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Ingrid Paoletti · Massimiliano Nastri

Executive Design of the Façade Systems

Typologies and Technologies of the Advanced Building Envelopes

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Preface

The study, developed inside the experimental laboratory *Material Balance Research* within the Architecture, Built Environment and Construction Engineering—ABC Department at the Politecnico di Milano, examines the advanced façade systems according to the constitutive and typological characters, as well as the functional and applicative requirements such as the expressive, constructive and interactive criteria toward the environmental, perceptive and energy conditions.

The work involves to examine the typological and technological constitution of the principal advanced façade systems in the contemporary design and experimental scenario, proposing itself as a knowledge and operational tool currently lacking in the technical literature of the sector at an international level. The work considers the field of advanced façade systems in a scientific way, constituting a support for the study and the executive design. Compared to the pre-existing literature on envelope systems, the work investigates in detail, in an analytical form, the constitution of the components on a typological and geometrical, functional and constructive level, on the basis of the documents and knowledges acquired from the essential contemporary production and construction references. At the same time, the work is configured in manual form as a reference for understanding and application with respect to traditional and complex façade systems.

The study is aimed at researchers, designers and, in general, operators in the field of the advanced façade systems, considering that the level of composition of the work is directed at experts in the specific matter, who require a tool of a high explanatory and operational level. This is not a basic text, but a work that goes beyond the literature expressed on the subject at an architectural, descriptive or narrative level.

The main topics concern the technological determination of lightweight prefabricated external curtain wall envelopes, according to the development of façade components, also considering multi-material relationships and specialized layering. The thematic in-depth study focuses on structural, connection and interface references related to the functional and application requirements articulated with respect to the main advanced curtain wall types.

For each main type of façade, the work provides explanations and scientific information for investigating and designing the advanced façades according to the characteristics of the mullions and transoms façade system (stick system), of the structural sealant glazing façade system, of the unit façade system, of the suspended façade system and of the double-skin façade system. The explanation is made with the aid of analytical insights into the physical, connective and interface constitution, supported by details and documents acquired from the advanced production and construction sectors.

The book is envisaged to become the first work in a series of texts on the technical and scientific study of the advanced façade systems, planning to deal, in the future, with the contents related to the building site and construction phases, the specific constitution of the production methods and an in-depth study of the enclosure and cladding materials. The book, intended as a basis for scientific, academy and professional study, is proposed as a useful tool within university courses, specialized and master's courses, as well as a support for the preparation of expert technicians in the field of façade systems.

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Chapter 1
The Composition of the Façade Systems in Building Technology

1.1 The Typological, Functional and Operational Definition of the Façade Systems

The study deals with the envelope systems conceived as light prefabricated external walls (made in the laboratory and assembled on site), identified within the perimeter walls, in the form of homogeneous and uniform vertical enclosures in the external surfaces. The envelope systems are examined according to the flat vertical composition and the combination of a series of functions, such as the delimitation and protection of built spaces, visibility, regulation and control of thermal incidence, natural lighting and ventilation, with respect to climatic conditions and stresses (mechanical, thermo-hygrometric, wind and acoustic).

The envelope systems (which do not contribute to the main load-bearing performance) are considered as external enclosure units of the architectural organism, built by frames (mainly produced of metal, but also of wood or plastic materials) made of vertical and horizontal structural elements (which themselves are connected and anchored with interface devices to the main load-bearing structures, which are generally frame structures; [50]). These units, established as non-load-bearing external walls (and, therefore, supported by a vertical and/or horizontal support grid), consist of technical elements (with a modular production base) prefabricated and joined to the load-bearing structures of the architectural organism through mechanical assembly techniques, aiming at separating the interiors from the external environment [12, 42, 48].

The design, production and execution formulation of the envelope systems, aimed at performing morphological, physical-technical and environmental functions, is outlined within the evolved configuration of the *curtain wall* (known as "external curtain") and within the geometric and material continuity of the "lightweight facades" (or "curtain walls"), arranged outside the main structural apparatus [16, 25, 44, 45, 65]. The envelope systems are composed within structural frames capable of supporting, accommodating, combining, engaging and hooking the subordinate arrangements defined by the formulation of enclosure components [5]. Therefore,

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the elaboration of contemporary envelope systems relates to curtain walls and to the extension of the curtain wall applied to vertically developed buildings. This typology indicates an external non-load-bearing enclosure made of panels, of glass or other material, connected to a support frame that is assembled to the main structural elements (vertical and horizontal) of the architectural organism.

The composition of the façade systems through the design, production and application of lightweight prefabricated components is outlined in the form of the external curtain wall made on steel or reinforced concrete framed structures, as a unit that can be separated from the whole construction and has no load-bearing function [18, 54]. According to the European standards, the definition of *curtain walling* is expressed considering the curtain wall as «a network of vertical and horizontal load-bearing elements connected and anchored to the building structure, in order to support a continuous and lightweight façade cladding that must ensure all the typical functions of an external perimeter wall, including weather resistance, safety in use, security and environmental control, but which does not contribute to the load-bearing characteristics of the building structure» [63, p. 7].

The envelope is mainly made up of closing elements of the voids between the elements of the load-bearing framework, its morphology essentially depends on the materials and products used, on the laying methods and on the possible forms of surface finishing [22, p. 449].

Giovanna Franco and Stefano Musso's definition states that "in contemporary architecture, where the envelope is mainly made up of closing elements of voids inserted between the load-bearing framework elements, its morphology essentially depends on the materials and products used, on the methods of installation and on any forms of surface finish. Planks, slats, slabs, panels, shells, glazing, frames, windows, "coatings", can thus give different aspects to the envelope, in terms of surface, colour, texture, opacity or transparency, chiaroscuro effect and so on" [22, p. 449]. Furthermore, "the construction of the architectural envelope may use different connection types between the components of the actual envelope (internal connections) and the load-bearing structure of the building (external connections). The connection types and methods may vary according to materials and products used, to the building structure and to the number of functional layers that make up the envelope. In general, in contemporary construction the envelope elements may be inserted between the grids of the building's external structure, or they may be leaning against the exterior, directly attached to beams and pillars, or tied to a different, specially prepared support structure" (ibid.). Following on from Franco and Musso's definition, it can be seen that all materials can be used independently or mixed, in one or more layers (possibly with the insertion of insulating material within the specific "package"), and their external surface can be variously finished for general or specific purposes.

Furthermore, during the construction of the building envelope, different types of connection can be used between the parts making up the envelope itself (internal connections) and between this and the load-bearing structure of the building (external connections). The types and methods of connection vary according to the materials and products used, the structural typology of the building, and the number of functional layers of which the envelope is composed. In general, in contemporary construction, the elements of the envelope may be inserted between the grids of the buildings external structure, or they may be leaning against the exterior, directly attached to the beams and columns, or tied to a different, specially prepared support structure (ibid.) (Fig. 1.1).

The evolved configuration of the *curtain wall* takes shape according to the conditions, the impulse and the supply deriving from the widespread technical openness of the window and door industry for façade systems (already defined by the processes of *components approach* or *componenting*, with the use of aggregative rules for the assembly of pieces), which identifies a sphere characterized both by the multiplicity of combinations, and by the synergies between technical elements and materials of

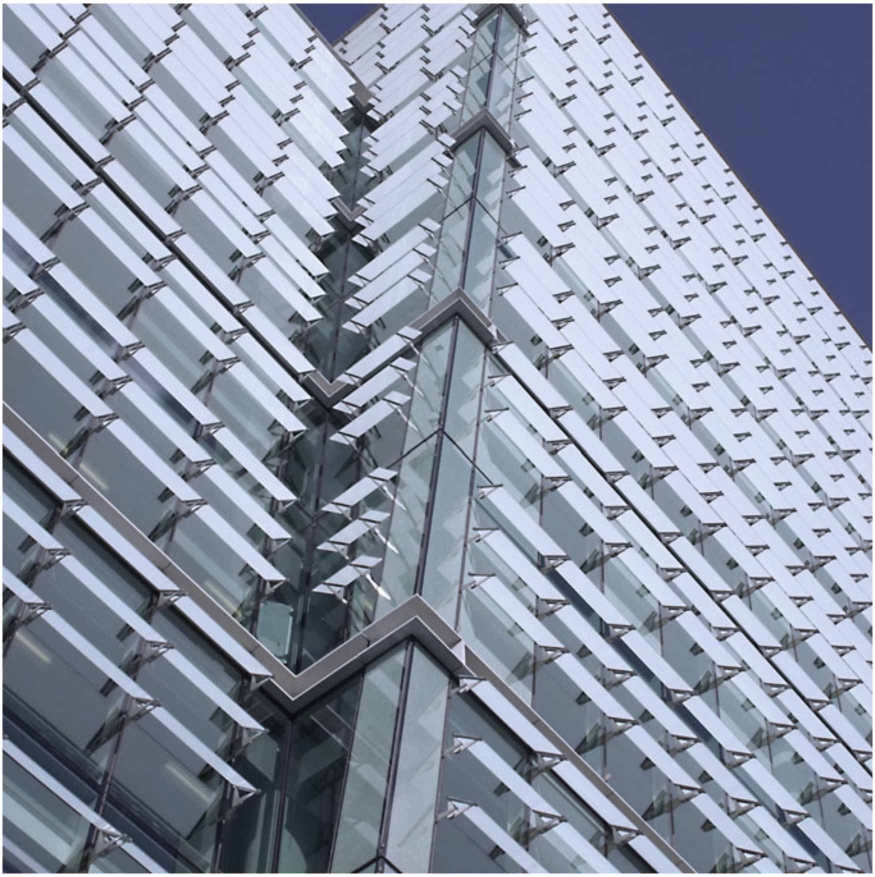

Fig. 1.1 Sidell Gibson Architects, *One Snow Hill* Building, Birmingham. Study of façade systems designed as light prefabricated "vertical perimeter walls", according to the delimitation and protection of built spaces, the regulation of thermal incidence, natural lighting and ventilation, the control of internal climatic conditions and the control of mechanical, thermo-hygrometric and acoustic stresses. © Courtesy of Focchi

different productive origin, which must support the criteria of flexible relationship between the contents referring to the structural and closing elements, to the connection and functional devices, up to the assembling methods (according to the environmental and technological performances that are going to be examined and obtained). Following Giovanna Franco and Stefano Musso's definition, we can notice that all materials can be used independently or mixed, in one or more layers (possibly with the interposition of insulating material within the specific "package"), and with variously finished in their external surface according to generic or specialized purposes (ibid.).

Within the design, production and construction scenario, the envelope systems are examined with respect to:

- the role of transition between internal and external space, independently, on a morpho-typological level, with respect to the intended uses of the architectural organism and according to the combination of performance contents (as useful skin) and external aspects (as *ornamental packaging skin*);
- the constitution of the components in an integrated form, characterized by specialization processes aimed at assuming the overall quality at different levels, according to the procedures of structural, connective, geometric and dimensional coordination, in order to allow both the mechanical assembly methods and the application to multiple building types (Fig. 1.2).

Therefore, the envelope systems participate in the assignment of the expressive contents of architecture, so that the external composition of the architectural organism coincides with the functional and constructive solutions adopted for the vertical enclosures, through the reduction of material incidence, the perceptive dematerialization and the enhancement of the meanings related to lightness and transparency. Moreover, in relation to the results of contemporary research, the examination of the technical and executive configuration of the envelope systems also addresses the innovative opportunities of morpho-typological expression correlated to aspects of a functional nature.

This leads the design and application scenario to constant experimentation and considers the closing elements in their progressive acquisition of tools and performance solutions aimed at increasing performance with respect to mechanical and environmental stress as well as energy, light and air exchanges.

The concept of envelope systems made from prefabricated components, therefore, includes the development of membranes separated from the supporting frames, with the necessary performance to provide protection and improve the ergonomics of interiors [49].

The development of the systems takes place with respect to the constitution of:

- the layered composition, according to the "selective" search for functional arrangements and materials, in accordance with "performance planning" procedures and through the translation of the "requirements package" into a "technological package" (or "layered construction");

Fig. 1.2 Mario Cucinella Architects, *SIEEB* (*Sino-Italian ecological and energy efficient building*), Beijing. Façade systems examined as the external enclosing unit of the building organism, executed by means of the frameworks, made up of vertical and horizontal structural elements, in turn connected to the main load-bearing structures with interface devices, and by means of the "aggregative rules" for the assembly of the "pieces", according to the *component approach* or *componenting* processes. © Courtesy of Mario Cucinella Architects

- the "specialized" units with "dynamic" or "interactive" behavior, composed of functional elements designed and calibrated to actively "respond" to environmental stress, through perceptual and "organic" contact with external climatic conditions.

The building envelope is determined, on a conceptual and executive level, in the building "façade" (from the Latin *facies*), understood as:

- the external boundary with a representative function in the urban space with respect to the procedures of spatial composition: this is done through the (structural or formal) frameworks constituted by the frames and the corresponding backgrounds that are included;
- the integration tool towards the fruition and functional characters of both the context and the environmental, atmospheric and perceptive characters [13].

In this perspective, the conception, production and construction of the envelope systems, by using semi-finished elements or small finished components to be assembled on site, is configured as an activity of selection, adaptation and connection of products.

In this regard, the convergence between design culture and industrial culture is outlined according to the flexibility of the production chains, the innovation oriented to the flexibility (but also to the specialization) of the products and the provision of new performances, while respecting the principles of multi-material relationship and specialized stratification: this, on the whole, determines the fine-tuning of functions according to specific needs, compared to products that manifest morphological neutrality and numerous possibilities of use, articulation and joining [43].

According to this approach, the compositional elaboration of the envelope systems (in the form of orders and rules conforming to the use of planar, modular and often industrially manufactured elements) is examined through:

- the application of traditional materials, on the basis of references and allusions to the physical properties of their surfaces, grading and modulations on the façade level;
- the use of morpho-typological rules which are mediated with respect to the prefabricated components, the connection methods of which establish the logic of correlation both expressive and executive;
- the poetics of construction aimed at defining the semantic criteria of the frames and enclosures in conformity with the expression of the principles and modes of relationship between the parts and the materials. In this regard, the elaboration of the envelope systems considers the procedures of mechanical assembly as a strategy aimed at specifying the design and executive practice no longer according to a fixed and immutable configuration, but rather as an activity that identifies a series of feasible solutions, allowing, in some cases, the reversibility of the construction [20, 28]. The production of materials, semi-finished products, components and construction procedures for the shell is varied and heterogeneous, with assembly techniques becoming "compositional techniques". In this way, elements and materials are articulated in the search for a language that necessarily becomes differentiated in its parts, formed by compound idioms and governed by a syntax in continuous mutation: the elaboration of the shell is proposed within an "indeterminate" configuration (opposite to the conception of the architectural organism as a *finite object*) containing, in a simultaneous way, permanence and transformation, transparency and "dematerialization".

The implementation of envelope systems observes the following conditions:

- the adaptability of building products, within industrial logics characterized by high flexibility and construction strategies capable of encompassing different execution techniques. In particular, adaptability refers to the degree of variability of the technical elements, proportional to their degree of aggregation flexibility, that is, to their degree of autonomy in modifying their interactions with those belonging

to other elements, which are conceived in an open manner through the use of solutions designed to allow subsequent integration;
- modularity, which, as a design and construction strategy, requires interchangeability and the possibility of combining technical elements, based on operational and procedural references such as standardization and modular coordination. In particular, modular coordination constitutes a method for determining the dimensions of technical elements and the structures they create, also in order to realize the conditions for a market of interchangeable and dimensionally selected building products. The module, therefore, is no longer the exclusive function of the measure, but becomes a function of the object understood not as a finished element, but as a basic element, moving from the "module-measure" to the "module-object" for both the frames and the enclosure apparatus;
- flexibility, which proposes the adaptation, by means of extension or convertibility, of characteristics already present in the system or in the technical elements, both structural and enclosure [55] (Fig. 1.3).

1.2 The Productive and Executive Articulation of the Façade Systems

The façade systems, designed and produced according to general needs, requirements and performance or for individual applications, are defined as light prefabricated external walls, executed in the form of curtain walls, cellular curtain walls, double skin curtain walls, structural curtain walls, suspended curtain walls and curtain walls with point fixing. In particular, both mullion and transom metal frame and structural and cellular façade types are specified by fixed and/or openable transparent closing elements, also combined with opaque elements (or *spandrels*, consisting of stratified panels, covered with pre-painted metal laminates, or panels with a ventilated air chamber and covered with glass or stone).

The façade systems are mainly considered with respect to the formulation of the structural apparatuses and connection devices, capable of resisting static and dynamic loads (such as wind stresses) and the deformations of the main load-bearing structures of the architectural organism (in order to support the movements due to differential settlements, to the inflections of pillars and beams, to horizontal loads). The structural apparatuses and connection devices are also identified in relation to their ability to respond to expansion and contraction phenomena, such as:

- thermal type, in order to absorb the stresses caused by temperature differences between indoor and outdoor, which can lead to deformations of the closing elements;
- hygroscopic, in order to allow differential movements of the enclosure elements due to humidity variations [39].

Fig. 1.3 Massimiliano Fuksas, *My Zeil*, Frankfurt. Elaboration of the envelope within an “indeterminate” architectural configuration (opposite to the conception of the building organism as a *finite object*) containing, in a simultaneous manner, the functions of transparency and “dematerialization”, the criteria of “improvisation” and the punctual study of the construction elements. © Courtesy of AGC Glass Italia

The load-bearing structural apparatus (consisting of the vertical and horizontal frames), the interface and connection devices, the components and the technical enclosure elements are then specified with respect to the requirements relating to:

- thermal resistance, so as to prevent the passage of heat by conduction, avoiding thermal bridges (especially in the case of metal profiles) which can cause localized condensation of water vapor on the internal surfaces of the enclosures;
- resistance to oxidation, exposure to ultraviolet rays and corrosion of metal parts;
- water tightness, by providing connective solutions (through the correct application of joints) capable of waterproofing situations of accumulation (e.g. in the interstices and along the projections) and of infiltration (e.g. in the joints);
- air-tightness, providing connective solutions capable of preventing infiltration of high flow rates into the interior, combined with the need to avoid the phenomena of water vapour condensation and acoustic transmission. This is achieved through the correct application of sealants, gaskets (for closing and filling joints) and drainage methods;
- vapour-tightness by providing direct solutions for the evacuation of condensation water;
- fire resistance;
- durability and maintainability, providing solutions capable of allowing periodic cleaning, repair and replacement of technical elements [15].

The building envelope study examines the typological and productive, functional and executive articulation of:

- the curtain wall system (*stick system*), consisting of a load-bearing frame of mullions and transoms (generally made of alluminium or steel, as well as PVC) arranged according to structural, morphological and enclosure requirements using glass elements (generally double-glazed) and/or panels (such as the *panel system*, in the form of prefabricated two-dimensional elements with an outer covering surface and thermal and acoustic insulation layers). This system, both for flat or polygonal development, involves installation on site after preparation of the frame elements, which consists of cutting and machining the profiles (mainly extruded alluminium) to allow assembly procedures (using scaffolding at the perimeter of the building). These procedures concern, in particular:
  - the execution of the vertical elements (mullions) to the main supporting structure;
  - the execution of the horizontal elements (transoms) to the mullions;
  - the application of the vertical enclosures (in double glazing or *spandrel* form, these with monolithic glazing and panels behind or with steel, alluminium, composite or stone cladding elements);
- the structural façade system (*structural sealant glazing* or *glass curtain wall*), determined by the load-bearing frame (defined as adaptation and, in general, made of alluminium or steel) assembled in the laboratory and applied on site to the load-bearing structure of the architectural organism (with the use of scaffolding at

the perimeter of the construction), where the closing elements (generally, monolithic glass panes or double-glazing) are made using structural silicone (without mechanical constraints, inside the profile grooves). The structural façade system consists of:

- the *strip window* or *two-sided supported system*, also known as “two-sided glazing”, where the closing elements are applied to the frame by means of the structural silicone sealant, on the two opposite vertical sides of the mullions and by means of mechanical retaining flaps on the horizontal sides;
- the *total wall* or *four-sided supported system,* also known as “four-sided glazing”, in which the closing elements are applied to the frame using structural silicone sealant on all sides of the profiles;

- the *unitized façade system*, determined by the load-bearing mullion and transom frame (generally in alluminium or steel) with a vertical extension that includes the height of the compartment and the stringcourse section, with closing elements. This system, preferred for vertical constructions (with the use of lifting equipment at height for perimeter assembly) requires that the unitized façade system components are structurally independent and that they are connected to each other with telescopic or plug-in joints: these are capable of allowing, after installation, the movements for calibration on the façade level, carried out by means of the vertical and horizontal configuration profiles for performing the contiguity connections [37];
- the *suspended curtain wall* or *point fixed curtain wall* (or structural glass façade), determined by the use of glass sheet enclosure elements (made of vertical groups) by means of punctual constraints (in the form of mechanically supported fixing devices). These in turn are connected to steel cable frames anchored to the main load-bearing structure of the architectural organism (or to steel frames, usually tubular). Moreover, the *point-fixing façade system* is determined by the assembly of the glazing elements (with or without perforation) on metal supports (generally made of steel) [61, 62];
- the *double skin façade system*, determined in the transition from the continuous curtain to the multilayer type and articulating the specific performance of the layers and the relative technical elements. This involves the possibility of creating the cavity between the two walls for thermal and acoustic insulation, for ventilation and for housing functional devices (especially sunshade screens) as well as for plant ducts. The double-wall involves the use of a glass screen (or second skin) outside the vertical enclosure, with the aim of optimizing the functions of the ventilation in the cavity. The double skin system can be divided into the following types: façade with continuous cavity, without division, with discontinuous cavity and active façade [34, 53, pp. 233–240].

