Steel Structures that Breathe: Two Extensively Glazed Buildings that Integrate Natural Ventilation within Structural Members

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Abstract

The paper is a case study of two extensively-glazed steel-framed buildings, Jean Prouvé's 1957 temporary school in Villejuif, France, and, Müller Verdan Architekten's 2006 Sporthalle "Gotthelf" in Thun, Switzerland, that integrate natural ventilation within the building structure itself.

Practically, this unique approach enables the designers to provide usually mutually exclusive features, large glass formats and natural ventilation, without incurring the various penalties associated with operating such very heavy elements.

Conceptually, the idea of integrating the ventilation function within structural members goes against the standard orthodoxy consisting of the separation of enclosure systems from skeletal structural systems. This dichotomy has been one of the canonical rules of Modern Architecture ever since Le Corbusier enshrined it in his "Five Points". It remains today the prevailing paradigm in curtain wall-type envelopes.

These two projects deserve to be better known because of their integrative design intelligence, and, because they challenge the dominant paradigm of separation of structure and enclosure, and in doing so, they open interesting design perspectives regarding the sustainable integration of natural ventilation in buildings.

The method for researching Prouvé's building is archival research- and analysis-based. In the case of the Müller Verdan's Sporthalle, the analysis of drawings is complemented with direct on-site observations and conversations with the architects. The paper also compares and contrasts the two projects with special focus on their structural and natural ventilation aspects.

Keywords: Natural ventilation, Structure, Integration

Introduction

In many climatic contexts, natural ventilation is an important design approach to deliver comfortable and "delightful" thermal conditions while also achieving energy consumption-minimization sustainability goals. Letting air flow in and out of a building requires some sort of operable inlets and outlets to control the magnitude of the buoyancy-based (stack-effect ventilation) or pressure difference-based (cross-ventilation) natural ventilation. Typically, operable windows deliver this natural ventilation function along with daylighting and sight, among other functions.

Historically, such windows have been part of openings "punched" through the plane of, for example, heavy masonry or balloon-framed walls acting both as structure and enclosure. Throughout the 20th century, the separation of the building enclosure from the building structure was ushered by successive developments in iron, reinforced concrete, and steel skeletal frame structures. Le Corbusier enshrined the "ribbon window" as an icon of modernity, the undisturbed horizontal continuity of which resulted from the separation of the structural frame and the building envelope. The advent of commercial curtain walls after WWII made this paradigm of separation of enclosure from structure even more dominant and ubiquitous throughout the Western world.

Accompanying these evolutions were plate glass and, later on, float glass manufacturing advances that made large glass sheets more readily available. Large glass elements, however, are very heavy and thus, hard to operate. Their substantial weight predisposes them to remain as fixed glass elements within the façade, perfect for sight and transparency, but lacking in their ability to participate in the natural ventilation of the building. Operating large and heavy glass sheets usually comes at the aesthetic cost of a visually-heavy frame that appears incongruous with the appearance of lightweightness that we unconsciously associate with the transparency of glass. Alternate solutions to a heavy frame exist: centrally vertically pivoting windows that balance the weight of the glass, for example, or top-hung sliding windows such as those developed by Richard Neutra with very filigree frames. Subdividing the large glass so as to create a smaller, thus more easily operable opening, is another option. While this approach presents interesting compositional opportunities, it nonetheless contradicts the original design intention of employing exclusively large glass elements. For the designer, not compromising, i.e. keeping the large glass undivided, often results in abandoning the natural ventilation capability of the envelope and substituting it with a mechanical ventilation system.

The two cases examined below, Jean Prouvé's 1957 temporary school in Villejuif, France, and, müller verdan architekten's 2003 Sporthalle "Gotthelf" in Thun, Switzerland, are two rare instances in which the architectural designers achieve both the "large glass" and the natural ventilation by means of an ingenious and unorthodox move, namely, integrating the natural ventilation directly within building structure members.

The method used for investigating Prouvé's building is based on an analysis of various documentary, publication and archival documents. In the case of the project by müller verdan architekten, the analysis of published materials and plans obtained from the architects is complemented with direct on-site observations and conversations with the designers.

