably high snow loading, the building also lies within a seismic zone and was designed for horizontal forces of c7% of the total vertical loads.

#### Natural lighting design

An early design discussion between Ernst Beyeler and Renzo Piano centred on the issue of natural light. Beyeler had seen the Menil Foundation building in Houston<sup>1,2</sup> by Piano and Arups, and was keen to have the same quality of colour and generosity of daylight in his own museum. It was agreed that natural light be admitted across the whole ground floor roof and that construction should maximise the opening hours when the collection can be seen under daylight alone. At the same time, it was recognised that the Beyeler Collection is of international importance and that its long-term conservation was a top priority. The current best practise standards for exposure of works of art to light in terms of illumination level and spectral content had therefore to be observed.

After studying natural light data for Basle, Arups recommended a target daylight factor of 4% - around twice that in most European museums - with an active shading system to control internal light levels within predetermined limits, particularly on bright summer days.

This brief is met by the all-covering multi-layer glass roof. Outermost are the fritted glass brises-soleil, positioned to prevent direct sun penetration during all museum opening times but otherwise maximising the admittance of diffuse light from the rest of the sky vault. Beneath this, the weather-proof double-glazed skin incorporates a high performance ultraviolet filter to remove the most damaging parts of the electromagnetic spectrum. The system of motorised aluminium louvre blades immediately below are computer-controlled to create the desired light levels in each ground floor room. Different light levels can be selected for each as necessary for conservation or viewing considerations. Outside museum opening hours, the louvres are closed to prevent unnecessary exposure of the artworks to light. The louvre system is in the loft thermal buffer zone - in summer the external brises-soleil and the active louvres combine to prevent 98% of incident solar radiation from reaching the gallery climatic zones beneath.

The lower boundary of the loft is formed by a laminated glass ceiling to the galleries, which can be walked on to access and maintain the louvre motors and supplementary electric lights in the loft. As daylight fades, triphosphor linear fluorescent fittings are gradually energised to maintain the desired light levels.

Perforated metal panels carrying a diffusing paper insert form the visible ceiling in the ground floor galleries. This final layer partially hides the complexity of the roof construction above and gives a calm and uniform light to each room. Additional small low-voltage spotlights on stems at the junctions of each ceiling panel allow for the occasional highlighting, particularly of sculpture which benefits from more strongly directional illumination.



4. The west gallery looking north: the glazed wall on the left overlooks fields; the main gallery is behind the wall on the right. At the far end, access to the temporary exhibition space in the basement is via a glass lift.

5. Looking south out to the lily pond.



6. The west wall, looking north.

#### Mechanical and electrical engineering

Air-conditioning is strongly discouraged in Switzerland. The Swiss voted some years ago to abandon the development of nuclear power on environmental grounds and to reduce their reliance on electricity bought from France, much of which is nuclear-generated. The government therefore legislated to reduce the national demand, one of their first targets being energy used in buildings.

But what then for priceless works of art which, according to current wisdom, require strict control of their environment, particularly humidity?

Fortunately special exceptions are made, subject to certain conditions:

- A 'statement of need' must be submitted to the local authority justifying mechanical cooling and ventilation. Arups prepared this for the client, based on the use of the building for the display of valuable works owned or borrowed by him, and current guide-lines and recommendations for viewing and storing works of art.
- A dynamic analysis of annual energy use must be carried out and submitted to demonstrate that the building is as energy-efficient as possible. The local authority examines this in detail and may request further energy-saving measures.

7. Typical large gallery space.



8. Brises soleil, looking west.



### Energy analysis

The required analysis was carried out using the AR&D program ENERGY2, which makes use of the thermal and radiation algorithm of ROOM to dynamically model a representative part (c50%) of the museum. A detailed model for the AHU plant and heating and cooling systems was designed, including control narratives which required ENERGY2 to be modified. After calculating the power required by the building for every hour of the year - real weather data for Basle was used - the data was presented as a histogram of energy consumption itemised by heating, cooling, lighting, etc. Annual energy cost and global warming effect (CO<sub>2</sub> production) were derived depending on the energy source: gas or electricity.