The composition of the envelope systems constituted by the use of transparent enclosures, considers the surfaces applied to the façades in their morphological expression and interaction with the external environmental stresses, considering especially the procedures of control of the thermal and luminous transmission. The explanation concerns the productive and functional modalities of the techniques and materials aimed, in general, at the reduction of the loss or accumulation of heat (due to solar radiation), as well as the dynamic selection of the solar rays and the calibration of the light, in observance to the types of use required (Fig. 1.4). The study explains the characteristics of the products according to their properties, processing and applications considered as elements of the building envelope, examined with regard to their ability to influence energy and environmental conditions. In particular, the transparent closing elements are investigated (on the basis of a series of physical and geometric parameters) with regard to the thermal, lighting and acoustic strategies to be adopted for the functionality of the architectural organism and with respect to the ergonomic requirements of the interiors [3].

On this basis, the composition of the envelope systems is outlined with respect to the types, compatible solutions and procedures of use expressed in relation to the main references of a thermal, luminous and radiant nature. This is done through the definition of performance (at the mechanical, thermo-hygrometric, lighting and acoustic levels), execution (according to the relationships with the frames and joints) and the in-depth examination of the main factors of a physical, functional and applicative nature. In addition, the treatment detects the contributions of studies referring both to materials and devices from the experimental research sectors, and to the possibilities of being transferred from the advanced technology sectors.

These contributions support, in the context of the systems under examination, the methods aimed at optimizing the physical, mechanical, chemical and thermal characteristics of the transparent surfaces, in order to calibrate the comfort conditions in the built spaces and the energy management criteria. In this case, the study exposes high-performance materials and compounds, indicated in the principles of both mediation between light transmission and thermal conduction (in order to reduce thermal dispersion without affecting transparency), and control of incident solar radiation (also with the adoption of selective coatings or shielding devices) [35].

In this respect, transparent enclosure elements applied to façade systems are established by:

- the passive use and transformation of solar radiation, using technical solutions aimed at capturing, accumulating and distributing the energy produced without the need for plant equipment. These solutions take on the functions of controlling the microclimate of the built spaces and the energy balance, according to the basic principles of solar heating and lighting;
- the use and active transformation of solar radiation, involving the use of technical solutions aimed at capturing, accumulating and distributing solar energy. These solutions involve the contribution of devices (in the form of collectors) capable of integrating the exploitation of heat, natural light or convection phenomena related to air flows [47, 68].

The composition of the envelope systems constituted by the use of opaque enclosures observes, according to contemporary experimental production, the determination of an applicative sphere aimed at evoking and detecting archetypal and tectonic

Fig. 1.4 Jim Clemes, *Centre Royale Monterrey*, Luxembourg City. Envelope components arranged in an "integrated" form according to the processes of "specialization", in accordance with the configuration of the layers of materials, composed of or resulting from the assembly of multiple elements, and the processes of "aggregation" between functional apparatuses. © Courtesy of Berti

(as an expression of concrete and physical reality) properties. In general, this field has the purpose of developing external enclosures defined by:

- the use of products belonging to the construction "tradition", however inserted in the strategies (compositional, productive and executive) belonging to evolved technologies;

- the hybridization of consolidated typologies, through the use of frames different in terms of materials, mechanics and connections [8].

Moreover, the area under examination addresses the visualization of alternative types for façade systems and is part of the progressive and linear developments in the construction sector and functional deepening. This is done with respect to a scenario where adaptable products and materials are used, simple, finished and small sized elements are marketed and diffused within the industrial logics characterized by high flexibility, capable of including and combining different solutions. The use of opaque enclosures expresses the façade systems with respect to:

- the tendency to rationalize and reinvent both the components and the conventional modes of application and interface, in an integrated approach to the multiplicity and variety of expressive possibilities;
- the hybridization of traditional materials, in order to legitimize the maintenance of the solid and massive presence, within the growing virtuality and ephemeral, dynamic and metamorphic configuration of the envelope [66].

The morphological and functional development that is outlined appears to be directed towards affirming the steady character of the unitary composition, by the expressive balance of the closing parts, as a response to the broken continuity of traditional languages and techniques, to the integration of types and multiple fragments in the external constitution of architecture. This is achieved through:

- the application of elements capable of wrapping both the surfaces and the supporting and connecting apparatus, grafting themselves between the current processes of technical complexity and productive and linguistic articulation, often leading to the loss of the homogeneity and material congruity of the envelope [72];
- the assimilation of the characteristics of industrial production, aimed at overcoming the dichotomy between tradition and innovation, constituting an experimental basis both for the updating of sedimented practices and techniques accepted as valid, and for the promotion of compatible solutions, of significant insertions characterized by the complementarity between consolidated and evolved materials and construction procedures [40] (Fig. 1.5).

1.3 The Environmental and Energy Functioning of the Façade Systems

The envelope systems are defined as applications aimed at isolating, filtering or absorbing external climatic stresses (mainly thermal and luminous), in order to reduce the impact of technical devices. The systems are presented as instruments of mediation between the external environmental conditions and the ergonomic aspects of the built spaces, through specific performance reactions. These reactions are calibrated and variable according to the stresses and comfort requirements, highlighting the possible contributions to the reduction of energy use [17, 21, 27]. In this regard,

Fig. 1.5 Atelier Jean Nouvel, *Musée du Quai Branly*, Paris. "Component" elaboration of envelope systems according to the criteria of *tectonic poetics*, which alludes to the "expressive potential" of technology and is expressed as the "art of connection", emphasizing the "poetics of construction", aimed at manifesting the connective modes of frame and enclosure. © By the Authors

the systems are treated as interchange tools because of their ability to respond to external stresses, through the development of different functional levels (in terms of material, structure and thickness) and through the use of regulation means that allow to handle (in a natural, or passive form, and in an artificial, or active form) the interactions with the environment. For this reason, the enclosure elements behave as osmotic membranes acting according to processes of exchange of energy, light and air flows [26, 32].

The typological examination introduces the identification of the closing elements that constitute the stratification of the envelope systems, according to the specialized functions developed with the precise subdivision of the performances assigned to the different materials and devices. The analysis then focuses on the perspectives of “dynamic interaction” between the envelope systems and the external environment. This is done by observing the criteria aimed at realizing built spaces in a steady and balanced way, with the possibility of transferring, modifying or repelling external stresses, according to the sustainable and low-energy concept of the components made up as reactive and sensitive surfaces to climatic stresses [14, 56] (Figs. 1.6 and 1.7).

The development of the environmental aspect of façade systems is associated with the concept of “envelope-machine”, as a support and integration of functional elements, involving the transformation of the enclosures into “mechanical bodies”, into “active diaphragms”, which promote or hinder exchange (especially in thermal and aerial terms) with the exterior (thus playing a key role in energy regulation).This is achieved through the constitution of the “envelope-machine” as a tool capable of transforming external environmental resources into energy sources for defining the microclimate of interior spaces.

The advanced building envelope is considered as a *dynamic interface* [2], i.e. as a structure of exchange between the environmental stresses and the fruition needs of the internal spaces, having evolutive plasticity and adaptation qualities to the different

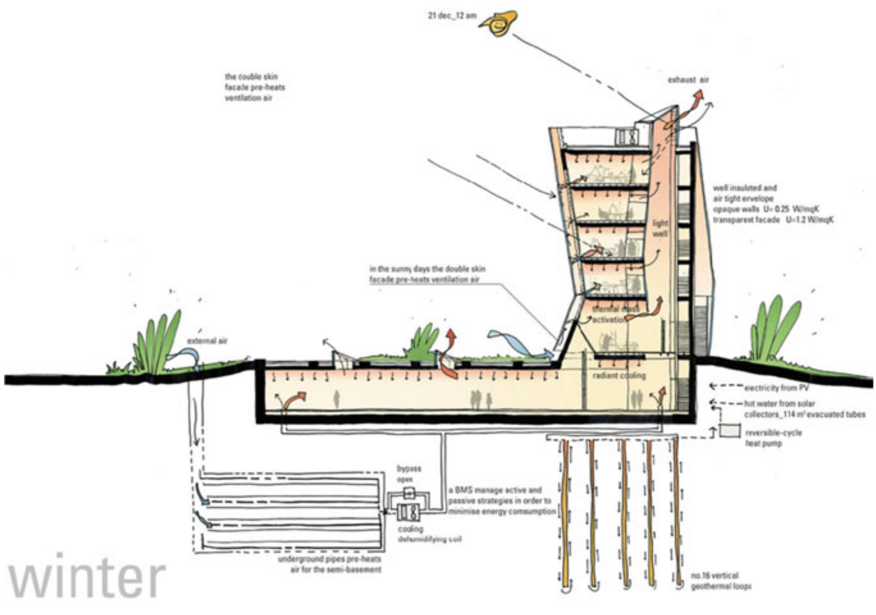

Fig. 1.6 Mario Cucinella Architects, *CSET* (*Centre for Sustainable Energy Technologies*), Ningbo (China). Functionality of the “environmental mechanisms” (heating procedures): the system combines external air entering the tower and from the geothermal ducts. © Courtesy of MCA

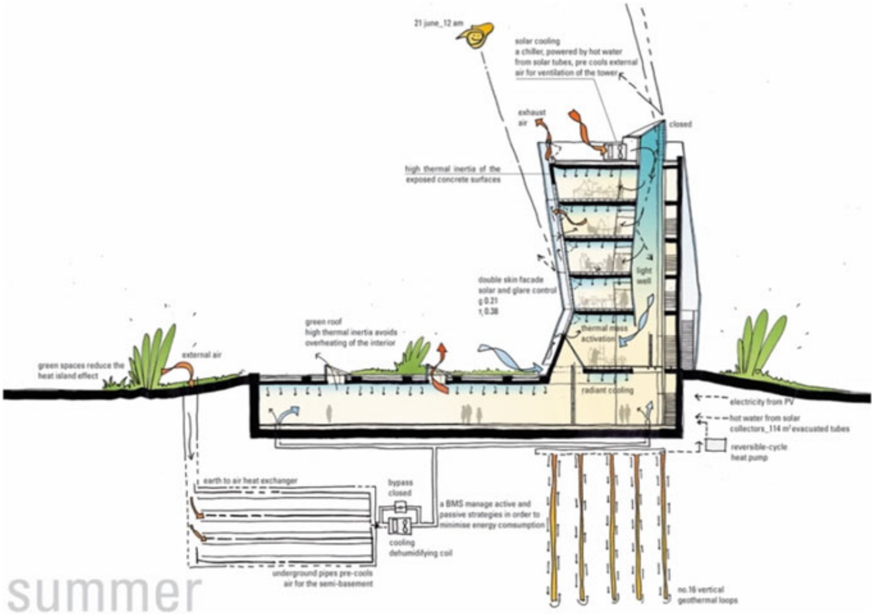

Fig. 1.7 Mario Cucinella Architects, *CSET* (*Centre for Sustainable Energy Technologies*), Ningbo (China). Functionality of the “environmental mechanisms” (cooling procedures): the integrated system provides mechanical cooling of the air entering the rooms. © Courtesy of MCA

loads coming from the environment [57]. The experimentation here expresses the intention to integrate the climatic conditions and to convey them into the interior spaces according to established procedures and levels, to build components in the form of biomechanical prototypes in which the different parts specialize to achieve a certain function (ibid.).

In particular, the envelope systems are assumed as mediation and reaction apparatuses towards external stresses, considering their sensitive and organic nature (in the form of *technical skin*), their physical and material consistency, which is progressively determined towards integrated layers and performances that act, with adaptation and control capacity, according to the well-being requirements and reduction of energy consumption in built spaces. This assumption therefore focuses, on the one hand, on the aspects related to the adaptation and progressive control of thermal and energy exchanges between the internal “micro-environment” and the external “macro-environment”, identifying this area as a catalyst in the type-technological evolution of the building envelope; on the other hand, on the experimentation of technological and construction solutions aimed at optimizing these exchanges, as well as, obviously, on the expressive and communicative content that this experimentation implies [2, p. 17]. The definition of the envelope systems is thus carried out in the analysis of the dimensional consistency, which considers the building envelope as a system consisting of interacting parts, whose thickness varies according to the overall operation (ibid., p. 20).

Furthermore, the envelope systems are defined as external apparatuses capable of interpreting the functions and needs of their users as an *eco-efficient envelope*, as selective and multi-purpose filters, in relation to climatic conditions and ergonomic comfort requirements (of a thermo-hygrometric nature, relating to temperature control, humidity levels and ventilation. They also have a visual aspect, relating to perception towards the outside and control of lighting levels; an acoustic aspect, relating to insulation from sound stress; and an olfactory aspect, relating to control of air quality; [46]) (Fig. 1.8). The combination of passive and active operating procedures regulates the creation of systems capable of self-regulation, sensitive to external climatic changes and to comfort requirements (both thermal and visual) and interiors ventilation [74]. In this regard, the environmental and adaptive strategy, in relation to Atkin's study [4], develops the envelope systems according to their metabolic effectiveness and their instinctive reactive capacity, configuring themselves as *intelligent skins* endowed with automatic performance (by means of functional criteria of autonomous regulation) and membranes defined as *biological skins* (capable of reacting against external agents through the activation of sensors and protective devices). Furthermore, the biological relationship considering the regulation systems (computerized building management systems, BMS) and the corresponding opportunities for opening and closing, protection, shielding and environmental incorporation, identifies the *hypothalamic function* reactive to external and internal stresses.

The analysis is then expressed through the investigation of systems as organic compounds, adaptable and adjustable as *biological skins* and as *multifunctional skins*, i.e. as absorbing, radiating, reflecting, filtering and transferring (thermal, luminous, aerial) devices. In particular, the use of elements with dynamic and reactive behavior assumes the use of surfaces for the control of solar radiation, consisting of filtering or shielding sections able to modulate their transparency according to the level and distribution of natural light in the interior spaces.

The systems design thus exposes the *techno-organic* [73] properties through the interpretation and assimilation of environmental conditions in a combination with the use of advanced techniques (in *organitech* form; [36]). In this manner, the study involves the investigation of artificial (or organic) systems integrated with natural systems, as tools for accumulation, channelling, protection and calibration of passive energies that can provide buildings with heating, air conditioning and ventilation. Consequently, the building envelopes are expressed by environmental diaphragms and by *neuronic façades*, built like "natural organisms", or rather like machines that aim to reproduce, manage and metabolize natural processes according to criteria of active understanding [51, 52].

The closing elements of the envelope systems are especially investigated with respect to their character of modified physicality, which the experimental research tends to transform in thick and in *intelligent systems interface* ([2], p. 42). At the same way, also the main materials that constitute the external surfaces are analyzed with respect to their transformation processes from stable entities to designable entities

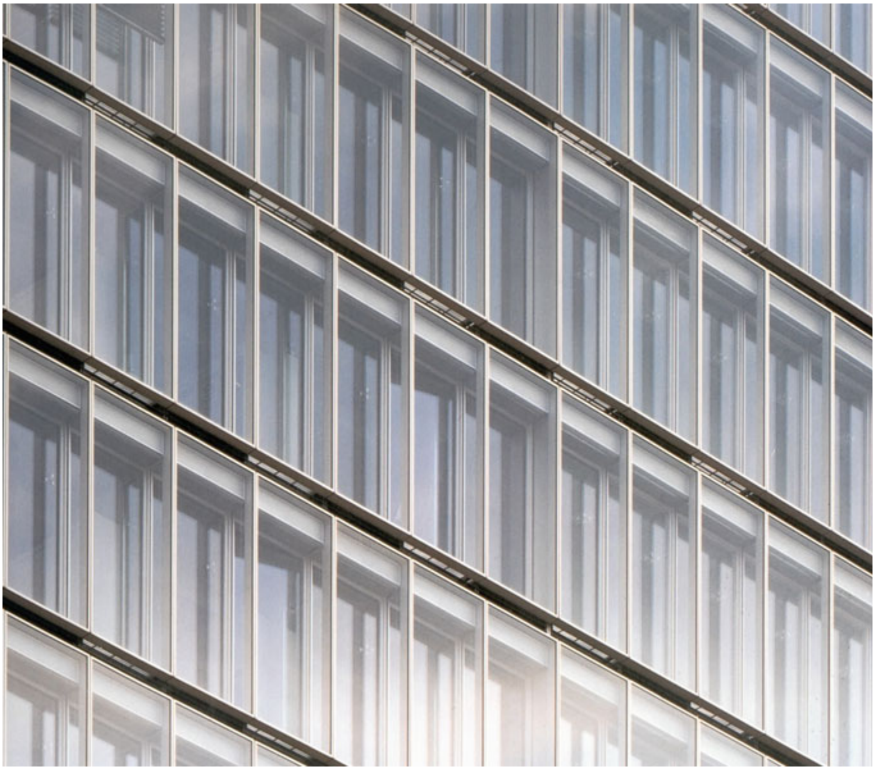

Fig. 1.8 Christoph Ingenhoven and Jürgen Overdiek, Bank in Stadtsparkasse, Düsseldorf. Study of the envelope systems related to the need to contain energy consumption and reduce polluting emissions, as well as to establish the solutions capable of balancing the relationship between climatic conditions and wellbeing in built spaces. Constitution of façade components in the form of "osmotic screens" aimed at: (1) the capture of convective flows, by means of louvers, and the passive natural ventilation of interior spaces; (2) the expulsion of internal air, according to aerodynamic geometry deflectors. © Courtesy of Ingenhoven and Overdiek

according to a specific performance plan. In this case, the application of the envelope materials, in the form of designable entities, is examined with respect to the outcomes of the solutions in which the functions tend to become complex (in a controlled and managed way) and combined, achieving multiple performances through the correlation of different agents and layers. This is done by:

- the integration possibilities of functions related to enclosure elements, where relationships and interfaces (physical, performing) are arranged between individual parts and materials of a system or component;
- the development of custom-made enclosure elements, using materials specifically produced to perform certain functions and without having to adapt to the limits imposed by original and predetermined properties. This is achieved by replacing composites made from multiple devices, assembled together, with

elements resulting from the union of different surfaces within a single polyvalent layer [38];

- the systems capability to react to environmental stresses, according to passive or active regulation processes (by manual, mechanical or computerized commands) induced by electrical, thermal and lighting triggers that modify, through alterations in the physical or chemical structure, the disposition of the enclosing elements or the properties of materials. The study of envelope systems is linked to research on sustainability in the construction industry, which considers the need to reduce energy consumption and polluting emissions with respect to the implementation of solutions that can establish high environmental performance. In this regard, the contribution of the envelope systems is related to the performance of technological systems, considering the operational procedures designed to balance the relationship between climatic conditions and well-being in built spaces [1, 19].

The design and application field of building envelope systems includes the evolution of conceptual and operational apparatuses referring to the foundations and requirements of environmental sustainability, addressing:

- the eco-efficiency of transformation processes, whereby the planning, production and construction process (understood as *environmentally conscious design*) is determined, in its global form, both in the interaction with the eco-systems harmony, and in the acquisition of the appropriate levels of both environmental and urban quality [69];
- the paradigms of sustainability, defined by the principles expressed in a series of reports and protocols sanctioned internationally. These address the consequences of environmental impacts (caused to a large extent by management practices, especially energy management, of buildings) and are aimed both at protecting the environment and bio-ecological balances, and at preserving non-renewable (both material and energy) resources, as a basic condition for development [64] (Fig. 1.9).

The analysis of envelope systems is linked to the way they interact with climate factors, thereby promoting the primary examination (aimed at the design, functional and application conception) of the external environmental conditions relating to:

- the (apparent) solar path and height above the horizon according to the specific context (latitude) and seasonal periods, which determine the intensity and angle of solar radiation;
- the intensity of solar radiation according to the orientation and inclination of the elevations;
- the solar radiation, either direct and/or indirect (according to the radiation being reflected from the celestial vault and the surrounding environment), according to the different wavelengths;
- the amount of energy input estimated according to the climatic conditions and the energy demand linked to the intended uses.

Fig. 1.9 *Energy System*. “Specialized” and calibrated elaboration of the envelope with respect to the fine-tuning of the “organic” devices integrated with external stresses and the plant engineering apparatus, in the form of the interfaces of interaction, mediation and interchange with climatic actions © Courtesy of Schüco

In general, building envelope systems are permeable to solar radiation, leading to the generation of energy inputs that can be accumulated, transmitted (by thermal conduction) and radiated into the interiors (depending on the thermal conductivity of the closing materials). The exposure, due to the different irradiation, affects the energy production of solar radiation, contributing to solar gains following the heating of the built spaces and their structures. In this regard, vertical façades (facing east, west and south) have a high energy production (which is mainly derived from direct radiation) during the periods of highest exposure to sunlight, thus indicating the need for solar protection [31].

With regard to the requirements concerning indoor climatic conditions, in relation to the use of building envelope systems, it is considered:

- the air temperature and relative humidity of the built-up spaces;
- the temperature and surface airstreams in the area around the closing elements;
- wellbeing requirements related to both the quality and quantity of light transmission and visual conditions.