The paper contributes to the literature at the intersection between construction, structure and natural ventilation. It showcases the fertility of systems' integration-based design approaches that have yielded unusual design responses by revisiting the dominant and, arguably, usually unchallenged paradigm of separation of structure and enclosure.

Literature sketch

The topic of natural ventilation integrated into structural elements has received very little attention in the literature, perhaps because it is at the intersection—or arguably, the periphery—of several disciplines. It is absent from five BTES conference proceedings spanning the period 2009-2017, in which the terms "vent" is used only twice, and "venting" and "vented" are each used only once. The literature on natural ventilation [Allard, 1998], [Etheridge, 2012], [Santamouris and Wouters, 2006] tends to focus on general principles. Only the latter of the three references cited here venture into discussing, in its penultimate chapter, various kind of "advanced components for ventilation", none of which have anything to do with the structure. The literature on structure, unsurprisingly, focuses on structural issues, among which serviceability and wind loading, but without typically ever encompassing natural ventilation concerns. A notable exception is Peter Rice's discussion of Jean Prouvé's Maison Tropicale [Rice, 1994]. The contemporary literature on building enclosure typically has adopted the mantra of the separation of enclosure and structure systems. The growing concern with thermal performance favors warm inboard columns that keep thermal bridging issues easily under control. Historically, as illustrated by [Ehrenkrantz, 1989] or Banham's "well-tempered environment", the systems integration literature, has placed all its chips on mechanical systems. This has trickled down in all construction textbooks by Ed Allen, Ching and Iano, and others who discuss integration of mechanical services within trusses, castellated or composite cellular. While the approaches of draining rain water down inside a tubular structural column or forced air within box beams and columns are well known, the concept of letting air through a wide flange or other structural member appears to be a blind spot of the literature except for a few other projects by Prouvé [Huber & Steinegger, 1971], [Beeren, 1981], [Sulzer, 2008]. Ford, in the Detail of Modern Architecture, volume 2, page 383, shows a cut isometry through the structural member described in the next section, but without much context and mistakenly designated as an aluminum extrusion. The architects Sauerbruch & Hutton used holes in twin concrete columns within the double façade of their 1998 Berlin-Adlershof Photonics Center design. One would think that the versatility of casting technology and the ingenuity of 19th century engineers and other tinkerers would have yielded instances of integration of natural ventilation into structural beams or columns, but such examples have eluted us thus far; the catalogue published in 1865 by The Architectural Iron Works of the City of New York—a fac-simile of which was published by [Badger, 1981]—contains cast iron storefront façades that integrated tracks for shutters and other closure elements, but none apparently dedicated to ventilation.

Jean Prouvé's School in Villejuif, 1956

Jean Prouvé (1901 - 1984) designed a temporary school for Villejuif, a southern suburb of Paris, France, in 1956, after relocating in Paris from Nancy and setting up a new company, "Les Constructions Jean Prouvé". There, together with engineer Serge Kétoff, architect Jean Masson and collaborator R. Guidici, he worked on the modular design of the school erected in 1957. A masterful experiment in prefabricated architecture, the school was destined to be temporary—some call it rather hyperbolically "nomade" [nomadic]. The school was indeed dismantled three years only after its erection according to [Schein, 1964]. A positive in the unfortunate fate of this building was that some elements of the building's kit-of-parts were salvaged and re-erected in the form of an architecture office. More recently, thanks to the growing attention received by Prouvé's various creations, the structure was acquired by a gallery, restored, and put for sale. [Seguin, 2015]. A time-lapse video produced by the gallery responsible for the building's second reincarnation strikingly captures the ingenuous kit-of-part quality that infuses the building's exquisite aesthetic.

Prior literature on the school, as, for example, [Mannell, 2006] has mostly focused on its structure with little to none examination of the ventilation aspect of the building. This exposé draws from the writings of [Pascaud, 1957], [Huber & Steinegger, 1971], [Beeren, 1981], [Sulzer, 2008], as well as drawings from the Prouvé archive at the Centre Pompidou in Paris [MNAM-CCI, 2007].