ENERGY2 analysis was used to evaluate the cost/energy benefit of features like displacement ventilation, thermal wheels, and heat recovery from the chiller. Interestingly, energy saving by creating thermally massive internal walls was shown to be negligible due to the 24-hour environmental control. An ice store was installed on the Swiss consultant's recommendation, although it does not reduce overall energy consumption. The Swiss strongly advocate ice stores and using off-peak electricity (with tariff incentives), as they can thus reduce their peak daytime demand and the corresponding in-flow of nuclear electricity from France.

### Building form and fabric

Arups' involvement from the outset meant they could control creating an energy-efficient building. The galleries are protected from climatic extremes (-11°C winter; 33°C summer) by thermal 'buffer' spaces on the roof and the east and west sides. In the roof the heated and ventilated 'loft' means that despite the 100% glazed roof, perimeter heating is only needed in the galleries with windows directly to the outside. To the east is a stone clad concrete wall and ancillary rooms; to the west the semi-conditioned 'winter garden' with countryside views - a place to rest and to circulate to the temporary exhibition gallery on the lower floor. The galleries are hence suitable for displacement ventilation - appropriate for a museum due to the low air velocities and low noise.

The roof shading scheme developed during the design period from factory-type northlights to external fins or shades in white diffusing glass with only 30% transmission, the elegant form and material of which became a major architectural feature. Further shading is provided by motorised blinds in the 'loft' and a light diffusing perforated suspended ceiling in the galleries.

### HVAC systems

A true displacement system was designed to reduce air velocities near the artwork to a minimum. The air is emitted at barely perceptible velocities from purpose-made wooden linear floor grilles which, with one floorboard either side, can be removed for cleaning the ductwork plenum below or access to electrical sockets (for portable display cabinets with a power/lighting requirement). Below the full-height windows perimeter heating is by trench convectors concealed below the same wooden grilles.

Air supply to each gallery module (typically 90m<sup>2</sup>) is controlled by VAV boxes mounted vertically in a 1.8m wide services 'corridor' on the basement level below, running most of the length of the building and containing 20 VAV boxes and associated supply and extract ducts - one at high level and one in a trench below a metal walkway. The VAV boxes are fed by two AHUs sized to give reasonable redundancy.

A fresh air and exhaust air AHU can provide up to 50% fresh air should external conditions be favourable. Rotary regenerators (thermal wheels) are utilised in two locations in the air system:

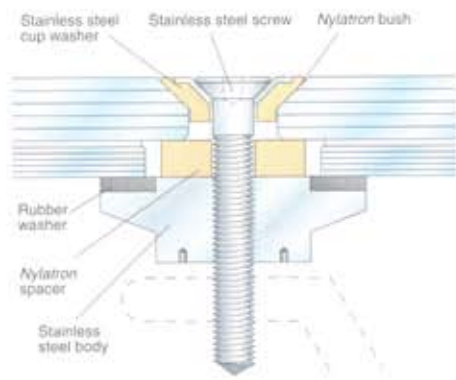
- the primary AHU to recover heat from the exhaust air in winter
- the main AHUs to obtain reheat following dehumidification by transferring heat from the extract air (cooling it in the process and thus reducing the cooling coil requirements when recirculating).

### Bolted glass roof panels

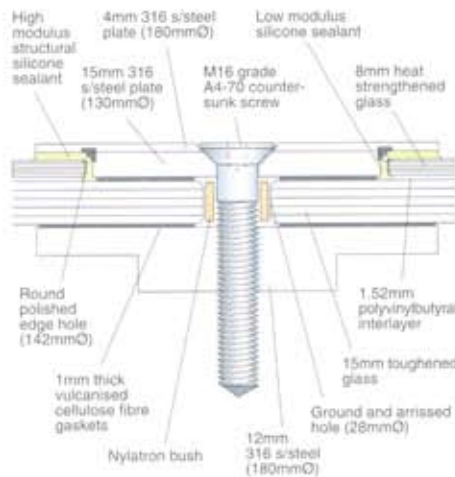
The 4000m<sup>2</sup> flat glass roof consists primarily of conventionally supported, double-glazed insulating units, but the cantilevered glass overhangs provided a particular challenge. As glass roof panels have become more popular, guidelines and codes of practice have developed for determining their composition and thickness. But whilst these codes were applicable to the conventional double-glazed panels, the roof incorporated other unusual glass elements not covered by such codes.