As far as the thermal quality of the envelope systems is concerned, which effects the possibility of energy saving through the exploitation of solar radiation, it is observed:

- the low thermal inertia, which provides sensitivity to cooling and overheating phenomena of built-up spaces due to prevailing transient thermal phenomena;
- the thermal dispersion due to infiltration losses, related to the joints between structural elements (i.e., with respect to frames) and closing elements [67].

At the production, design and construction level, it is necessary to define operational conditions of balance between conflicting requirements, such as the need to ensure a positive energy contribution during the winter period, reducing dispersion and providing thermal storage by transforming solar radiation into heat (according to the phenomena of thermal inertia) [70].

1.4 Interactive Processing of the Façade Systems

The interactive design of the envelope systems analyses the constitution of façade surfaces as an information support and as a communicative tool, according to technological and multimedia business [10], along with the progressive dematerialization and immaterial transformation of architecture. In this respect, the composition of the building envelope is expressed through the acquisition of new visual and virtual potentials, which transcend the material aspects, which aim at the metamorphosis of curtains and which stand out as communicative devices. Within this scenario, the composition of envelope systems is configured both according to the loss of perspective stability and according to the emphasis on membranes and programmable surfaces. In keeping with Baudrillard [6], herein lies our unique present-day architecture: large “screens” on which moving atoms, particles, molecules are reflected. Not a public setting, a public space, but gigantic spaces of circulation, ventilation and ephemeral insertion (Fig. 1.10).

The combination of expressive and performance opportunities, of working methods and morphological experiments, on which the composition of the interactive envelope is based, supports the evolution of compositional stylistic features, so that the architectural works take on increasingly enigmatic aspects: the absolute essentiality of the interiors is matched by an exasperated sophistication of design and effect on the outward appearance, to the point of making us imagine the future landscape of our cities only as a continuous series of thin, changing envelopes [11]. Such experimentation leads to alienation from the context in which the building envelopes are placed, in accordance with the desire to affirm that each work of architecture establishes itself through its own conceptual contents and its own principle of independent identity (ibid., p. 11) (Fig. 1.11).

Specifically, the envelope systems are considered according to:

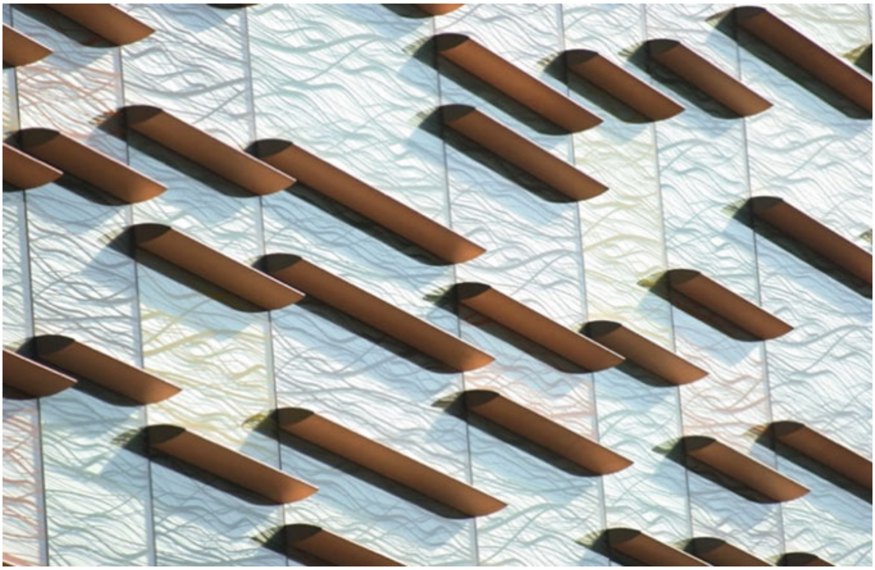

Fig. 1.10 Irene Sabato (Polis Engineering), Ivo Pellegri (DAGA Studio), *Guna Headquarters*, Milan. Enveloping "skin" and acquiring the role of "communicative transition" to the external space, refuting the paradigm that perspective expression must reflect typological articulation: application of the surface as an *ornamental packaging skin* directed towards the constitution of a *media building*, a tool for communication and interaction. © Courtesy of Saipam

- the formulation of scenographic and catalyzing mechanisms open to multiple expressive and functional solutions, such as accumulators of pictures and as urban transmitters, assigning to the façade curtains the function of configuring themselves as an autonomous and communicative support [33, 58];
- the elaboration of conceptual installations, through which the temporary, ephemeral and suggestive content of visual engagement is revealed, whose surfaces take in the suggestions of the media culture, thus asserting themselves as media façades, or *hypersurfaces* (as supports for the expressive potential of media; [7]);
- the modes of interaction and merging between the architectural work and the context, through the development of surfaces marked by discontinuities, foldings or stratifications, according to fluid and dynamic morphologies. The surfaces are examined as membranes, active and structured, connected to the concept of continuous movement and modulation. They are not identified by the necessity to produce thickness in the wrapping of the curtains, but with regard to the paradigms of immediacy and instantaneousness [71].

The experimental elaboration of the envelope, then, examines the application of the enclosures on the basis of the environmental and spatial fading of boundaries (intended as the loss of their role as a clear-cut boundary between content and exterior). This is achieved through the dematerialization of the façades (aimed at a free

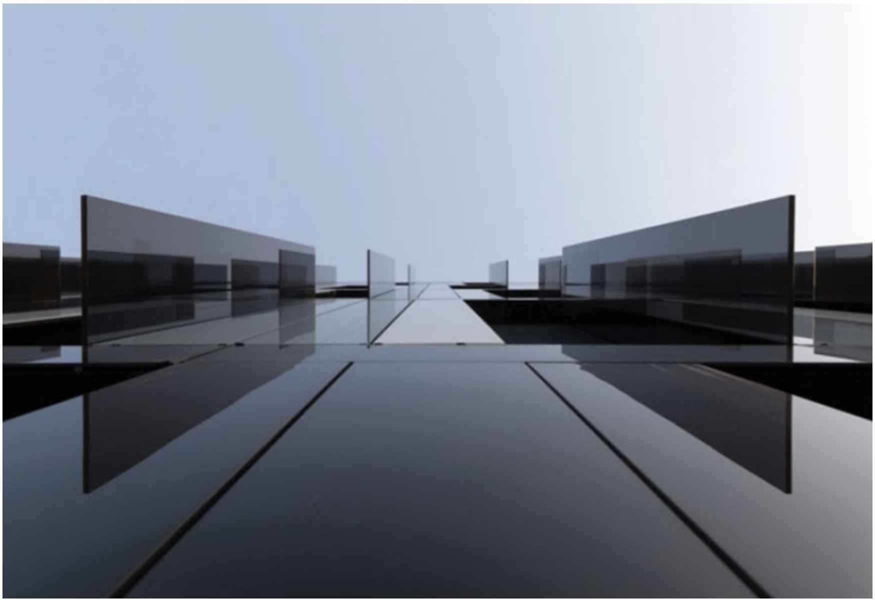

Fig. 1.11 Gianandrea Barreca and Giovanni La Varra, *"B5" Building, RCS—Media Group Headquarters*, Milan. Surface textures that take on the theme of the "barcode" rendered in a "dynamic" form through a cladding that alternates windowed parts with portions of the façade in screen-printed and coloured glass plates. © Courtesy of Focchi

conceptual, spatial, perceptive and evocative flow), operating on filters, diaphragms and transparencies. The interactive processing of envelope systems concerns, then, the dematerialization of containers, whereby surfaces reveal themselves as a media epidermis, as sensors capable of connecting reality phenomena and information demands [9, 60].

The surfaces achieve the relationship of "connection-transition" between the built volumes and the external, environmental and urban spaces, aiming at the architectural expression of "interstice", expressing the paradigms of *trans-architecture*, the possibilities of shape evolution (as morphing processes) and the projections of "speaking images", of graphic and *multimedia figures* [30].

The physical and material characters of surfaces are examined in relation to the loss of their tectonic consistency, proceeding to the expression of the permeability conditions, both functional and fruitive, and towards the aleatory articulation in conceptual and visual transitions, through:

- the contribution of digital processing, which allows to represent the organic, dynamic and metamorphic aspects of the envelope virtualization; the development of hypermedia perception standards, aimed at the deep layers of intellectual, emotional and sensorial reactivity [29],

Fig. 1.12 Valentina Bonato, Dario Cagol and Helmuth Niedermayr, *Alperia Tower*, Bolzano. Expressive criteria proper to the architecture of the "interstice", aimed both at breaking down the opposition between the physical and the immaterial, and at "metamorphic" interaction with space. © Courtesy of Oskar DaRiz

- the plastic tension of the enclosure, taken to the extreme of its functions, whereby the barriers of closure are bypassed by the inclusion and dilution of visual passages [41] (Fig. 1.12).

Therefore, the enclosures in fulfilling the purpose of wrapping and delimiting, are conceived as removable slabs, as almost immaterial and mobile presences, in order to generate dialectical relationships between built spaces and the external context and to emphasize the interactive and organic logic of architecture. In particular, the wrapping of the building envelopes is determined through differing or calibrated densities, according to the principle of porosity and reticulation. This is achieved by using cuts, pixels and openings, engraved and interposed on the perimeter curtains. The enclosures are thus examined, in general, according to:

- the procedures of dematerialization and interconnection, both spatial and visual, considering the surfaces in their light, transparent constitution, aimed at specifying a symbiotic and engaging relationship with the external space. The envelope

Fig. 1.13 Giovanni Vaccarini Architetti, *Société Privée de Gérance* (*SPG*), Geneva. "Thick surface" of the envelope, with the help of screen-printed glass and protruding steel supports, proposed in a "volumetric" key: perceptive "dematerialization" of the vertical enclosures, established in a diaphanous and ethereal manner, sensitive to the luminous and chromatic variations of the surrounding environment. © Courtesy of Alex Filz

systems are thus conceived through flexible and reactive, deformed and impalpable, metamorphic and unstable configurations, in relation to their transparency, reflection and opacity properties [30];

- the organic deformation procedures, considering the curtains as textures that flow through space due to their porous constitution, perceptible and intelligible according to the temporality of movement. The envelope systems are then intended as a vibrant and changeable configuration, sensitive and interactive, adjustable to the urban and immaterial environment [59].

The envelope systems are therefore articulated through a number of observations on part of contemporary architecture that displays, through its own external sensitive films, through its own skin, a desire for effective communication, relating to a position of discontinuity with respect to the urban context: these are design researches that seek to introduce new image accumulators and place identities, according to complex aggregation devices and hierarchies, no longer capable of being identified and ordered according to the usual categories of urban analysis [23, 24] (Fig. 1.13). The elaboration of surfaces refers to the sophisticated artifices relating to the procedures of industrial design, identifying the technological progress that affects the visual communication field with a new and different architectural materiality, which is also consistently expressed on the external finishes and coverings: this essentially concerns the physical, material and superficial meaning of façades, which are characterized by a lightness that is both dense and interactive, a support for information, whose mechanisms allow for a multitude of performances in a solid and compact composition.

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Chapter 2
The Typology of the Mullions and Transoms Façade System

2.1 The Geometrical, Executive and Connective Configuration of the Mullions and Transoms Framing

The curtain walling system in the mullion and transom type (*stick system*) is determined by the load-bearing framework arranged according to structural, morphological and enclosure requirements, through the application of the glass elements (in general, in double-glazed panels) and opaque panels (as *panel system*, in the form of prefabricated surfaces, composed of the cladding, external and internal, and both thermal and acoustic insulating stratification). The system, adopted for flat or polygonal development, is installed on site after the preparation of the frame elements, which consists of the cutting and machining of the profiles aimed at:

- the assembly of the vertical profiles (mullions) to the main load-bearing structure;
- the assembly of the horizontal elements (transoms) to the mullions;
- the assembly of the vertical enclosures (in insulating glass or *spandrel* form, with monolithic glass panels and the panels behind or with external cladding elements) (Fig. 2.1).

The mullion and transom façade system offers versatility due to the possible use of different types of frames, such as self-balancing projecting frames (with structural glazing), self-balancing projecting frames with traditional mortise or glazing bead glazing, tilt-and-turn thermal break frames, and doors with inward or outward opening sashes. In the case of tilt-and-turn, the frames are equipped with self-balancing compasses (in stainless steel) that allow variable opening according to the type used (Figs. 2.2 and 2.3).

Specifically, the mullion and transom façade system is made up of the frame comprising the mullion profiles, which have a quadrangular and homogenous tubular section (with the rear rib larger than the normal side rib), and provided, on the front rib, with:

- the threaded linear pin (endless type), for fastening the pressure device;

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PoliMI SpringerBriefs, https://doi.org/10.1007/978-3-031-44893-5_2

Fig. 2.1 Seiv Group, *Sidi Sport* Headquarters, Maser (Treviso). Modulation of the mullions and transoms façade system according to the application of the glazing fixing devices and the overlapping of the cladding boards. © Courtesy of Schüco

Fig. 2.2 Nicholas Grimshaw and Partners, Building in 25 Gresham Street, London. Construction of the mullions and transoms façade system according to the interposition of the horizontal spandrel panels between each level of the curtain. © By the Authors

Fig. 2.3 Giuseppe Colucci, School Building, Fauglia (Pisa). Framing of the façade system within the vertical structures, with the interposition of the windows ans doors related to the profiles of the homogeneous curtain wall. © Courtesy of Schüco

- the parallel couple of seats for cavity the internal gaskets (in general, in EPDM, ethylene-propylene elastomer).

The transverse geometries of the mullions (with the lateral dimension between 50–85 mm and the longitudinal dimension between 50–225 mm) are specified with respect to the expected mechanical stresses, the overall geometries of the modules and the value of the moment of inertia (Fig. 2.4).

The jointing and static reinforcement of the mullions takes place through the insertion (in the cavity) of cantilevers, the transversal geometries of which vary with respect to the expected mechanical stresses and the overall dimensions of the modules: the cantilevers are composed of profiles (in aluminium or galvanized steel) characterized by two parallel ribs (aligned with the lateral ribs of the mullions themselves) connected (in the homogeneity of the extrusion) to two normal ribs at the ends, of which the front section is set back, projecting the continuous vertical ribbing and stiffening elements.

The transverse geometries of the mullions can be executed in the combined form, i.e. defined in such a way as to create two disconnected and specular box sections in the cavity. Inside the tubular sections, connected by means of the interposition of the baffles projected from one profile towards the grooves included by the other coupled

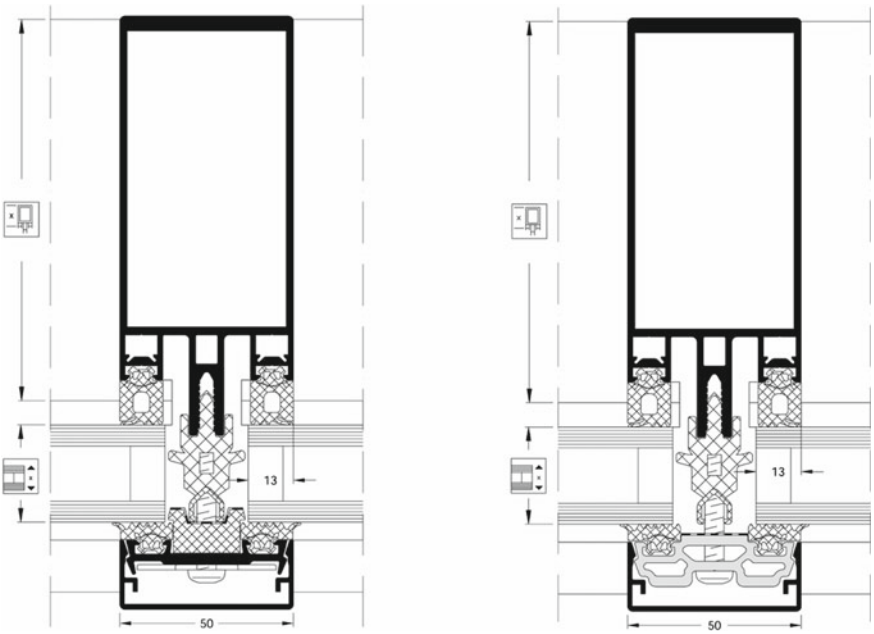

Fig. 2.4 Façade system made up of the frame including the mullion profiles, as vertical load-bearing structural elements, consisting of the homogenous quadrangular tubular section (with the rear rib larger than the normal side partitions), the threaded linear pin ("endless" type), on the front rib, for the purpose of fixing the pressure device. © Courtesy of Schüco

profile (according to the connection made by the polyflor brush gaskets, housed in the appropriate slots), the steel stiffening cantilevers are inserted; finally, from the profile equipped with the grooves, the profile stretched to the groove of the coupled profile is projected towards the front, with the closure by means of a gasket.

On the front side, the arrangement of the central linear pin (provided with the insulating insert), the cavity for the internal gaskets and the press fastening, with external gaskets, on the double-glazing sheets is realized.

The joint or static reinforcement of the mullions in the combined type also considers the insertion (in the cavity of the two box sections contained within the tubular profile) of two elements, composed of the close parallel ribs, connected (in the homogeneity of the extrusion) to two normal ribs at the ends, stretched until they lap the internal surfaces of the lateral ribs of the mullions (Figs. 2.5 and 2.6).

The increase in performance, established with respect to the traditional mullion and transom type, is expressed both by the supports for the enclosures, in the form of insulating strips equipped with the double specular section, and by the insertion

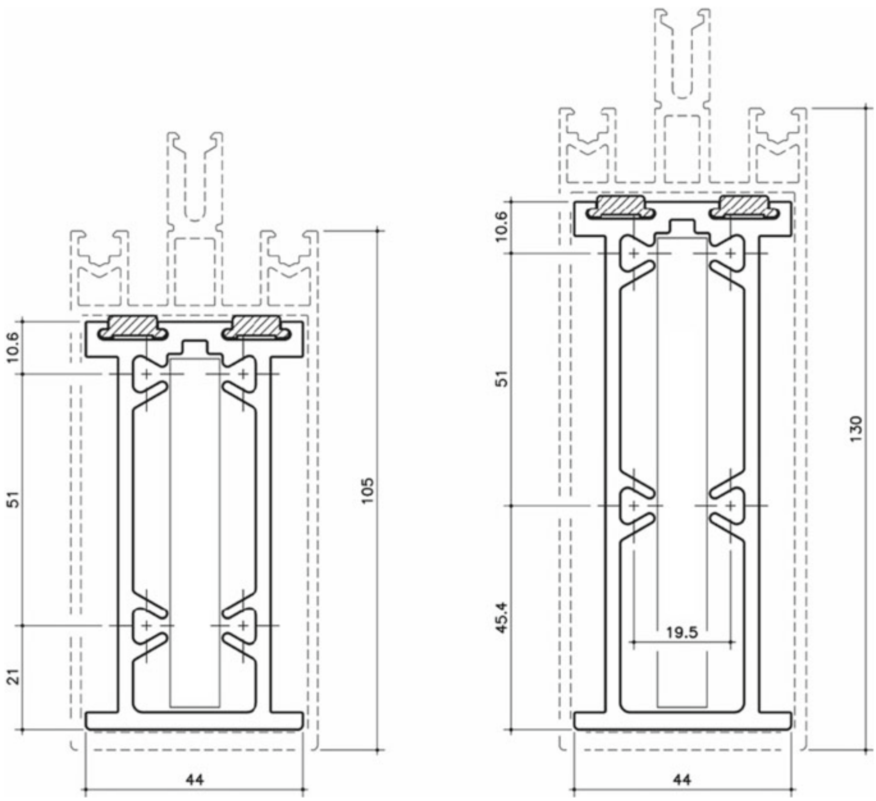

Fig. 2.5 Aluminium mullions horizontal sections stiffened by means of cantilevers, composed of aluminium or galvanized steel profiles, for two parallel ribs (aligned with the side ribs) or two normal ribs at the ends. © Courtesy of Aluk

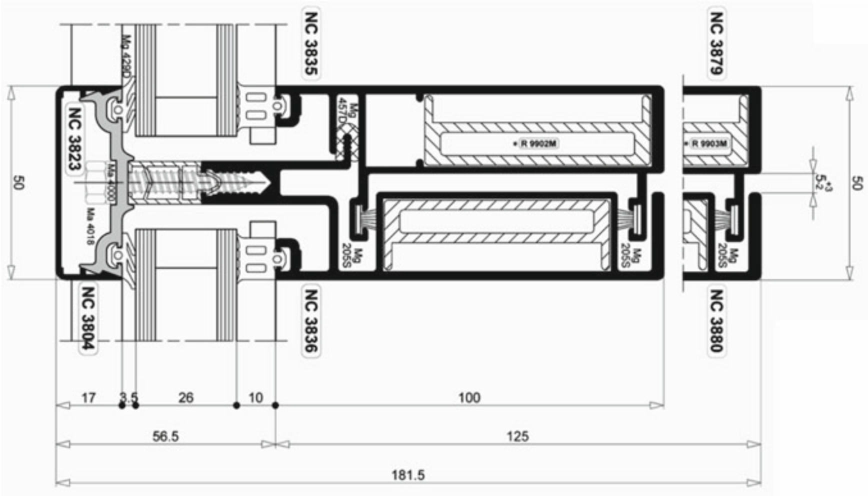

Fig. 2.6 Type of mullion in the combined form involving the insertion of cantilevers, for jointing or static reinforcement in the cavity, connected to two normal ribs at the ends, the arrangement of the cavity for the internal gaskets, the arrangement of the central linear pin and the pressure device, with external gaskets, on the double-glazing sheets. © Courtesy of Metra

of external ribs aimed at the junction with the press recess: this is with the aim of increasing the insulated interface portions between the aluminium profiles and the insulating glass panels (Fig. 2.7).