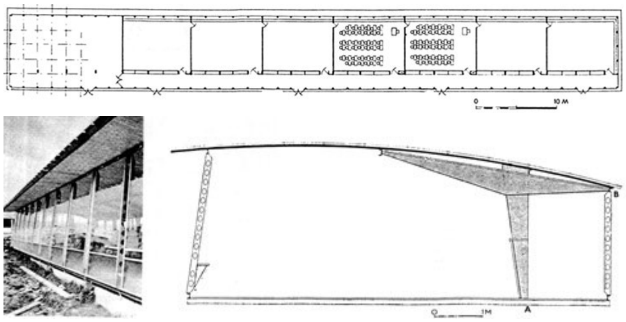

Fig. 1. Top: plan of the typical seven-classroom school with north-facing single loaded corridor. Bottom left: the slanted extensively-glazed south façade shaded by the roof cantilever. Bottom right: Building cross section with the corridor-side "poteau aérateur" tying the T-shaped "béquille" down, and the classroom-side slanted "poteau aérateur" tying the thin wood roof down, thus giving it a gentle curvature.

The temporary school for Villejuif was composed of three similar long bar buildings on an Est-West axis. The typical classroom bar was 75.25 meter long by 8.75 meter wide and was based on a 1.75 meter square grid module (fig.1 top). Along the building's length, seven South-facing classrooms, each five by four modules rectangles (8.75m x 7m) were distributed along a North-facing one-module wide (1.75m) single-loaded corridor terminating into an eight module-long indoor recreation area occupying the whole bar width.

The building iconic cross section visible in fig.1 shows the thin and gently-cambered roof made of wood with its cantilever shading the tilted glass South façade. Over the northern half of the building, the roof was resting on three purlins supported by a graceful asymmetrically T-shaped structural member that Prouvé called the "béquille" [crutch]. The béquilles, which were part of the boundary between the corridor and the classrooms were pin-jointed at their base, and were stabilized by 2.45m tall vertical V-shaped tie-down elements called "poteau aérateur" ("venting post") placed on the module. The tapered T-shaped béquille was made of custom brake-pressed steel plates. The lapping intersection of the twin cross bar elements and the twin leg elements ensured a rigid, moment-carrying connection between the two sets of elements. Structurally, the corridor-side poteau aérateur together with the béquille formed a three-pin half-portal frame that braced the building in the transverse direction. In the long direction, the béquilles were spaced 3.5m on center except for the one-module wide (1.75m) bay marking the entrance to each classroom.

The roof decking was constructed with flat 75cm-wide by 9.80m long and 40 mm thick, 3-ply "contrecollé" wood panels similar to today's cross laminated timber. A tongue-and-groove joint linked adjacent panels together. The roof curvature resulted from flexibly bending the flat wood panels down and bolting them onto a C-shape purlin resting on top of the inward-leaning South-facing poteaux aérateurs. While not the focus of this paper, it is nonetheless worth highlighting another unorthodox engineering move by Prouvé in the way the wood decking shifts position within the building's structural hierarchy. For instance, over the three purlins supported by the béquille, the roof wood panels are mere secondary structure, i.e. decking; in contrast, where they span 3.80m over the classroom, the roof wood panels are now primary structural components insofar that they "actively" connect the "free-standing" South façade's "poteau aérateur", a primary structure member, to the rest of the béquille+-tie-down primary structure. The roof was clad with aluminum panels resting on a layer of wood-fiber-based thermally and acoustically insulating board laid onto the contrecollé wood panels.

The "poteaux aérateurs" and the large fixed glass

All around the building's perimeter, all poteaux aérateurs—the 3.25m-tall ones along the South façade, and the 2.45m-tall ones along the North facade, as well as those of varying heights of the East and West narrow end facades— were located on the 1.75m grid module. Each V-shaped poteau aérateur appear to have been 300mm wide by 150mm deep with a 50mm-wide central flat-bottom and with 37.5mm flanges on each sides onto which the large glazing elements were fastened (see figure 2). The angle between the two legs of the V appear to have been 60 degrees. Radii between the different planes of the profile indicate that they were custom brake-pressed from a blank flat steel sheet probably 450mm wide and possibly as thin as 3 or 4mm-thick.