9. The lily pond and the south overhang.





10.  
(a) above: conventional bolted glass fixing;  
(b) right: roof panel fixing detail designed for Beyeler Gallery



The overhangs did not need to be insulating double-glazed units, instead they comprise laminated, single-glazed panels. The design of the four cantilevering corner panels warrants particular discussion since, due to their unique, asymmetric configuration and the differences in behaviour of laminated glass under various loading conditions, their design is not covered by any codes.

Unlike steel or reinforced concrete, glass has very low tensile strength which cannot be appreciably increased by variations in chemical composition.

However, heat treating basic annealed glass can produce different levels of residual compressive stress in its surfaces. This acts like a prestress which must be overcome before tensile failure can occur, effectively strengthening the glass.

The corner panels are 3.2m x 2.39m, with the primary support 900mm in from the shorter edge and 1.23m from the longer edge, creating a 1.5m cantilever to the free corner. The panel composition selected was a pane of heat-strengthened glass, 8mm thick, laminated on top of a 12mm toughened glass pane using four 0.38mm layers of polyvinyl butyral interlayer.

Although contrary to the conventional practice of placing the toughened layer on top, this design ensures that should the lower, toughened glass break, the upper layer works compositely with the broken layer, preventing instantaneous collapse and complying with the safety plan.

The panel was analysed in four stages by hand calculations, a linear model in Oasys' General Structural Analysis (GSA) program, a large deflection theory model in Nastran, and finally more hand calculations to justify the 'central' clamping detail. This detail supports 64% of the total weight of the panel, so to keep stresses within permissible limits, the diameter of the clamping plate at the primary support was increased to 180mm. This was governed by the need to rigidly clamp the thicker, bottom layer of glass to eliminate bending stresses across the bolt hole and prevent failure of the roof panel.

A test programme written by Arup Façade Engineering simulated the effects of maintenance personnel, snow, and windloads, and confirmed the panel's behaviour if accidental damage caused the top, toughened layer to fail. This prototype panel was successfully tested in Germany in September 1996.

#### Conclusion

Work began on site in the summer of 1994 and was completed in 1997. The new Beyeler Foundation Museum was opened during a series of festivities between 14-19 October 1997, to great acclaim.

#### References

- (1) BARKER, Tom, *et al*. The Menil Collection, Houston, Texas. *The Arup Journal*, 18(1), pp2-7, April 1983.
- (2) RICE, Peter. Menil Collection Museum roof: evolving the form. *The Arup Journal*, 22(2), pp2-5, Summer 1987.

11. Monet's *Water Lilies* triptych at the south end.



#### Credits

**Client:**  
Beyeler Foundation  
**Architect:**  
Renzo Piano Building Workshop

**Consulting engineers:**  
Ove Arup and Partners Betsy Almond, Duccia Farnetani, John Jo Hammill, Richard Matthews, Sarah Kaethner, Eleanor O'Doherty, Stuart Smith, Barney Wainwright, Jane Wernick, Richard White (structural)  
Tom Barker, Andy Sedgwick, Andrew McDowell, Lidia Johnson, Jonathan Ward, Emmanuelle Danisi, Hilary Calon, Mike Holmes, Neil Beverley, Alex Wilson (building services)  
Graham Dodd, Antony Smith (façade)  
Darren Sri-Tharan, Derek Woodcraft (draughtsman)

**Consultants to Mr Beyeler:**  
Florian Vischer; Urs Albrecht  
**Local consultants:**  
Cyrill Burger & Partner AG (structural)  
Ing. Bureau Jakob Forrer (mechanical)  
EAG (electrical); Bogenschutz AG (plumbing)  
**Main contractor:**  
Zublin & Wenk AG  
**Steelwork contractors:**  
Jakem AG (roof)  
Nyfeler Otto AG + Preiswerk & Esse AG (winter garden and walls)

**Sub-contractors:**  
Sulzer (mechanical);  
EAG (electrical)  
Vegla/Lanz (glazing)

**Illustrations:**  
1, 4: Michael Denance  
2, 3, 10: Martin Hall  
5-7, 11: Beyeler Foundation  
9: Antony Smith  
8: Jane Wernick