The composition of the mullions for the corner interfaces is realized by the projection, on two sides, of both the threaded linear pin for fixing the pressure device, and the parallel couple of seats for cavity the internal gaskets: the arrangement can be produced in a specular form with respect to the longitudinal axis of the profile (with square transversal dimensions), or in a misaligned form for the use of a tubular profile with longitudinal development (Fig. 2.8).

In order to realize the internal angles, the filling profiles are assembled, with respect to the cavity seats of the internal gaskets, either of box section and composed according to different diagonal openings of the main rib, or of homogenous section capable of realizing the fixing and support connection on the lateral ribs of the mullion: the assembly contemplates the sealing of the cavity seats (using an elastic product) and the fixing by means of screws (approximately every 250 mm) (Fig. 2.9). This is observed through:

- external angular construction, which involves the use of the angular mullion type, characterized by the external projection of the linear pins and the couple of cavities for the external gaskets: the assembly of the enclosures involves the insertion of the angular portion in aluminium sheet metal casing, equipped at the ends with plastic connection profiles for insertion in the geometric space occupied, in the development of the façade, by the double-glazed enclosures;

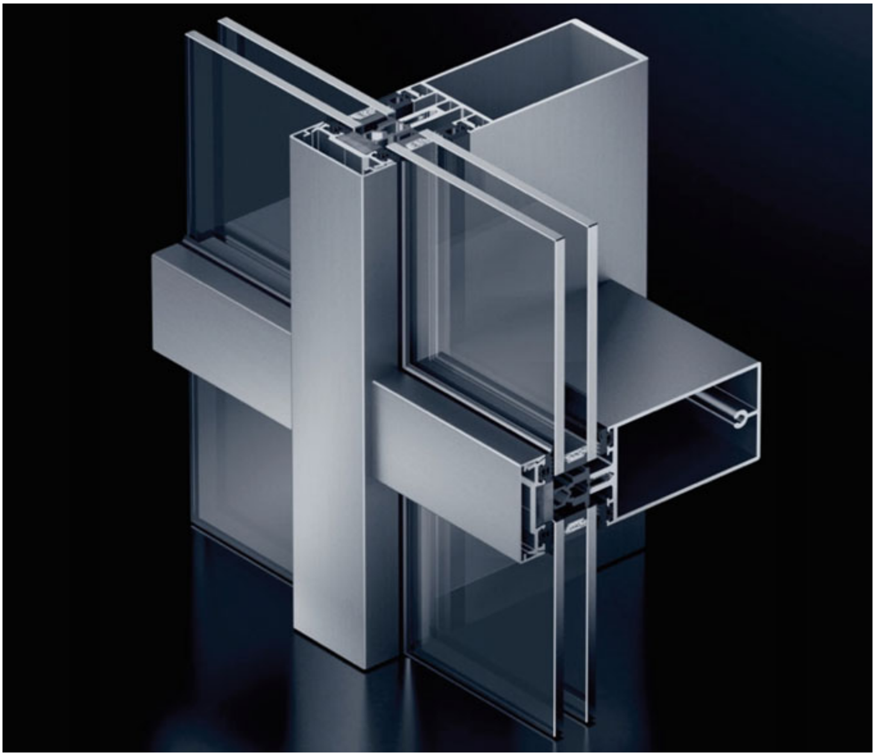

Fig. 2.7 Performance increase expressed by the supports for the enclosures, through the application of the insulating strips, equipped with a double specular section, the provision of chambers and ribs aimed at the junction with the press recess and the increase of the insulated connective portions between the aluminium profiles and the insulating glass panels. © Courtesy of Schüco

- the construction of transversal angles (internal or external) to the façade plane (between 0°–15°), which involves the use of both internal and external gaskets on the mullions and transoms in the standard types, capable of accommodating planar variations (requiring the application of butyl tape on the outside of the vertical enclosures at the interface with the press fastening) (Fig. 2.10);
- the construction of transverse angles (internal or external) to the façade plane, in the transition from the planar to the angular condition, which entails the use of mullions equipped with the inclination of a cavity for the internal seal, in order to accommodate, together with the bending of the pressure device, the vertical enclosure geometry. In this case, both the pressure device and the outer cover are shaped according to the angle established at the façade plane (by crossing two specular snap-in connection sections) (Fig. 2.11);
- the construction of internal angles, which entails the use of mullions equipped with the assembly, with respect to the cavity slots for the internal gaskets, of the filler profiles at the ends of which, towards the outside, are located the recesses

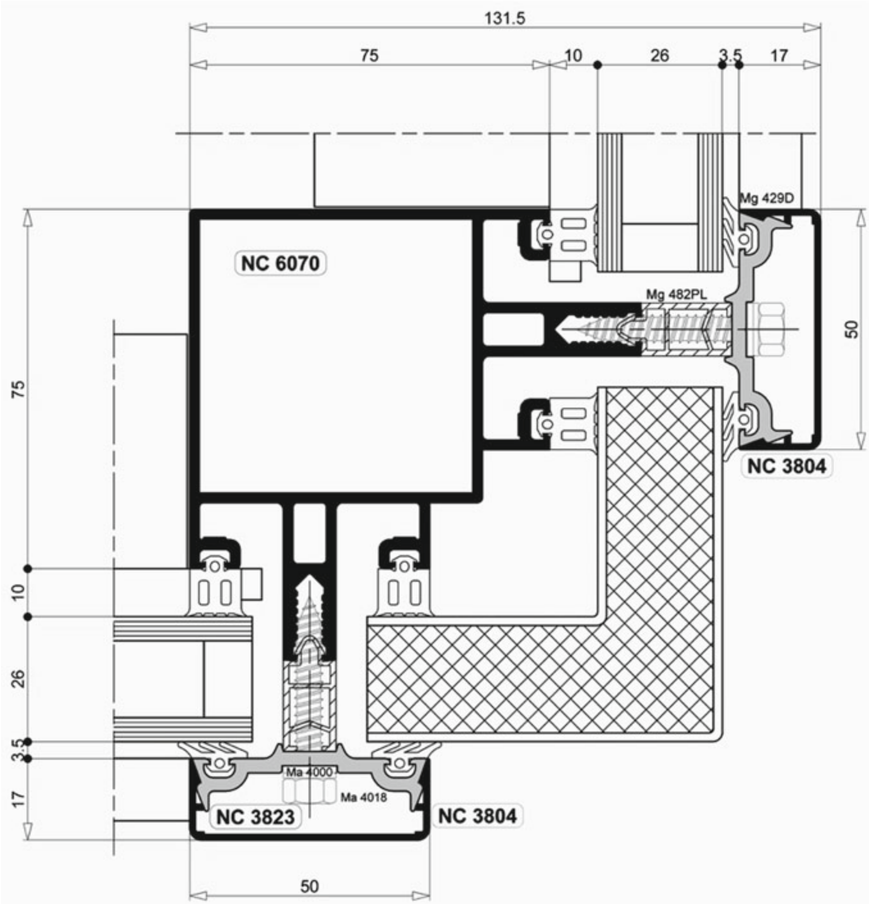

Fig. 2.8 Composition of the mullion for the corner interfaces realized by the projection, on two sides, of the threaded linear pin for fixing the pressure device and the parallel couple of seats for cavity the internal seals. The arrangement takes place either in specular form or in misaligned form, by the use of a longitudinally developed tubular profile. © Courtesy of Metra

for the clamping of the gaskets. The pressure device is articulated to provide for the passage of the screwing and, in the lateral projections, the inclusion of the glazing gaskets. In the case of a mullion with small profile dimensions, two box profiles (with oblique cross-sections) are assembled to the cavity slots for the internal gaskets, at the ends of which, are the cavity slots for the gaskets made normal to the glazing plane (Fig. 2.12).

The execution of the angular interfaces is also determined through the use of two coupled sections of mullion, composed of median cuts of the tubular structure (stiffened by the passage of the steel sleeves inside): this is through both the internal connection made by means of the relationship between two circular projections

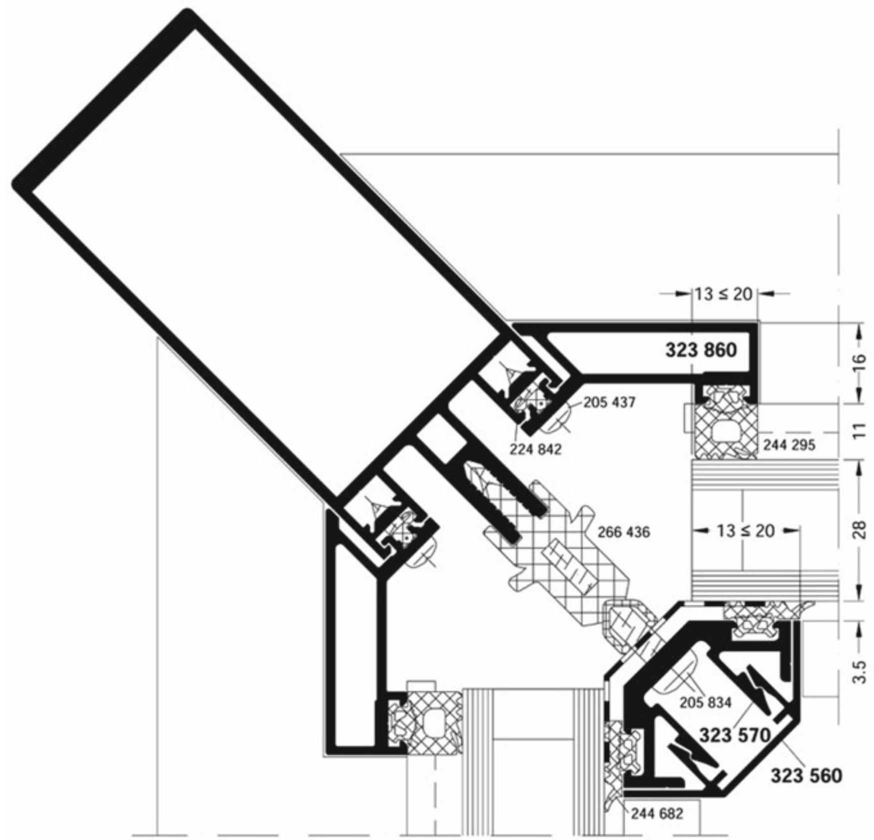

Fig. 2.9 Construction of the corner interfaces involves the assembly of the filler profiles, with respect to the inner gasket cavity seats, of box section and composed according to different diagonal openings of the main rib, the sealing of the cavity seats (by means of an elastic product) and fixing by means of screws. © Courtesy of Schüco

(capable of producing the angle by rotation), and the interposition, as the enclosure defined by the pressure device, of a shaped plate enveloping the dowel (of a configuration suited to the established angle), the surfaces of which realize the support and sealing plane for the gaskets (Fig. 2.13).

The façade system in the mullion and transom typology is realized by the frame including the transom profiles, as horizontal load-bearing structural elements, consisting of the quadrangular tubular section (applied to the mullions by means of self-tapping screws or "U"-bolts), equipped with homogenous parts (with the rear rib also larger than the normal lateral ribs): the transoms are provided, on the front rib, with both the threaded linear pin (of the "endless" type) for fixing the pressure device and the parallel couple of seats for cavity the internal gaskets (Fig. 2.14).

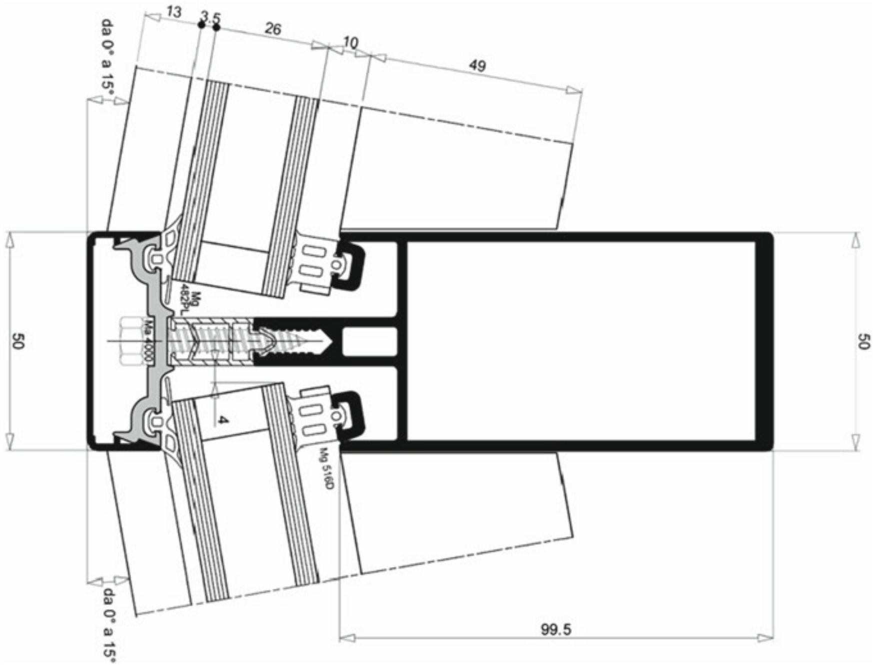

Fig. 2.10 Construction of transversal angles to the façade plane (between 0°–15°) which involves the use, on the mullions and transoms in the standard types, of both cavity and gaskets capable of accommodating planar variations, and the application of butyl tape on the outside of the vertical enclosures at the interface with the pressure device. © Courtesy of Metra

The geometries of the transoms (with the lateral dimension between 50–80 mm) are determined with respect to the mechanical stresses, the overall dimensions of the modules and the value of the moment of inertia (Fig. 2.15). Again, the geometries of the transoms may be executed in the open form on a rib (with the lateral dimension of 70 mm and the longitudinal dimension of 85–175 mm), for the upper and lower connections of the system, with connecting profile segments and with the insertion of a longitudinal box section (inside the opposite rib) and transverse (inside towards the front rib).

The mechanical execution of the transoms involves the priority of the holes on the mullions, using accessories to calibrate the holes on the tubular profile ribs, in the cavity for the internal gaskets and on the threaded linear pins.

Then, the application of the transoms to the mullions considers interface procedures according to:

- the "T" joint (by screwing into the through holes in the horizontal cavities of the transoms), after cutting the vertical cavities for the gaskets (according to the height of the transoms) and interposing the linear sealing element;

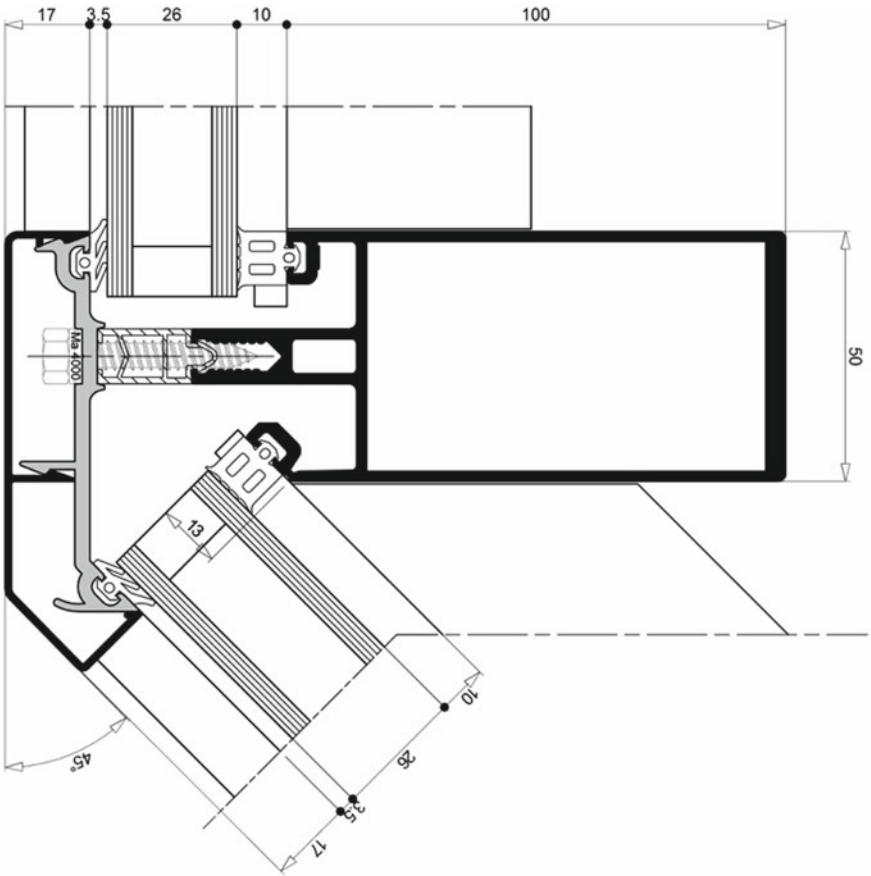

Fig. 2.11 Construction of transversal angles to the façade plane which involves the use of the mullions equipped with the inclination of a cavity seat for the inner seal, the application of the pressure device with wing extension and bending at the end, the application of the shaped outer cover (according to the angle established at the façade plane and the crossing of the two specular sections of snap connection). © Courtesy of Metra

- the execution on the coupling of the "U"-bolts, with spring, "slide" or "U" section pins, made on the lateral partitions of the mullions (Fig. 2.16).

The application of insulating glass panels to the mullion and transom frame involves provisional clamping using standard profiles in the form of reduced pieces of perforated underlay with gaskets. An insulating profile fixed to the mullions and transoms is prepared in the laboratory involving:

- the application of the clamping elements for the glass panels (placed at a distance of 600 mm, observing the maximum distance of 200 mm from the horizontal axis

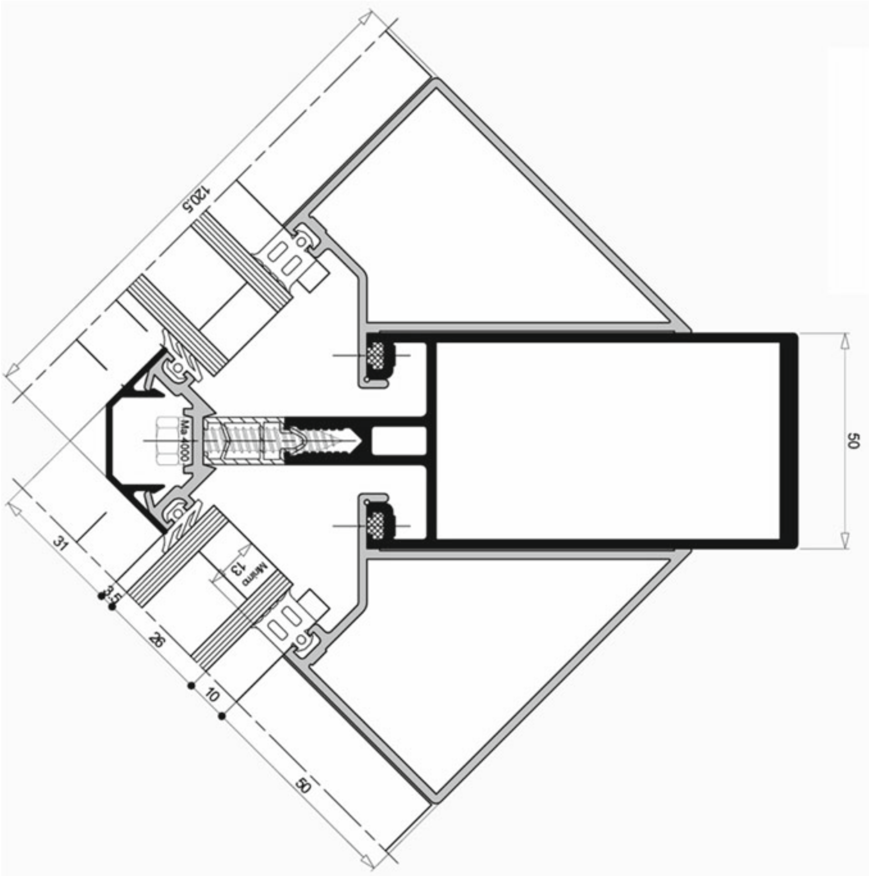

Fig. 2.12 Construction of the inside corners which involves the use of uprights fitted with the assembly of the facing profiles, at the ends of which are the recesses for the gaskets, and the pressure device, that is articulated to provide both the passage of the screwing and the inclusion of the gaskets. © Courtesy of Metra

of the transoms and the maximum distance of 300 mm from the vertical axis of the mullions), with the snap-on execution, following their assembly;

- the fixing of the glass panels in accordance with the tolerances referred to the thickness dimension of 24–50 mm (± 1 mm), with insertion greater than 13 mm (± 1 mm);
- the execution of the pressure devices (without removal of the locking elements).