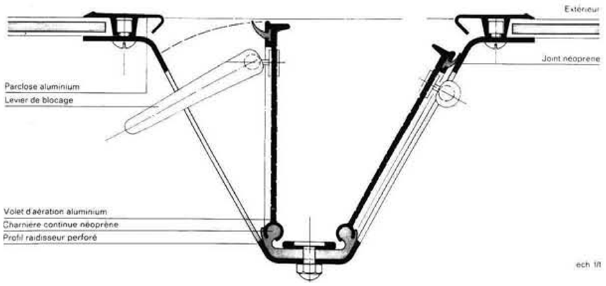

Fig. 2. Horizontal /perpendicular section through the flanged V-shaped "poteau aérateur" [venting post] with the flap on the left in open position.

The facades' single, approximately 147cm-wide clear plate glass elements were continuously edge-clamped to the poteaux aérateurs' flanges by means of an aluminum extrusion and gasket, held into place by small screws exposed to the inside. According to [Beeren, 1981], the glass participated to the in-plane bracing of the façade. The upper edge of the glass elements was discontinuously edge-held by means of two clamping plates bolted into the roof purlin. The 2.45m-tall corridor-side glass façade was vertically subdivided in three equal size glazing lites. Fig.1 shows that the classroom façade was fitted with a continuous shelf-table, the level of which was an estimated 50mm below the level of the horizontal rail that separated the upper, approx. 240cm-tall clear glass panel from the lower, approx. 75cm-tall wired glass panel.

The ventilation function of the poteau aérateur was implemented via a series of circular cutouts—120mm-diameter according to [Pascaud, 1957]— spaced an estimated 205mm on center of both flanges (legs) and slightly off-center of the centerline of each of the V-shape profile legs. This configuration resulted in two sets of nine cutouts (one set per leg/flange) over the height of each corridor façade posts (13 for the classroom-side façade poteaux aérateurs). The drawing number 4N24297 in the Prouvé archive at the Centre Pompidou [MNAM-CCI, 2007] shows an earlier design version of the façade kit-of-parts that included the poteau aérateur alternating with another simpler post without ventilation capability. This design also included a horizontal infill metal panel with a line of round vents located directly under the roof, above the glass, which was subdivided and comprised an operable window.

As visible in fig.2 and fig.3, two outward-opening extruded aluminum flaps, one for each leg of the V, shut the series of venting cutouts close independently from each other. A handle was provided to operate the shutter and let the air in by unlocking it and pushing the shutter open through one of the circular vents.

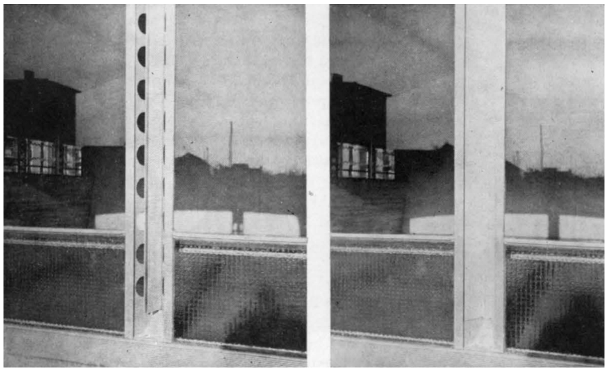

Fig. 3 (left) the poteau aérateur seen from outside with the flaps in open position. (right) flaps in close position.

These shutters were hinged via a fish-mouth profile along one long edge of the extruded flap that "bit" onto a continuous bulbous neoprene extrusion affixed on the flat bottom of the poteau aérateur. On the inside, this flat feature of the venting posts also served as a surface against which the interior partition elements separating adjacent classrooms could abut.

Besides the continuous hinge on inner vertical edge fo the flap, a snap-on gasket along the outer vertical edge provided air and water tightness. The solution at the shorts ends of the flap is not known. It is possible that these were left ungasketted, which would have allowed condensation water on the inside face of the flap to flush out unimpeded.