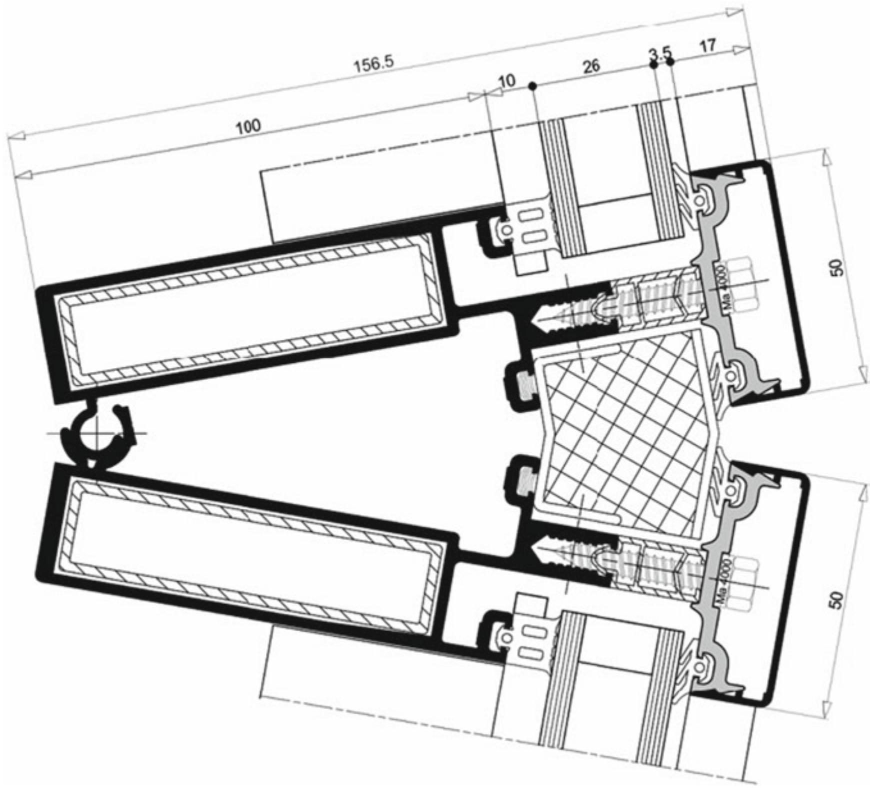

Fig. 2.13 Execution of the angular interfaces determined through the use of two coupled sections of mullions, composed of the median cuts of the tubular structure, the internal connection carried out by the two circular projections and the application of the pressure device. © Courtesy of Metra

2.2 The Functional, Constructive and Coordination Procedures Between the Façade System and the Window and Door Frames

The connection between the main structural apparatus and the opening frame involves the assembly of the rebate frame to the mullion, by means of fastening to the linear central pivot of the wing projected by the profile composed of:

- the linear cavity, aimed at accommodating the system's pressure device;
- the external rib to accommodate the gripping gasket on the pressure device;
- the cavity for the rebate gasket on the opening frame sash.

The opening frame has a tubular profile to support the ribs of the couple of polyamide bars directed to the glazing bead device, the latter aimed at the connection (by means of structural silicone) of the double-glazed enclosure (Fig. 2.17).

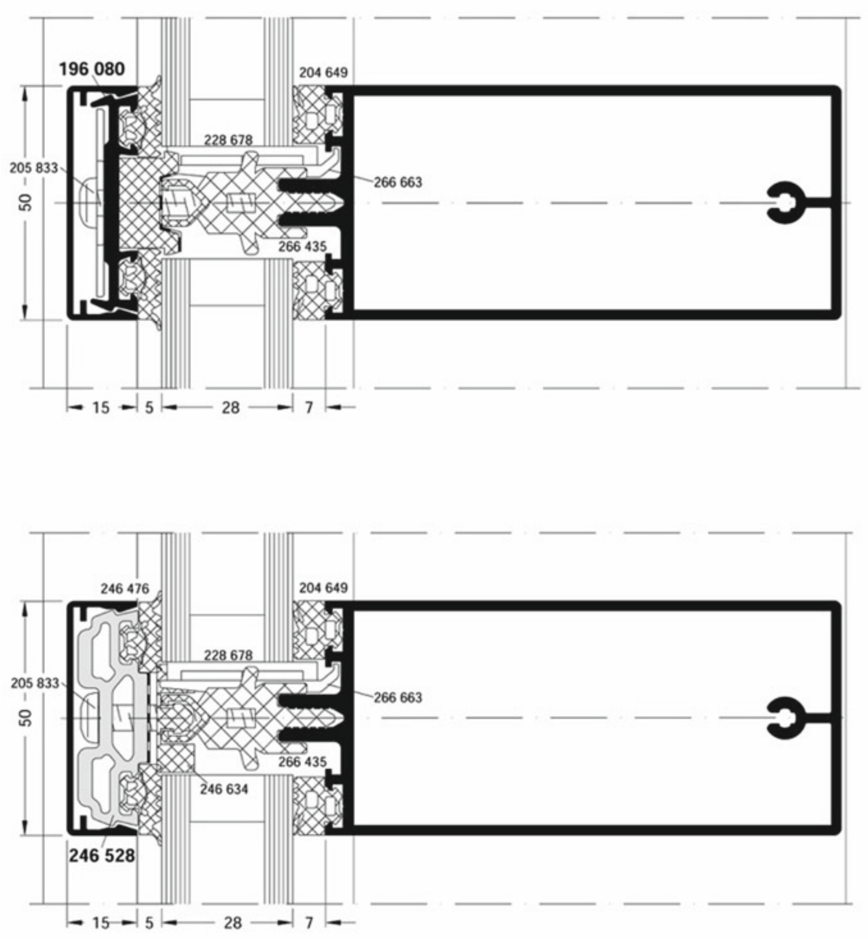

Fig. 2.14 Transoms profiles as horizontal load-bearing structural elements consisting of the homogenous quadrangular tubular section, the attachment to the mullions by means of self-tapping screws or "U"-bolts and the threaded linear pin on the front rib. © Courtesy of Schüco

The construction of the opening frame involves, with respect to the connective technical interfaces:

- the use of screen-printed glass panels in the perimeter step;
- the use of the external monolithic and safety glass panel;
- the difference in height between the external module with the covers and the internal module defined by the supporting frame;
- the determination of the thickness related to the opaque panel.

The application of the opening frame implies the execution of the fixed profile above the transom (according to the configuration due to two tubular sections, the first

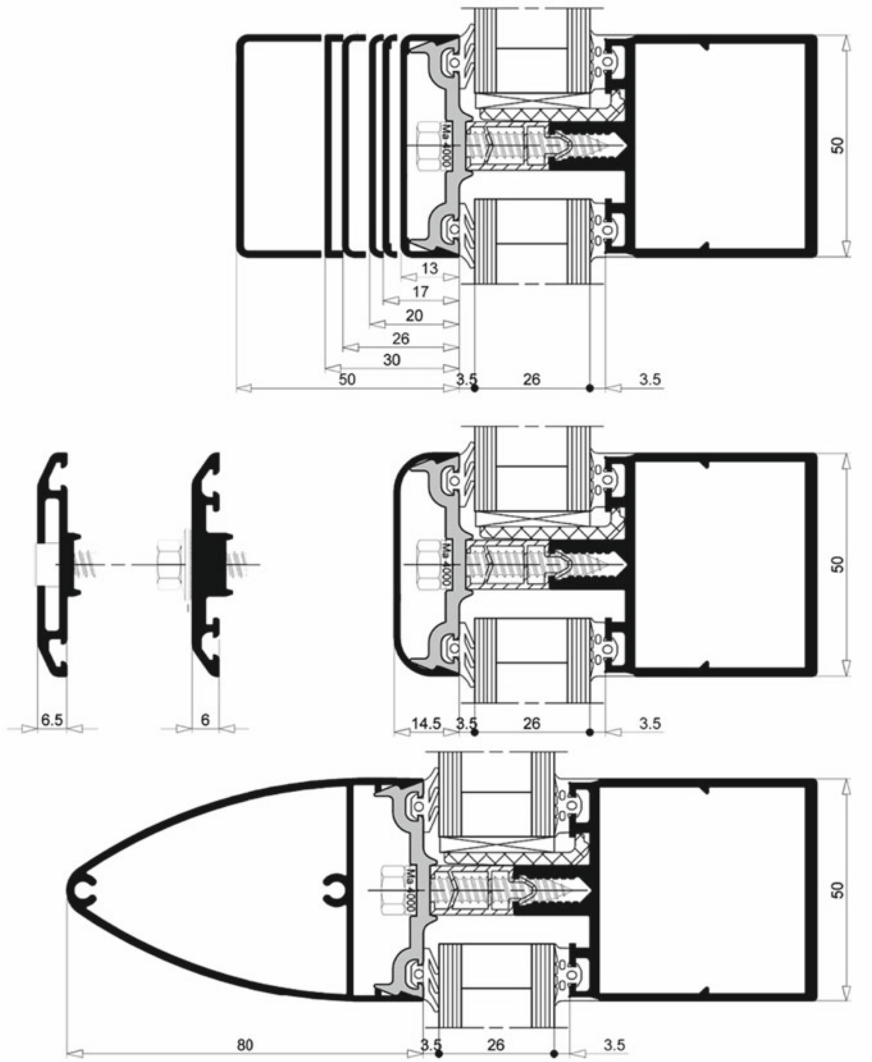

Fig. 2.15 Geometric constitution of the transoms (with lateral dimension varying between 50–80 mm and longitudinal dimension varying between 180–200 mm) established with respect to the mechanical stresses, the overall dimensions of the frames and the value of the moment of inertia. © Courtesy of Metra

resting on the transom, the second inserted in the geometry and dimension established by the double-glazing enclosure), to which the rebate profile is grafted to the upper mobile profile (made up of the tubular section and the "U" wing projection, aimed at the mechanical retention of the double-glazing unit). Similarly, the fixed profile,

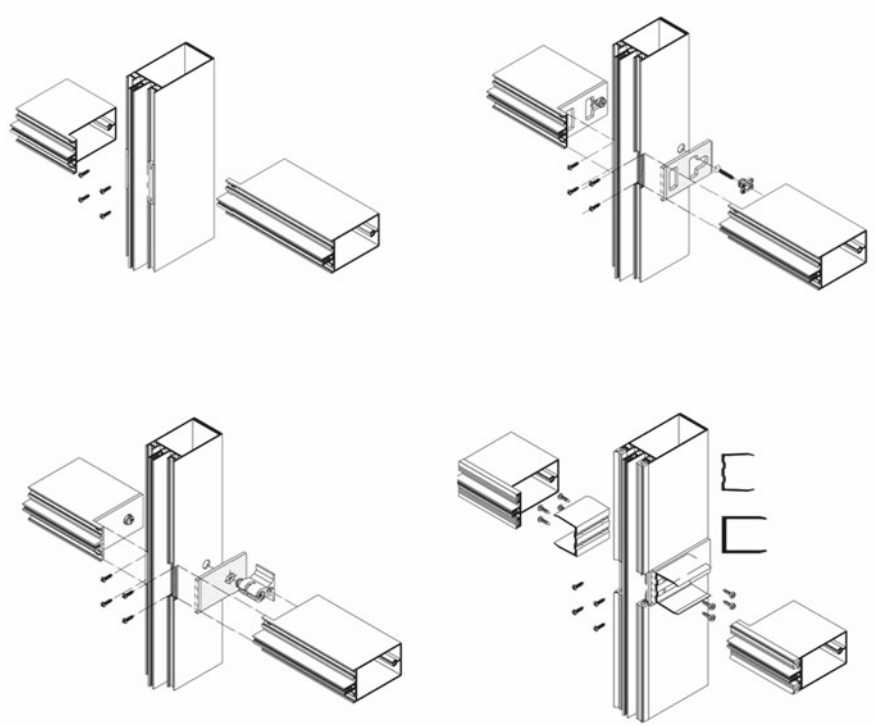

Fig. 2.16 Procedures for assembling the transoms by drilling the holes on the mullions, using the accessories defined as “jigs”, by calibrating the holes on the partitions of the tubular profiles, the holes in the cavities for the internal gaskets and the holes on the linear pins. © Courtesy of Schüco

with respect to the tubular sections, includes the stop shape for the movable profile (Fig. 2.18).

The application of the opening frame observes the use (in the articulation of the hinged profile) of the extension, from the glazing bead profile, of the retaining section of the glazing bead with respect to the external panel (while the internal panel determines the surface for the gasket included in the projected seat of the tubular part of the frame). The enclosure of the frame specifies the adherence of the external seal (inserted between the lower portion of the glazing bead and the vertical projection of the ribbed foil extended by the hinged frame), with respect to the inclined profile inserted between the cavities (planar and normal to the façade) arranged by the frame profile (beyond the transom) (Fig. 2.19).

The application of the hinged frame, in order to obtain the visible surface of the glass related to the sash, considers the use of the “Y” locking device connected to the extension of the hinged frame and penetrating into the interface between the two panels, while the planar face to the façade allows the insertion of the silicone fixing (towards the external pane). The interface of the projecting sash considers the execution of the glass blocking device according to the wing extension of the section

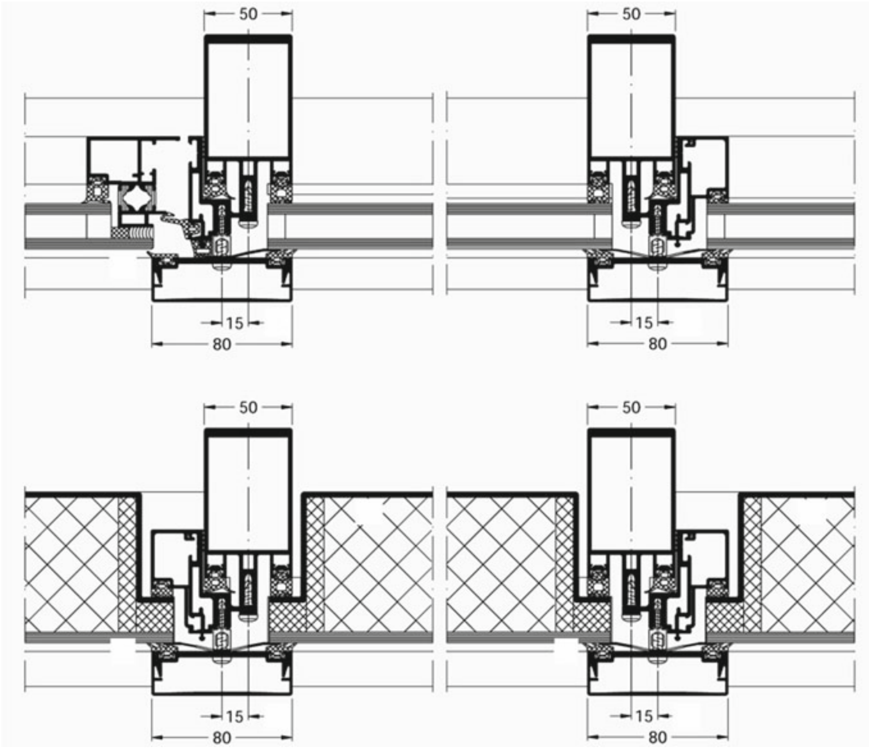

Fig. 2.17 Construction of the opening frame which involves the use of either screen-printed glass panels in the perimeter step, or the monolithic and safety type outer pane, the difference in height between the outer module with the covers and the inner module defined by the supporting frame, the determination of the thickness of the opaque panel. © Courtesy of Schüco

connected to the tubular shape of the sash profile, providing both the insertion in the interface between the two panels of the insulating glass unit (with the silicone fixing), and the lower insertion of the support segment (Fig. 2.20). In the case of the interior opening frame application, the façade system adopts the assembly of the rebate frame with respect to the inclusion of its tubular profile in the geometric and dimensional portion occupied by the double-glazed unit.

This profile, tightened by the pressure device within the inner and outer gaskets, is articulated according to the insertion of the sealing gasket (on the surface normal to the façade): this is extended to the trapezoidal tubular section (from which the support and locking device of the double-glazed enclosure is arranged) connected to the profile of the rebated frame. At the same time, the transom supports and determines, according to the press fastening, the inclusion of the rebate profile, articulated (beyond the tubular section) by means of the insertion (on the upper surface) of the sealing gasket: this is inclined for the escape of rainwater from the slots applied in the profile, extended beyond the rebate tubular section and planar to the façade. The

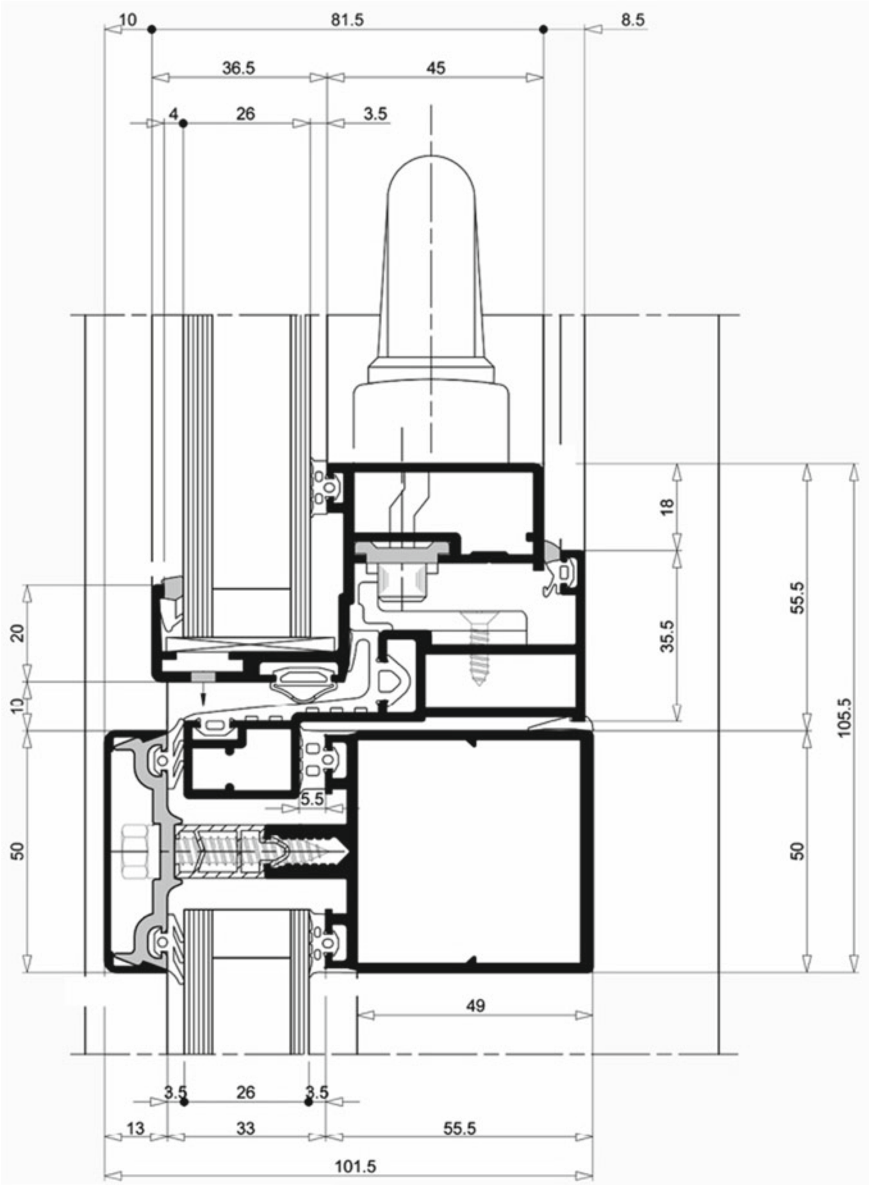

Fig. 2.18 Application of the opening frame which involves the execution of the rebate frame above the transom, in accordance with the configuration due to the tubular section resting on the transom, the tubular section inserted in the geometry of the double-glazing enclosure and the insertion of the shape. © Courtesy of Metra

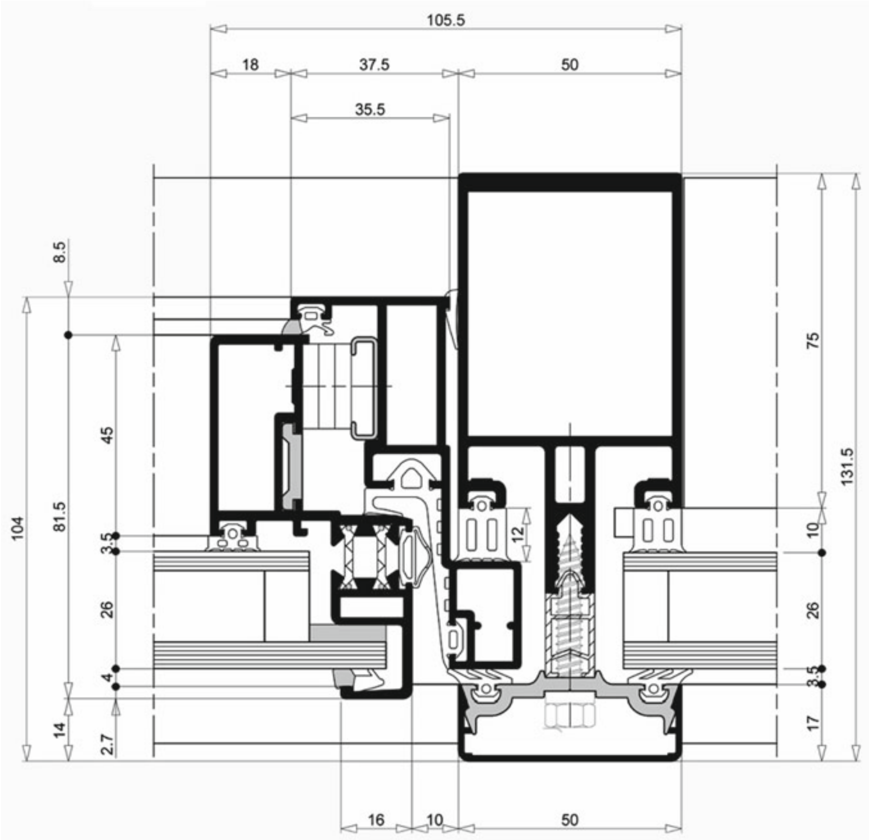

Fig. 2.19 Construction of the opening frame which observes, in the articulation of the sash profile, the application of the glazing bead profile, with a retaining element of the external pane, and the grip of the gasket beyond the tubular section of the profile. © Courtesy of Metra

enclosure includes the gasket rebate on the trapezoidal tubular section, from which the supporting and locking device of the double-glazing enclosure connected to the profile of the hinged frame unfolds (Fig. 2.21).

The application of the inward-turning opening is realized through the inclusion of the rebate frame, with thermal break, in the geometric and dimensional portion occupied by the double-glazed enclosure, according to the insertion of the portion between two linear profiles (one of which extends beyond the tubular section), jointed by the connecting bar. From the tubular section, the three-chamber insulating insert is projected, capable of including the sealing gasket: this extends to the trapezoidal chamber exposed by the internal insulating insert which, in conjunction with the external insert, connects the tubular section (to fix the hinge) with the external projection of the hinged frame (Fig. 2.22).

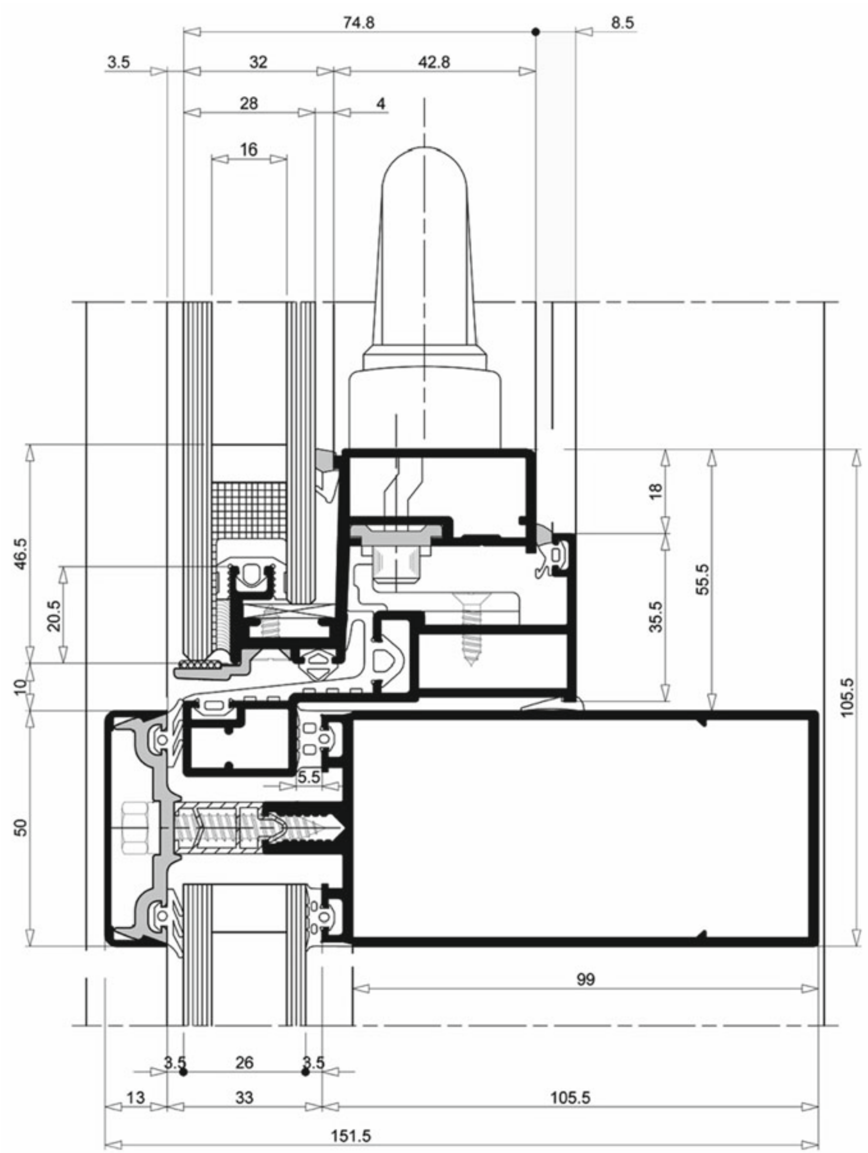

Fig. 2.20 Application of the frame, in order to obtain the visible surface of the glass related to the opening sash, which observes the use of the blocking device, connected to the extension of the sash frame and penetrating the interface between the two panels. The projecting opening sash type considers, at the interface between the two panels of the insulating glass unit, the execution of the glass blocking device, according to the wing extension of the section connected to the tubular section of the sash profile, the silicone fixing on the outer panel and the lower insertion of the support segment. © Courtesy of Metra

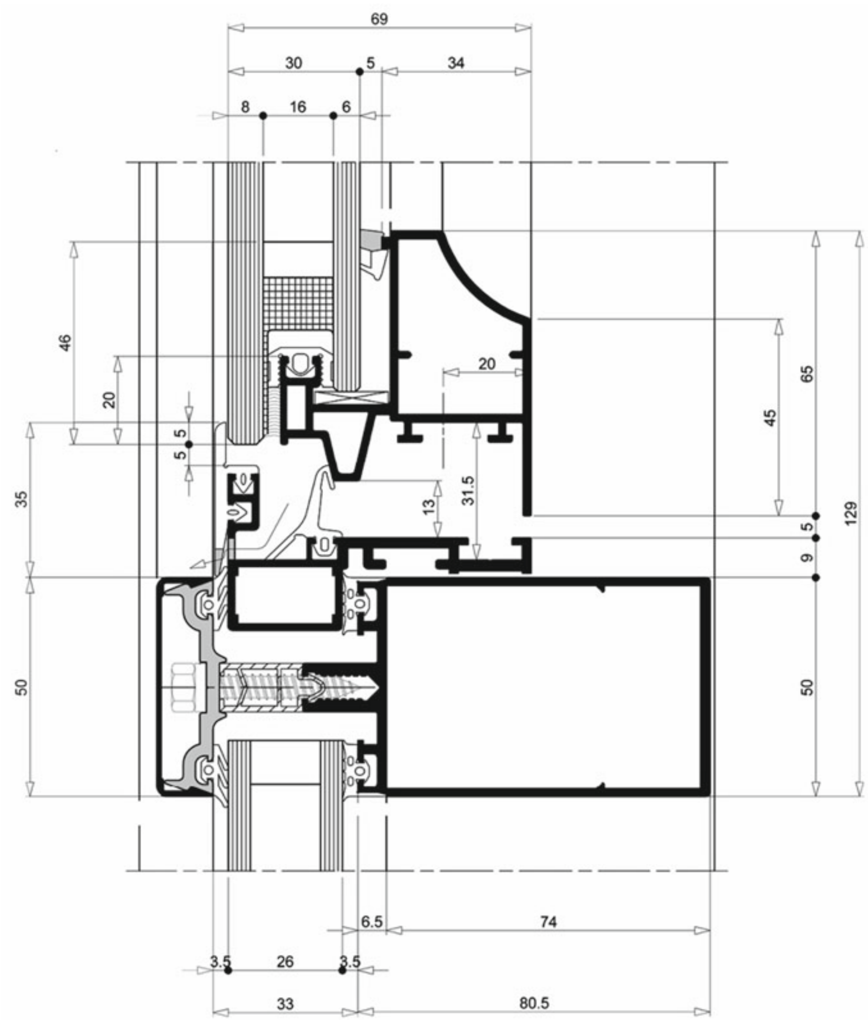

Fig. 2.21 Application of the inward opening frame which provides for the assembly of the rebate frame with respect to the inclusion of the tubular profile in the geometric portion occupied by the double-glazed unit, by means of the insertion (on the upper surface) of the sealing gasket, inclined to allow rainwater to escape, and the rebate of the sealing gasket on the trapezoidal tubular section, connected to the profile of the hinged frame. © Courtesy of Metra

In the case of the steel mullion and transom configuration, the fastening techniques with the pressure device provide for different assembly conditions and combination procedures according to multiple solutions, involving the interposition of double strips of gasket elements, between the external surfaces of the profiles and the glass panels. The gaskets of the system present a specular geometry, with the insertion "head" in the countersinks placed on axis according to the two linear strips, with

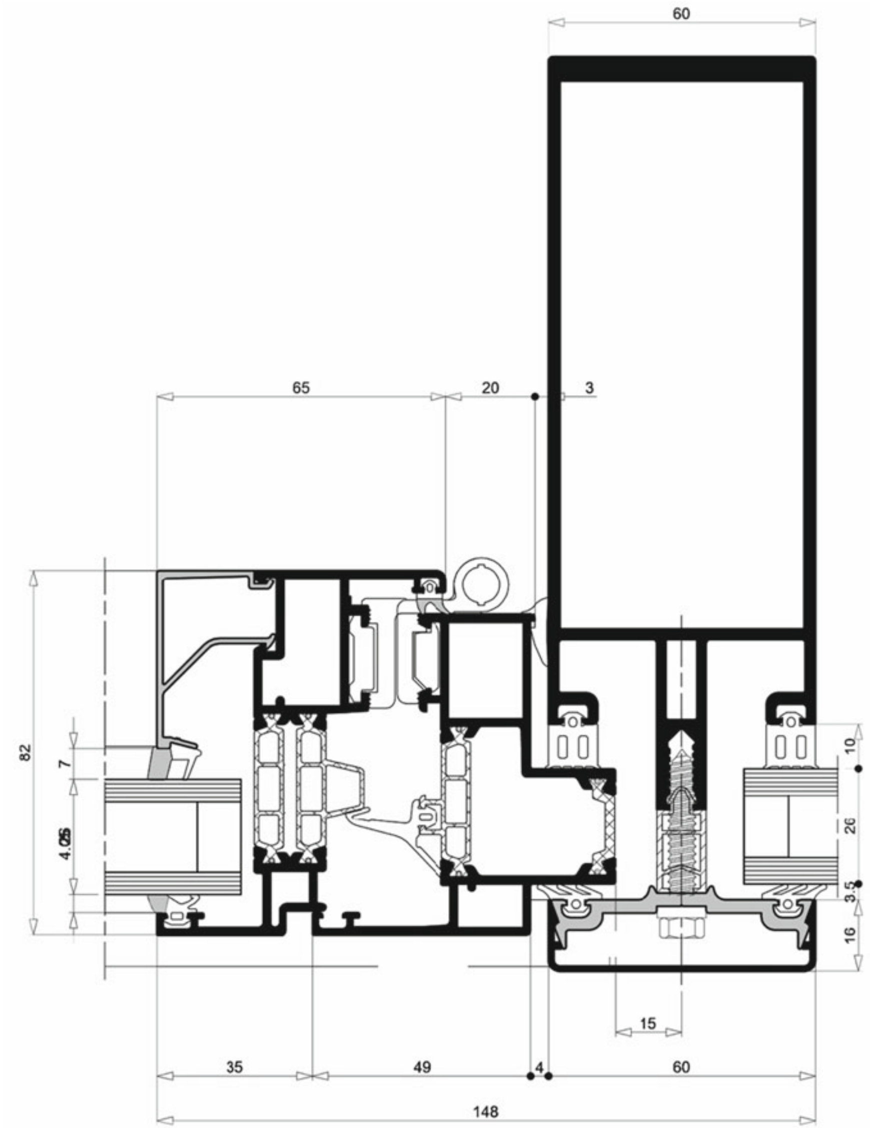

Fig. 2.22 Application of the inward opening to the façade system realized by the inclusion of the rebate frame in the geometric portion occupied by the double-glazing enclosure, according to the insertion of the sealing gasket, extended as far as the trapezoidal chamber, and the connection of the tubular section with the external projection of the hinged frame. © Courtesy of Metra

double surface striations. Tightness is achieved by the EPDM gaskets, embedded in the groove of the support profiles and the pressure device (Fig. 2.23).

In the case of the PVC mullion and transom configuration, the production of multi-chamber profiles for the construction of small façade systems is examined, characterized by:

- the high thermal and acoustic insulation values, together with the remarkable ability to eliminate the formation of surface condensation;

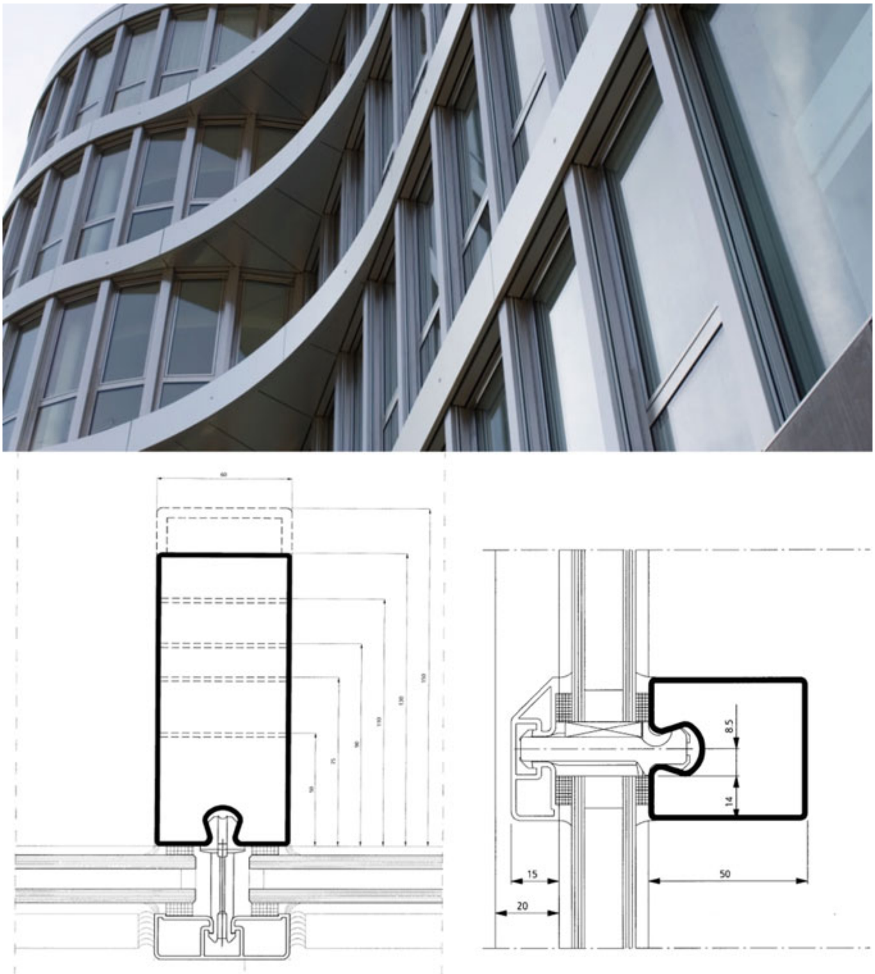

Fig. 2.23 Configuration of the steel mullion and transom façade type delineated according to the assembly procedures relating to the application of the enclosures by means of the fastening carried out by the pressure device and the interposition of the internal and external gaskets between the surfaces of the profiles and the insulating glass panels. © Courtesy of Forster

- the stability conditions obtained through the use of one-piece frames, with galvanized steel reinforcements and coupling sections (Fig. 2.24).

Fig. 2.24 Configuration of the PVC mullion and transom façade typology which observes, specifically, the constitution of monobloc frames, the definition of multi-chamber sections, capable of high thermo-acoustic insulation values and of reducing the formation of surface condensation, and the insertion of galvanized steel coupling reinforcements. © Courtesy of Finstral

Chapter 3
The Typology of the Structural Sealant Glazing Façade System

3.1 The Geometrical, Executive and Connective Configuration of the Framing for Structural Sealant Joints

The curtain wall system in the structural type (*structural sealant glazing* or *glass curtain wall*) is determined by the load-bearing frame (defined as “adaptation” and, in general, in aluminium or steel) assembled in the laboratory and applied on site to the elevation structure of the architectural organism, where the closing elements (in general, in double-glazing panes) are made using structural silicone (without mechanical constraints, inside the profile grooves). This implies the absence of visible external profiles with the consequent contrast of the joints that frame the enclosure modules, whose external panes must be tempered, for reasons of safety, transport and to prevent possible breakage caused by thermal shock (Fig. 3.1).

Within the constitution of the structural façade system, the mullions are defined by vertical load-bearing elements, with a quadrangular tubular structure, endowed with homogenous sections (with the rear rib being larger than the normal lateral ribs) and provided, on the front rib, with the central projections: these have the cavities and cavities for both the connection devices and the gaskets. These projections realize the connective interface to the side frame profiles, through the insertion of the internal central gasket, according to:

- the connection to the tubular profile, through the interposition of the gaskets;
- the extension, on the fronts to the façade, aimed at including both the cavities for the external gaskets, and the polyamide connectors for the assembly profiles (by means of structural silicone) to the double-glazing sheets (Fig. 3.2).

Moreover, the frame profiles and the vertical surfaces of the polyamide connectors (facing inwards from the profile structure) support the attachment of the central locking gaskets, which are equipped with the reciprocal rebate protuberances. The transverse geometries of the mullions (in general, with the lateral dimension of 70–85 mm and the longitudinal dimension of 20–225 mm) vary with respect to

I. Paoletti and M. Nastri, *Executive Design of the Façade Systems*,
PoliMI SpringerBriefs, https://doi.org/10.1007/978-3-031-44893-5_3

Fig. 3.1 Lotti Architetti, *Ascom* Office and Trade Building, Pistoia. Procedures for aligning façade modules in the absence of external profiles, using structural silicone support frames for transparent and opaque closures. © Courtesy of Schüco

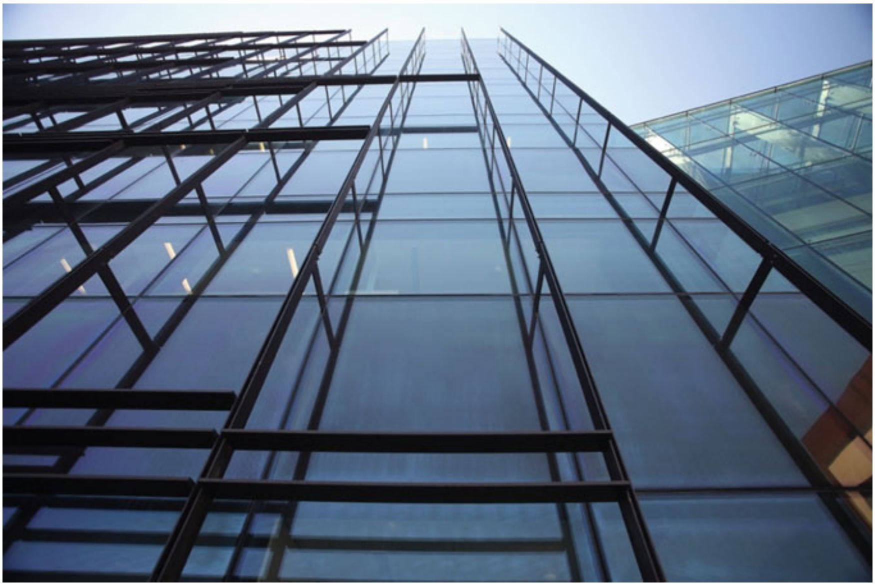

Fig. 3.2 EFA, *Chiesi Farmaceutici* Headquarters, Parma. Façade system completely planar and without external profiles, while the modules are framed by silicone joints and external rebate gaskets between the frame profiles. © Courtesy of EFA

Fig. 3.3 Massimiliano and Doriana Fuksas, Roofing System of ex *Unione Militare* Building, Rome. Construction of the "cloud" on the roof plane according to the connection interfaces between the profile rods supporting the structural silicone connections of the triangular glass enclosure panels. © Courtesy of Pichler Projects

the expected mechanical stresses, the overall dimensions of the modules and the value of the moment of inertia (Fig. 3.3). With respect to the assembly methods of double-glazing enclosures, it is observed:

- the type of system equipped with the profiles for the connection of the staggered enclosures, from which the cavity slots for the external gaskets are arranged, and the connections to the external sheet profiles by means of structural silicone;
- the type of system equipped with the extension of the lateral baffles related to the frame profiles, in order to reach the geometric dimension inherent to the surface of the internal panes. In this case, polyamide connections are extended from the frame profiles (in addition to the cavities for the external gaskets), in a single form and normal to the baffles, towards the laying profiles of the external panes by means of structural silicone;
- the type of system with the frame profiles provided with the slots for the external gaskets and connections to the polyamide fittings, directed to the support of the glazing bead profiles on the four sides (Fig. 3.4).

The executive configuration of the mullions provides the assembly of double-glazing panes, according to the installation on the outer pane by means of structural silicone fixing, involving both the use of reinforcements in the joint, with respect to the double-rib pin, and the extension of the polyamide bar fittings (Fig. 3.5).