Müller Verdan's Sporthalle Gotthelf, Thun, 2006

The Zürich-based architecture firm "müller verdan architekten" lead by Rafael Müller and Dominique Verdan completed the award-winning Sporthalle "Gotthelf" on the ground of the school of the same name in Thun, in the canton of Bern, Switzerland in 2006. The sport facility is used by both the school pupils and local sport clubs. Programmatically, it is a "dreifach-Turnhalle", a type of gym space commonly found in Switzerland, that is configurable either as three side-by-side basketball courts separated by hanging nets, or as one handball court along the building's long axis. The rectangular building dimensions are 50 x 40 meters. The sporthalle is sunken into the ground by 3.5 meter below grade level. The height of the volume above grade is 7.50-meter as visible in fig.4. In plan, a continuous ring of circulation runs along the entire rectangular perimeter at grade level and overlooks the court below Its WSW-facing portion is wider and serves as an entrance. It is screened from the sunken court space by a one-story bar volume housing various ancillary spaces and two staircases.

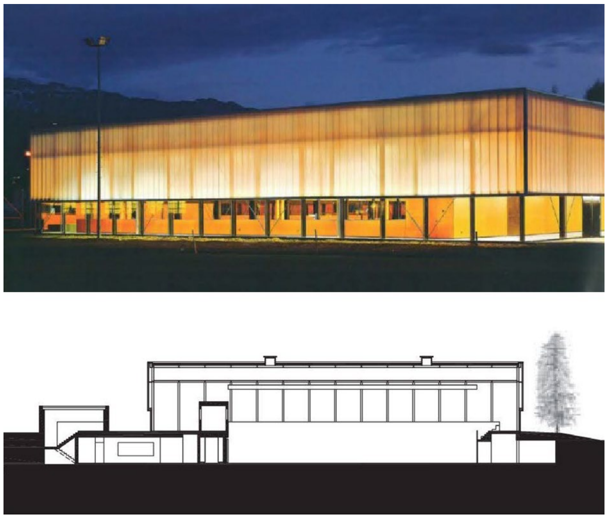

Fig. 4. Top: A view at dusk of the Sporthalle Gotthelf in Thun, Switzerland, by müller verdan Architekten showing the consistent treatment of the two-tiered horizontal composition of its facades. (pho: Alexander Henz). Bottom: Transverse section showing the approx. 5.30-meter clear headroom sunken practice space flanked with the changing rooms with independent stairwell access on one side and the sport equipment storage space on the other side. Two twin exhaust vents are visible at the roof level.

The primary structure of the roof is composed of ten 40-meter span, 1.47meter-deep welded plate girders that rest on HEA240 columns spaced 4.56 meters on-center. As fig 4. shows, in order to achieve a glowing lantern effect consistent across all four facades, the spans immediately adjacent to the two short facades have been designed without the girders but, instead, with beams—identical to those running along the long facades—supported by HEA180 columns spaced 2.83m on-center. The lateral bracing of the building occurs similarly on all four facades via diagonal steel rods terminated by end-fork fittings.

Figure 5 is a section through the WSW-facing long façade. All four facades are similarly composed based on two horizontal bands with minimized vertical joints and HEA 240 (or 180) columns positioned 10 cm inboard of the grade-level 2.2m-tall glass band. This lower transparent band is made of 10/14/6+6 thick insulated glazing units ("IGU") separated by vertical silicone joints aligned with the columns beneath. The upper band is 5.20-meter tall and projects 30 centimeters outward beyond the lower glass band plane. It is composed of 50cm-wide, 40mm-thick, six-cell vertical translucent polycarbonate panels stiffened by means of a polycarbonate stiffener aligned with the proprietary vertical tongue-and-groove joint on the inside.

As indicated in fig.5, wind loads are taken at four locations over the height of the façade. These are, from bottom to top: A) at the grade floor level, B) at the top of the glass band which is also the bottom of the polycarbonate band, C) at the level aligned with the roof girders' lower flange, and, D) along the roof curb edge.