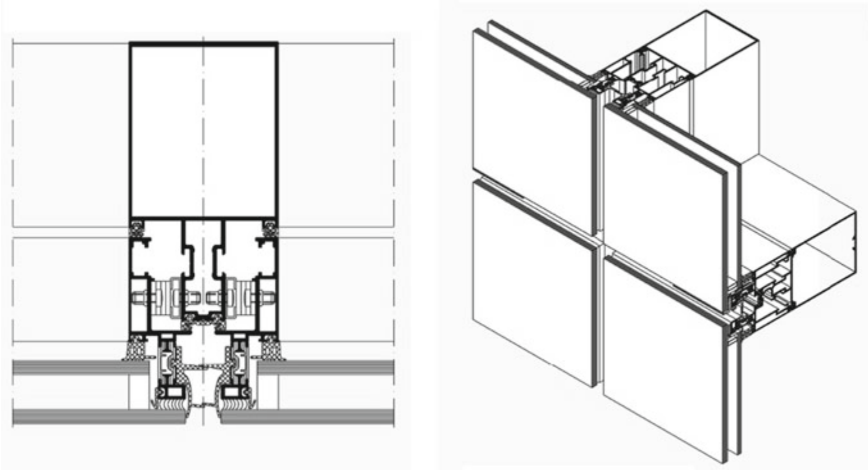

Fig. 3.4 Structural façade system which assumes the type with the extension of the lateral partitions relative to the frame profiles, according to the arrangement of the geometric dimension inherent to the surface of the inner pane of double-glazing. In addition, the system is realized by the frame comprising the mullions made up of the tubular section, endowed with homogenous sections and the central pivot, equipped with the cavities for the connection devices and the internal central gasket. © Courtesy of Schüco

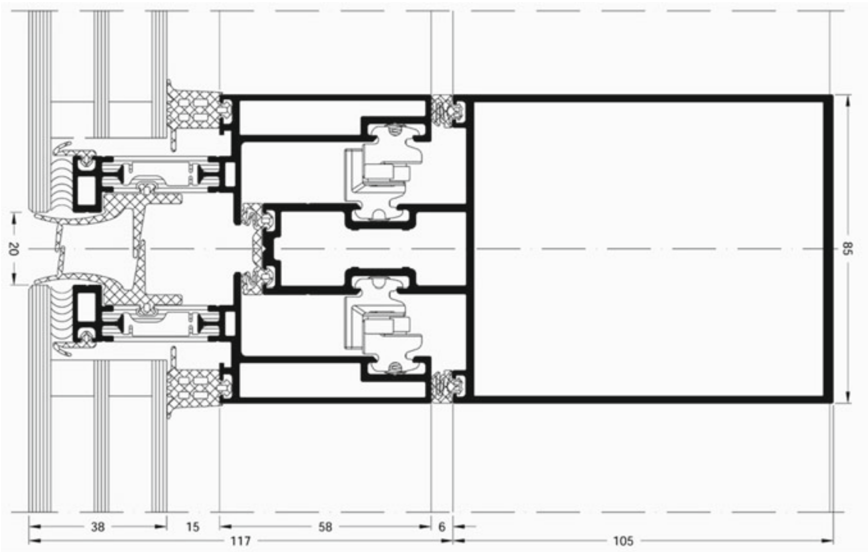

Fig. 3.5 Executive configuration of the interfaces of the structural system which involves the assembly of double-glazing panes, according to the installation on the outer pane by means of structural silicone fastening, the use of reinforcements in the joint to the post pin and the extension of the polyamide bar connectors. © Courtesy of Schüco

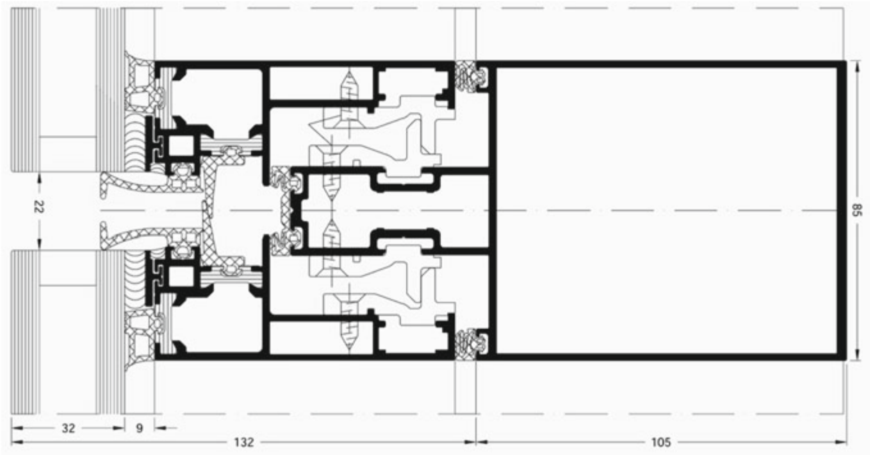

Fig. 3.6 Realization of the structural system which observes the assembly of the frame profiles (by means of their own tubular section) to the central linear pivot, the extension of the frame profiles towards the polyamide bar couplings, the execution of the continuous plane between the structural silicone fixing and the external gasket rebate. © Courtesy of Schüco

Construction of the system observes the assembly of the frame profiles connected, by means of their own tubular section, to the baffles of the central linear pivot, extended to form a connection (in polyamide rod) planar to the façade and directed to the laying profile: this assumes the execution of a continuous plane between the structural silicone fixing and the rebate of the external gasket (Fig. 3.6).

The constitution of the mullion may envisage the external projection of the central double-septum profile, with the internal transversal stiffener, on which the frame profiles are applied (in contiguity with the internal gaskets), with the tubular section and the wing projected towards.

- the cavity for the inner central seal;
- the connection device (by silicone joint), in a tubular profile connected by means of a couple of polyamide bars, of the double-glazing sheets (Fig. 3.7).

The same type of mullion also features the application of the insulating insert at the end of the external linear pin, in order to achieve the best thermal break conditions compared to the insertion of the internal central seal.

The typological constitution of the system makes explicit the way in which the triple-glazed (double-glazed) closures are assembled by means of the mechanical retainer projected beyond the installation profiles: specifically, the tubular sections of the profiles extend normal to the plane of the façade, to bend until they determine the flange of a geometry and size sufficient to contain the grip seal (towards the internal surface of the external glass pane). The polyamide fittings, which are attached to the frame profiles, are provided with the cavity for the central locking gaskets with double rebate (Fig. 3.8).

Fig. 3.7 Constitution of the structural system which observes the configuration of the mullion according to the external projection of the double-rib central pivot, with internal transverse stiffening, the lateral application of the frame profiles, with the wing section projecting towards the internal central seal, and the connection of the polyamide bar connectors. © Courtesy of Metra

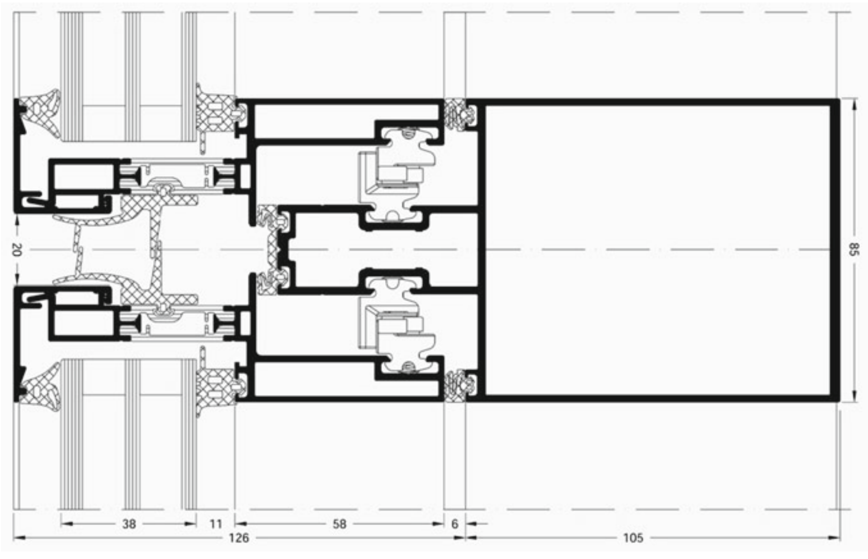

Fig. 3.8 Constitution of the system that makes explicit the way in which triple-glazing enclosures are assembled, by means of mechanical retention, considering both the normal extension to the façade plane and the bending to determine the containment flange of the external grip gasket, and the connection of the polyamide bar fittings to the frame profiles. © Courtesy of Schüco

The same type of mullion accommodates the support procedure of the double-glazing panes according to the use of glazing beads with mechanical retention: this is projected beyond the tubular section, through the baffles normal to the façade plane (including the cavity for the central sealing gaskets) and the segments defined by the perimeter edge (Fig. 3.9). The executive configuration of the mullions is also determined according to the combined type, composed of the specular aggregation of two profiles characterized mainly by:

- the linear tubular section, provided with the cavities (rear and front) necessary for the engagement of the vertical connection gaskets;
- the profiles extended normal to the façade plane, with the double tubular section and the cavity in between for the insertion of the jointing devices to the frame profiles (in the form of cast zinc clamps). These are equipped with the wing extension, planar to the façade, from which the couples of polyamide bars for connection to the frame profiles of the outer pane of insulating glass (by means of the structural silicone fixing) unfold (Fig. 3.10).

The façade typology also includes the possibility of the mullion in combined form by means of two specular profile sections, both with a tubular part: the connection

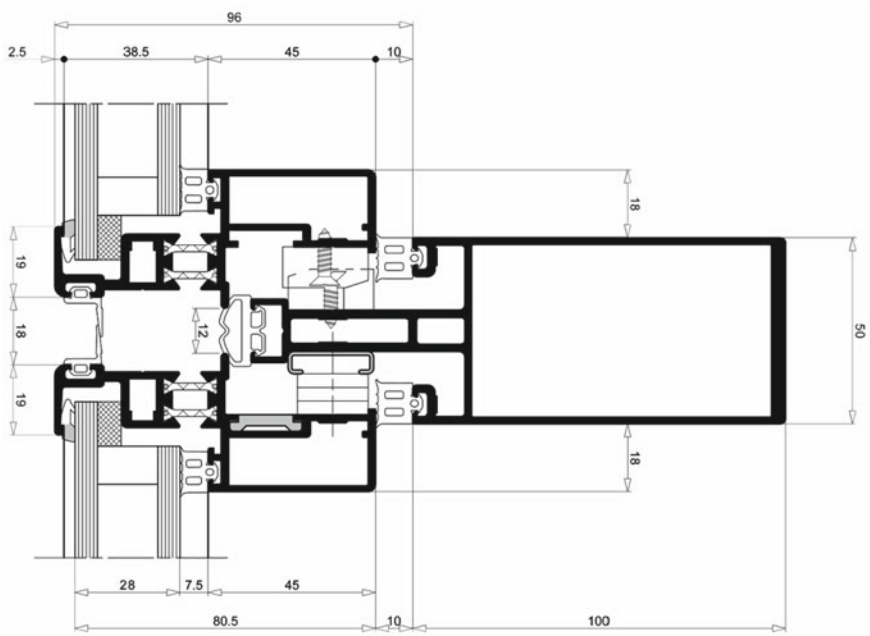

Fig. 3.9 Support procedure for double-glazing panes specified according to the use of the installation profiles supplemented by the mechanical retainer, noting the bending to determine the containment flange for the external grip gasket and the provision of cavity for the central sealing gaskets. © Courtesy of Metra

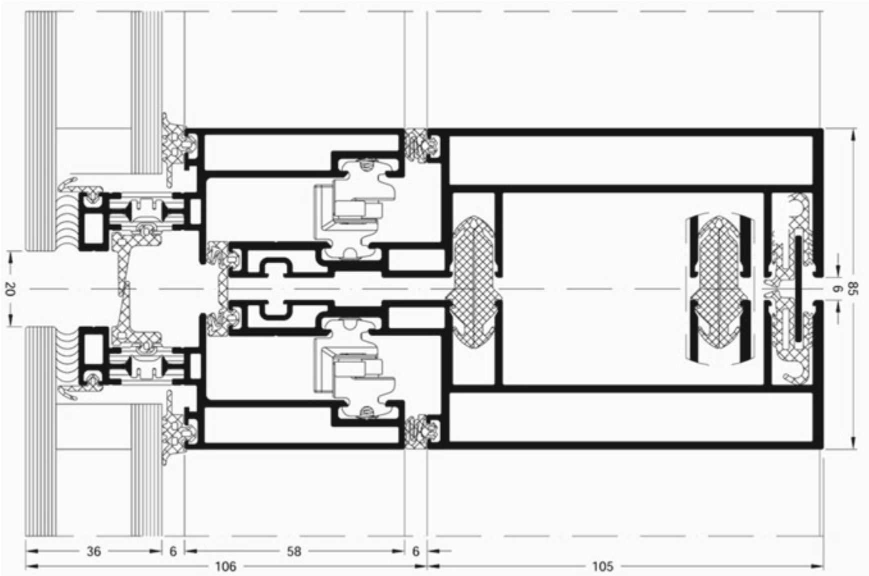

Fig. 3.10 Executive configuration of the mullions also determined according to the combined type, composed of the specular aggregation of two profiles made up of both the linear tubular section, provided with the cavities necessary for the insertion of the vertical connection gaskets, and the pins extended normal to the façade plane, with double tubular section. © Courtesy of Schüco

(with insertion of the polyflor brush gaskets) is made by means of the inclusion of the two laminar projections, stretched beyond the tubular profile of one section, in the grooves arranged by the tubular profile of the other section. The specular profiles unfold, towards the façade plane, either according to the extension of the lateral partitions to define the cavity for the internal gaskets, or according to the extension of a section (with a tubular extension in between) capable of realizing:

- the joint surface (for screwing) to the frame profiles;
- the insertion space for the intermediate gaskets, directed up to the rib (parallel to the façade plane) projected from the frame profiles (from which the double couples of polyamide bars are made to join the glazing beads);
- the extension of the internal rib to determine the cavity for the central closure gasket, with fins in contact with those for the external gaskets, inserted on the ribs (normal to the façade plane) of the glazing beads (Fig. 3.11).

The façade system can be executed according to the frame construction (in the *split wall* type), aimed at facilitating the construction procedures by means of on-site assembly, for the structural bonding of the double-glazing enclosures. The frame, anchored to the deck works (by means of the brackets fixed to the halfen profiles, previously embedded in the horizontal elevation structures), is composed of two specular tubular profiles: the aggregation provides for the insertion of the two wing

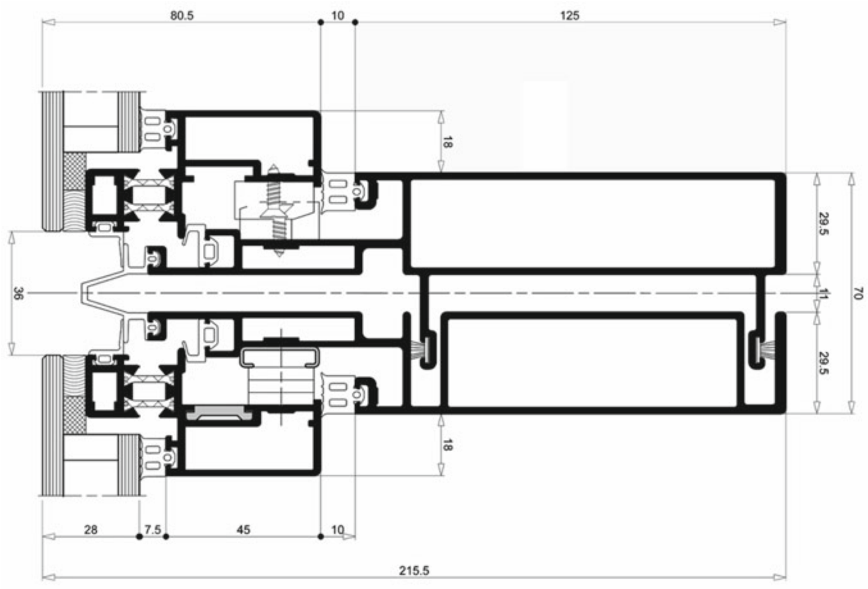

Fig. 3.11 Execution of the mullions in combined form which involves the specular assembly of the two profiles, realized by the connection through the two laminar projections (with polyflor brush gaskets), projected from the tubular profile of one section towards the cavities arranged on the other tubular profile, by the extension of the lateral baffles directed towards the cavity for the internal gaskets and by the projection of the central tubular pin. © Courtesy of Metra

projections of one profile within the grooves of the other, determining the interposition of an additional chamber. On the longitudinal axis of the two central ribs, the linear profiles (equipped with grooves for the interface with the transversal connection accessories) extend up to the cavity slots for the external gaskets. These, together with the internal gaskets (at the end sides of the tubular profiles of the mullion), interface with the tubular section frame profiles, extended as far as the planar extensions to the façade: from the front surface of the profiles, the couples of polyamide bars connecting to the glazing beads (for fixing the double-glazed units by means of structural silicone) project from the extensions and, from the tubular sections, the sealing gaskets on the internal surface of the panes (Fig. 3.12).

The construction of the system, in the case of assembly to the vertical surfaces of the deck works (by insertion within the couple of stainless steel angle brackets), involves the transversal connection (by double specular bolting) to the tubular sections of the mullions (stiffened by the insertion of the stainless steel canes). In the case of the type fitted with an outward-opening tilt-and-turn window, the inclusion of the frame profiles (with the tubular section and the planar projection to the curtain) is observed between the interfaces determined by the internal gaskets (in the cavities located at the ends of the combined mullion profiles) and external gaskets.

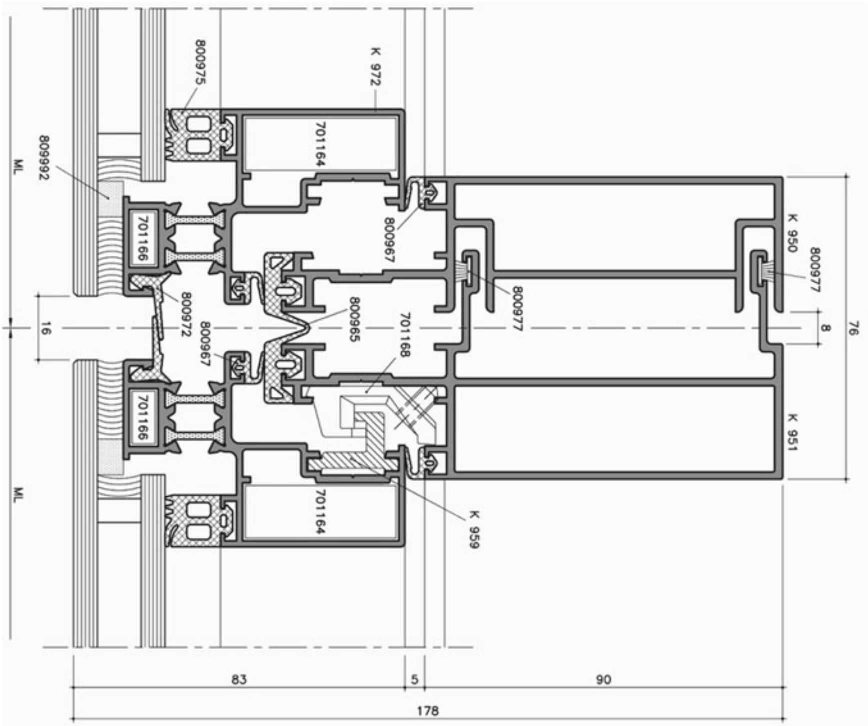

Fig. 3.12 Realization of the “frame” structural façade system, aimed at facilitating installation procedures by means of prefabrication of the modules, which implies the connection by means of the two laminar projections, protruding from the tubular profile of one section towards the cavities arranged on the other tubular profile. © Courtesy of AluK

3.2 The Functional, Constructive and Applicative Coordination Procedures of the Mullions and Transoms Framing

The frame profiles encompass both the opening devices (in stainless steel) and the ribs for the insertion of the double couples of polyamide bars directed to the external glazing beads: these are intended to include the compartments for cavity the central seals, the wing projections for the interposition of the panels and the structural silicone fixing (on the planar surface to the façade) (Fig. 3.13).