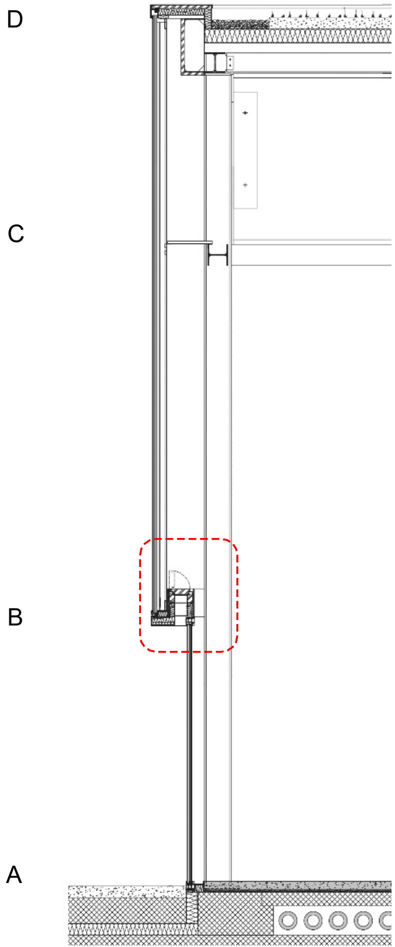

Fig.5. Section through the façade of the sporthalle with A through D wind bracing levels.

Conditions "A", "B", and "D" are conditions in which either the glazing units or the polycarbonate panels are continuously supported by means of U-shaped edge profiles. At condition "C", which is slightly above the middle of the upper polycarbonate band, wind loads on the panels are transmitted via brackets connecting the polycarbonate stiffening profile to the upper flange of rotated horizontal HEA240 ("H") shapes centered on the primary columns.

Figure 6 shows condition "B" where the air inlets are integrated in the web of the horizontal rotated HEA240 ("H") girts that are fastened eccentrically 33cm (centerline to centerline) away from the columns.

The thermally-broken horizontal glass framing rail at the top of the IGU is located below the horizontal "H" wind girt and flush with its inside-facing flange. The polycarbonate panels are positioned approx. 85mm in front of the outside-facing flange of the "H" girt, thus concealing it from view from the outside. The panels' lower edge is housed in a shallow thermally-broken aluminum extrusion.

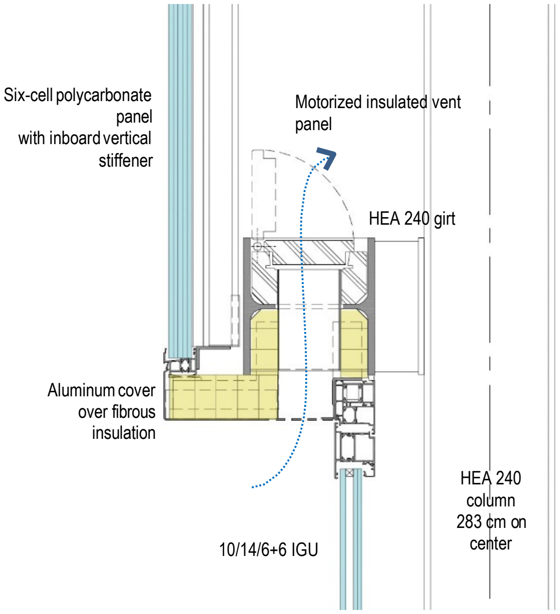

Fig. 6. Detail vertical section of the air inlet cut in the flange of a HEA240 profile at condition "B". The setback between the lower glass band and the upper translucent polycarbonate band provides a pathway for air to flow into the building.

Flush with the outside vertical face of the panel, a custom brake-pressed 2mm-thick anodized aluminum L-angle covers the 80mm-thick insulation. The portion of this closure angle's horizontal leg aligned with the web cutouts in the "H" girt above is perforated in order to allow for air passage. An insect screen is also provided. Spray foam insulation fills the voids between the H profile and short stubs of vertical PVC ducts through which the air enters the building. The opening of the air passage is controlled via motorized upward swinging insulated flaps visible on figures 6 and 7.

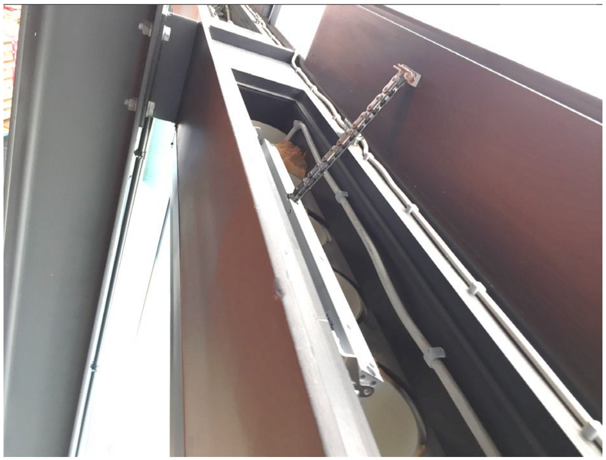

Fig. 7. The bay-width-sized ventilation flap in open position with one of its two 24V motor.

Seventeen 121mm-diameter cutouts, spaced 150 mm on-center are thus created per 2.83m-wide bay along the building's short sides. Each cut out is fitted with a section of a PVC tube with clear 105mm interior diameter. All vents within one bay are capped with a single concealed 201mm-wide by 2556mm-long motorized flap. Similarly twenty seven circular vents are provided per 4.56m bay along the building's long sides. Six pairs of insulated outlet vents are provided at the roof level. Each motorized awning-type vent is 4.32m-long by 42 cm-high, and is protected from rain by a 20cm overhang.

Fig. 8. View from above of two air inlets lined with short PVC stub. The slightly larger diameter cutout in the HEA240 is visible as is some sprayed-in foam insulation filling the lower cavity beneath the shape's web. The perforated closure angle is visible, but the insect screen resting directly only it is washed out in this photo by the author.

Compare and contrast

The integration of natural ventilation within the structure is a very seldom seen design move. For both the projects presented here, this approach was conceived and implemented by the architects themselves without the help of façade consultants.

Prouvé integrated the vents within the primary structure of the school. Mueller and Verdan integrated the vents within the sporthalle's secondary structure that supports the enclosure and braces it against the wind. Both designs, however, approach the provision of openings for ventilation via an analysis of where superfluous material is located within a structural member. Removing material along the neutral fiber of the web of the hot-rolled H-shape girt in the Sporthalle does not hamper the shape's ability to perform as a simply supported horizontal beam resisting wind loads. Similarly, the cutouts along the brake-pressed flanged V-profile of the poteaux aérateurs in Prouvé's school are also positioned along their neutral fiber. This position is optimum when analyzing the poteau aérateur as a slanted beam-column resisting wind loads. The presence of cutouts at the neutral fiber is inconsequential in the poteau aérateur subjected to axial tensile forces. In this case, of course, only the net cross section of material left in the poteau aérateur around a cutout is taken into account to evaluate tensile stresses. For what regards axially compressive forces in the poteau aérateur resulting from an exceptional wind and/or snow loading case, the position of the cutouts along the profile's neutral fiber only very marginally impacted its moment of inertia and radius of gyration, hence its ability to resist buckling.

In the sporthalle, the glass, as most often is the case, plays no structural role. In contrast, as noted by [Beeren, 1981], the glass panels in the temporary school are conceptualized in terms of flat shear planes contributing to the stabilization of the poteaux aérateurs.

Some differences between the two projects reflect differences in design preoccupations at the time of their design. The manually-operated and uninsulated poteau aérateurs of the school is crude compared to the motorized and insulated vent assembly of the sporthalle; similarly, so, the insect screen absent in the school vs. placed directly onto the perforations of the L-shaped aluminum closure element in the sporthalle.

The type of natural ventilation involved in both project is a little bit different. When the door between the classroom and the corridor was closed, the ventilation of the classroom in Villejuif was single-sided ventilation based on stack effect with bidirectional flow. On a cool day, warm indoor air would have flowed out of the vents located above the neutral plane—approximately above the mid-height of the room—and been replaced by incoming fresh outside air entering the room via the cutouts in the lower half of the poteau aérateur. In the case where the classroom door was left open, two ventilation regimes would have occurred. On a windless day, a stack-effect-based ventilation would have resulted due to the asymmetrical cross-section of the building and/or the temperature difference between the South and North façade. Alternatively, on a windy day, a cross-ventilation could have developed, with possibly a jet region in the part of the classroom directly aligned with the classroom door, as well as a recirculation region off of it. With its inlets in the façade and its outlets at the roof level, the sporthalle is naturally ventilated by stack-effect on a windless day. While this has neither been experimentally verified nor computationally modeled, one can hypothesize that there probably are particular temperature, wind direction and velocity conditions under which some of some inlets—tentatively, those near downwind corners—that occasionally act as air outlets due to their being temporarily within regions with lower negative pressures than those near the middle of the roof where the roof outlets are located.

In the temporary school, the classroom occupants would have been quite directly exposed to the incoming air. Conversely, in the sporthalle, the inlet vents are positioned slightly above the occupied level and therefore impact the building first and foremost. Its occupants are only indirectly affected. There are both advantages and disadvantages in terms of occupants' thermal comfort with both configurations throughout the seasons. While direct exposure to cold drafts would be undesirable, conversely, increased convective cooling via air drafts would be welcome to help offset an elevated interior air temperature, the solar radiation transmitted through the glass and the inward radiation of heat absorbed by the sunlit glass. In the school, opening the south-facing vents let the sun penetrate directly into the room around noon time. In the sporthalle, the glass band is shaded somewhat due to its setback. At lower sun angles on windless days, it is likely that the convection resulting from the heating up of the outermost pane of glass can be "sucked in" the inlets, thus tapping into a pre-heating effect potentially beneficial during cool days.

Both designs took into consideration the possibility of ventilating under light rain conditions. The façade inlets and roof outlets in the sporthalle are shielded locally by the façade setback and a bespoke overhang, respectively. In the temporary school, the wood roof projecting out over the tilted south façade provided a global protection of the vents against rain, arguably more efficiently so for the upper ones than the lower ones.

Visually, in the sporthalle, the air inlets, which are inserted flush between the upper edges of the HEA240 flanges, are completely concealed. The flaps, when in their open position, are also quite inconspicuous. In the temporary school, the ventilation scheme was also very discreet when looking at the façade tangentially from outside. In contrast, the experience of the opened vents from inside the classroom would have been quite striking with its two sets of "spots" of light dotting the height of the poteaux aérateurs.

Conclusion

What makes Prouvé's temporary school in Villejuif and Müller Verdan Architekten's sporthalle "Gotthelf" remarkable is not only the rarity of their approach to integrating natural ventilation within structural members, but also how they, in doing so, challenge the prevailing paradigm of separation between structure and enclosure. As such they are representatives of a unique "species" within the broader genre encompassing facades of buildings with skeletal structure.

These two projects point to a unique approach to natural ventilation that opens new design possibilities. They are a reminder that the dichotomy between structure and enclosure underlying generic curtain wall construction, if instituted into a dogma, ought to be questioned. The argument in favor of the separation between structure and enclosure typically has to do with the issue of the different of tolerance of construction of structure and building enclosure. In the two cases presented here, however, the designers overcome this otherwise valid constraint by simply associating the precision demanded in terms of air- and water-tightness of an operable vent system with that of easily achievable precise cutouts along the web of a structural member, itself manufactured with precision.

Jean Prouvé's integration of natural ventilation within the *primary* structure of the school seems like a heroic move made possible by the more lax thermal insulation requirements at the time. müller verdan architekten integrate the natural ventilation of the sporthalle in its *secondary* structure with great elegance. The column remains inboard and warm. This architect-driven design inspiringly navigates the conflicting demands placed on contemporary building enclosures. Its ingenuity sends an hopeful message in an age of BIM-powered off-the-shelf product-picking.

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