The application of the structural system with the outward tilted opening considers, with respect to the central pivot of the transom extended up to the gasket cavity locations, the interface related to:

- the upper assembly of the frame profile with the tubular section, aimed at containing both the gasket cavity on the internal surface of the double-glazing enclosure, and the couples of polyamide bars (from the planar extension to the

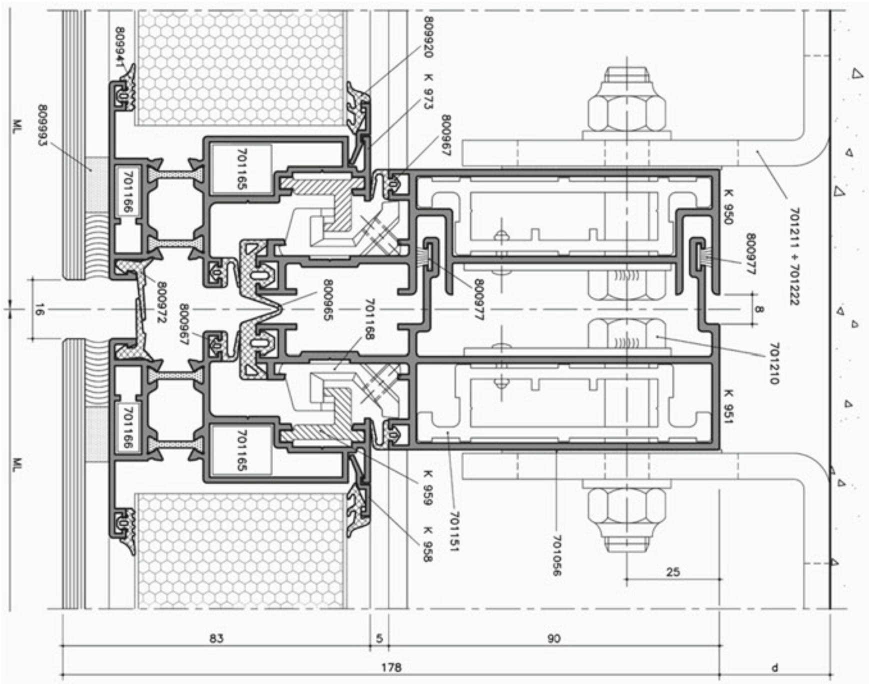

Fig. 3.13 Construction of the "frame" system, equipped with an outward-opening tilt-and-turn window frame, determined through the assembly to the vertical surfaces of the structural decks, by attaching to the couples of stainless steel angle brackets, stiffening the tubular sections of the mullions by means of steel shims. © Courtesy of AluK

façade) facing the external glazing bead (to support the dowel and aimed at accommodating the fixing of the structural silicone to the external pane);

- the lower assembly of the frame profile, intended to hold the glazing bead (according to the inclusion of the horizontal insert with gasket, together with the vertical projection from the glazing bead) (Fig. 3.14).

The structural façade system implies the construction by means of the mullion type with an "I" or "T" cross-section: this type realizes, by means of both the projection of the two lateral wing profiles, for the cavities to the internal gaskets, and the linear pivot (extended through the insulating insert), the interface conditions with the frame profiles, composed of the tubular section and the wing (planar to the façade) for the execution of the glazing beads (from which the external closing gaskets are arranged) (Fig. 3.15).

Within the system, the transoms are defined as horizontal load-bearing structural elements with a tubular profile equipped with a double-rib central pivot (onto which the fixed glazing beads are screwed) and connected to the frame profiles, according to the interposition of the internal gaskets. The wing projections extended from the tubular sections of the frame profiles accommodate both the cavities for the

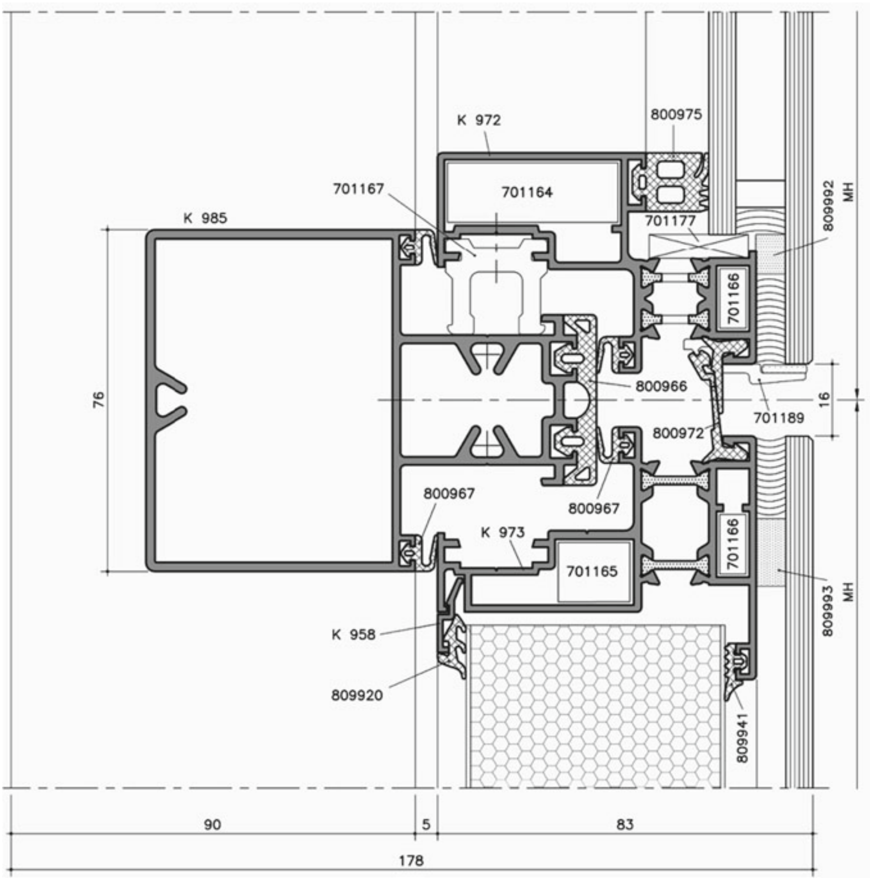

Fig. 3.14 Application of the structural "frame" system which considers, with respect to the central pivot of the transom, the articulation of the cavity seats for the intermediate gasket, the application of the lower support, aggregated to the cavity of the upper frame profile and the assembly of the *spandrel* panels. © Courtesy of AluK

external gaskets and the interface ribs to the double couples of polyamide bars for the aggregation of the laying profiles, facing:

- the interface with the central seals;
- the structural silicone fastening to the panes of the double-glazing enclosures;
- the support to the outer panes of the double-glazing closures (Fig. 3.16).

The constitution of the transoms foresees the external projection of the double septum central profile, on which the frame profiles are applied (in contiguity with the internal gaskets), with the tubular sections and the vertical wings: these are equipped with the cavity cavities for the external lateral gaskets and projected (in planar form to the façade) both towards the internal central gasket and towards the

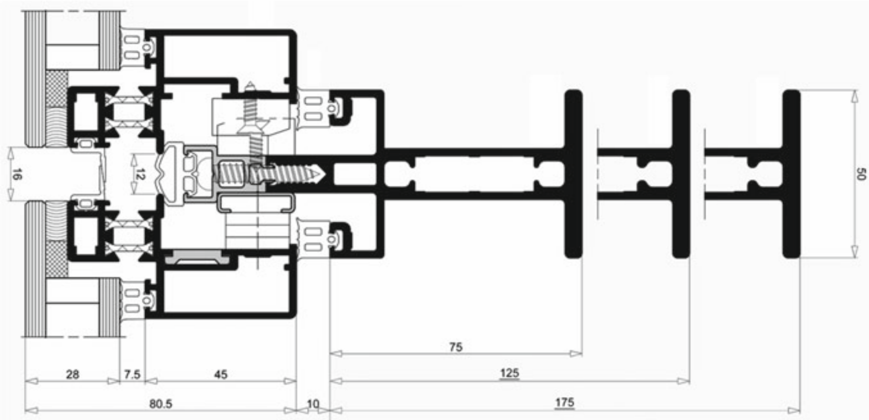

Fig. 3.15 Structural façade system is provided for the construction by means of the “I” or “T” cross-sectional mullion type, realized by the projection of the lateral wing profiles, directed to the cavity locations for the internal gaskets, the extension towards the central pivot (equipped with an insulating insert), and the connection of the frame profiles. © Courtesy of Metra

profiles connecting to the glazing beads (equipped with the central closing gaskets). In particular, the upper glazing bead realises with respect to.

- the upper surface, the support to the dowel on which the glazing bead is placed;
- the lower surface, the junction (by screwing) of the mechanical retainer extending beyond the silicone fixing to wrap around the end of the outer pane of the double-glazed unit.

The type of transom related to the triple-glazing system by means of the mechanical stop (projected beyond the installation profiles) involves the extension of the corner elements above the same tubular installation profiles, in order to accommodate the external grip gasket (towards the surface of the outer pane of glass). The polyamide fittings, which are attached to the frame profiles, are provided with the cavity slots for the central sealing gaskets with double rebate. The construction of the frame profiles and the installation profiles of the insulating glass panes, cut diagonally for the corner connection, observes the insertion of the “pin” brackets inside the tubular sections (Fig. 3.17).

The constitution of the transom considers the external projection of the double-rib central profile, against which the frame profiles are applied (in contiguity with the internal gaskets), with the tubular section and the vertical wing (planar to the façade): it is projected towards the cavity of the internal central gasket and towards the glazing beads (in tubular profiles, connected by means of the couple of polyamide bars) for fixing (with structural silicone) the double-glazing panes (Fig. 3.18).

The same typological interface constitution related to the transom is determined both for the use of the opening frame, the adjustment device of which is set on the

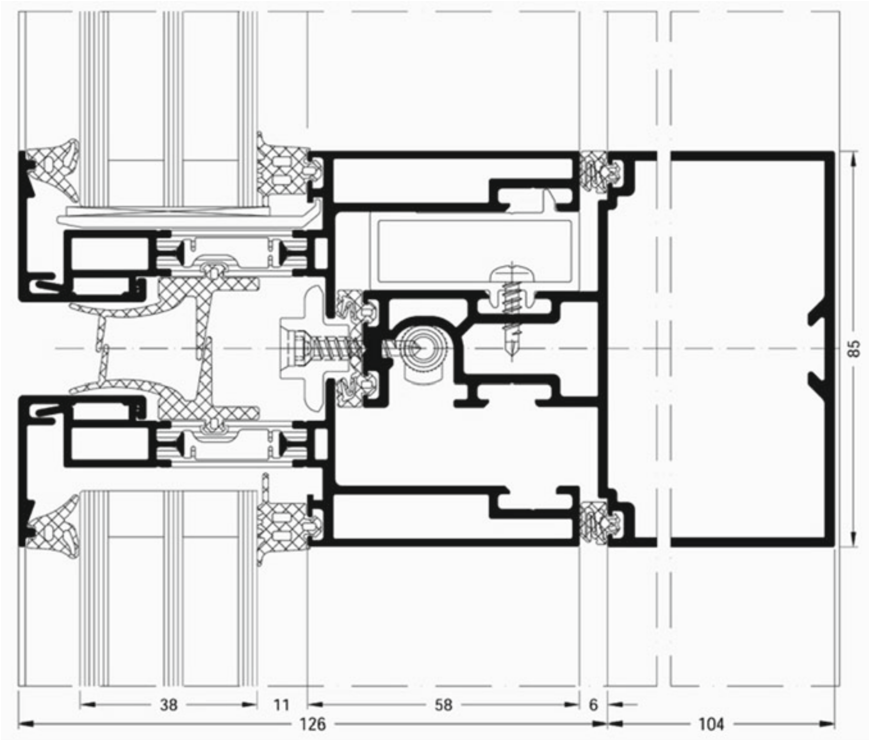

Fig. 3.16 Façade system realized by the frame including the transom profiles, consisting of the quadrangular tubular section, equipped with homogenous sections, the central pivot, the cavities for the connection devices and the internal central gasket. © Courtesy of Schüco

upper frame profile, and for the insertion of the opaque panel (in *spandrel* form) in the lower part, according to the assembly carried out by means of:

- the engagement from the groove on the inside corner of the lower frame profile;
- the grip established by the external seal, the seat of which is located at the end of the vertical wing section extended by the glazing bead.

In the case of the insertion of projecting opening components, the frame constitution involves:

- for the mullions, the assembly of the threaded bushings, connected to the compasses, between the rib of the front profile projection and the rib of the tubular cavity related to the frame profile;
- for the transoms, the application of the horizontal rib and cavity, within the tubular profile, to support the sash tilt support devices.

In the case of the insertion of opening components with parallel extension, the frame constitution involves:

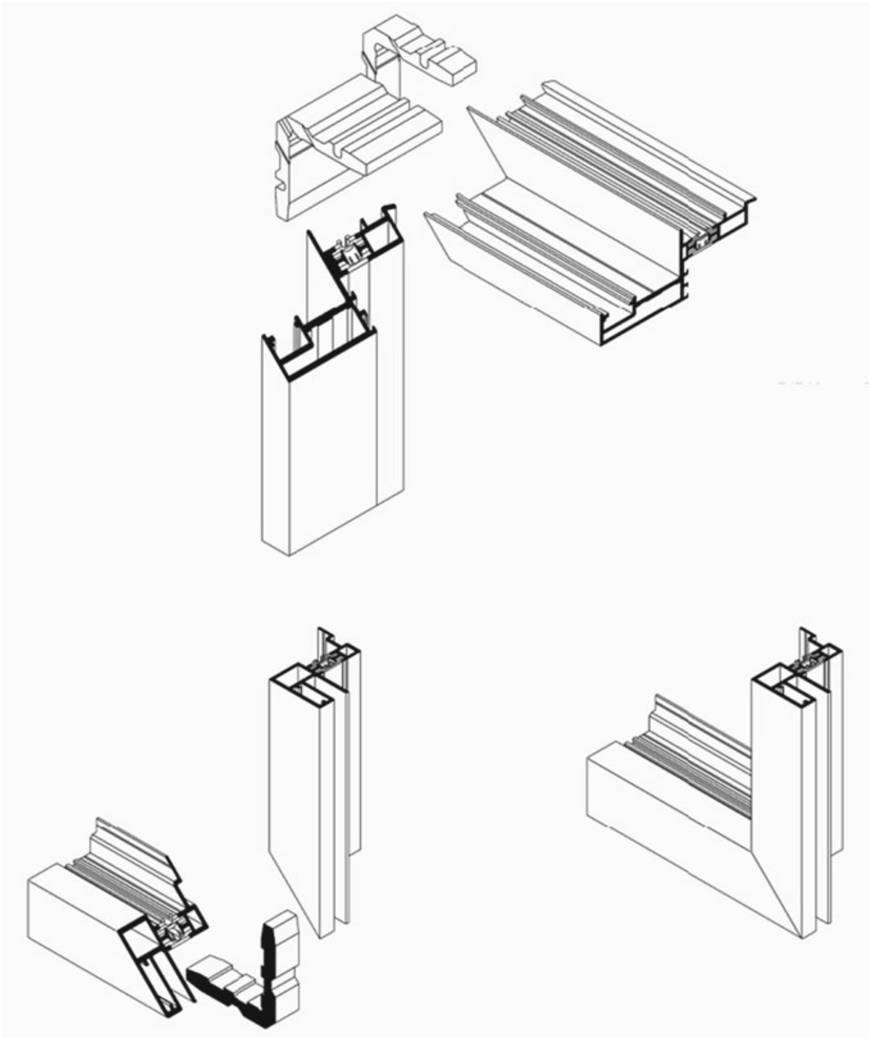

Fig. 3.17 Construction of the structural façade system including the connection procedures between the frame profiles and the double-glazing profiles, based on the diagonal cut for the corner connection and the insertion of the "plug" brackets. © Courtesy of Schüco

- for the mullions, the assembly of the opening devices between the cavity related to the rib of the front profile projection and the rib of the tubular cavity related to the frame profile;
- for the transoms, the application of the ribs and the cavities, within the tubular profiles, to support the lateral rotation devices of the sashes (Fig. 3.19).

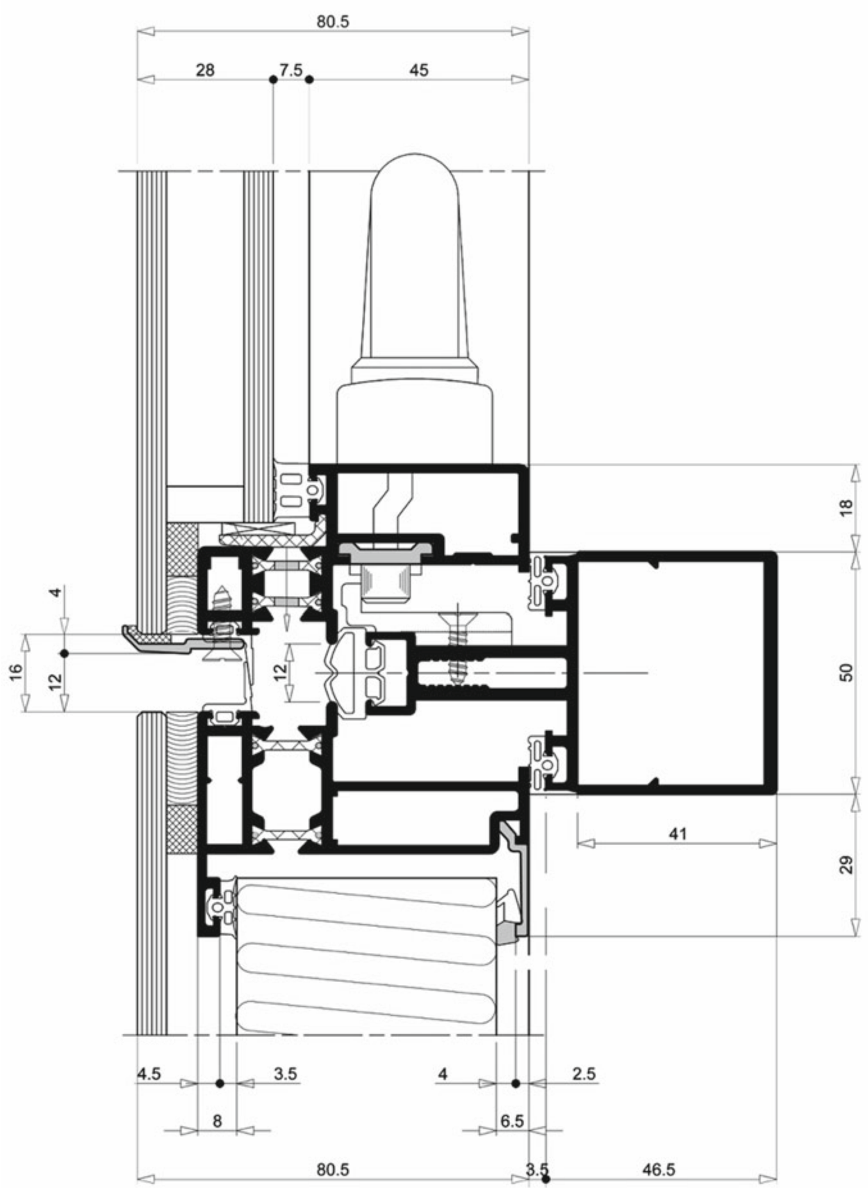

Fig. 3.18 Façade system made up of the frame including the transom profiles, consisting of the quadrangular tubular section, equipped with homogenous sections, the parallel couple of cavities for the internal gaskets, the central double-rib pivot, supporting the upper frame profile, and the cavity for the central intermediate gasket, which is rebated on the wing projections of the frame profiles. © Courtesy of Metra

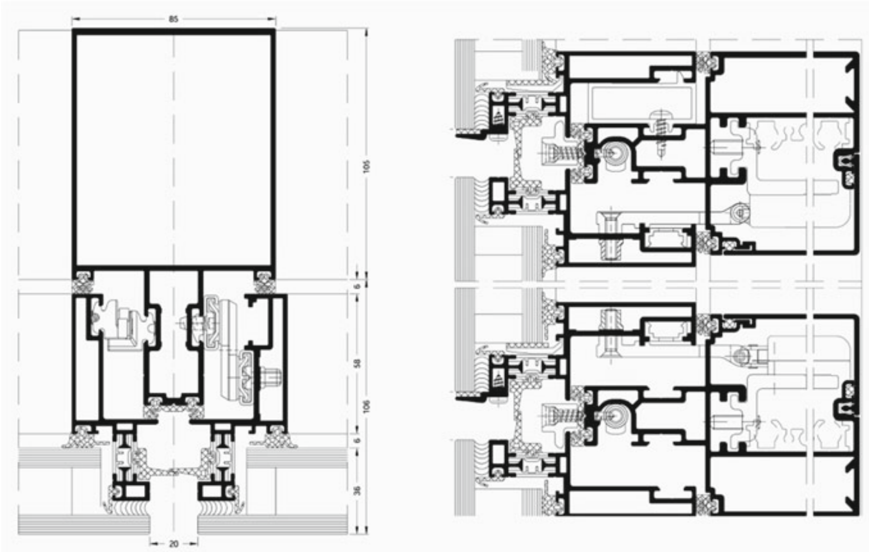

Fig. 3.19 Insertion of projecting or parallel opening components into the structural system entails, for mullions, the assembly of bushings connected to the compasses, between the pin and the tubular cavity related to a frame profile, and, for transoms, the application of a horizontal rib and cavity, to support both the tilt and turn of the sashes. © Courtesy of Schüco

The application of the *spandrel* panels, made in layered form including both internal and external aluminium cladding sheets, with the interposed thermal insulating panels, includes:

- for mullions, the fastening (by screwing) of the inner sheet metal to the outer rib related to the frame profile and the fastening (by screwing) of the outer sheet metal according to the pronounced flap up to the laying profile, extended beyond the frame profile by means of the couple of polyamide bars;
- for transoms, the inner sheet fastened (by screwing) to the upper rib related to the frame profile and the outer sheet fastened (by screwing) according to the pronounced lap up to the outer laying profile, extended beyond the frame profile by means of the couple of polyamide bars.

The application of the *spandrel* panels, with an external glass pane covering, internal closing sheet and interposed thermal insulation layer, includes, for both mullions and transoms, the fixing (by screwing) of the sheet to the rib (external, for the interface on the mullions, and upper, for the interface on the transoms) related to the frame profiles: these are fitted, at the front, with the cavity for the retaining device to the insulation and, in the normal projection to the façade plane, with the cavity for the external rebate gasket on the glazing sheet (Fig. 3.20).

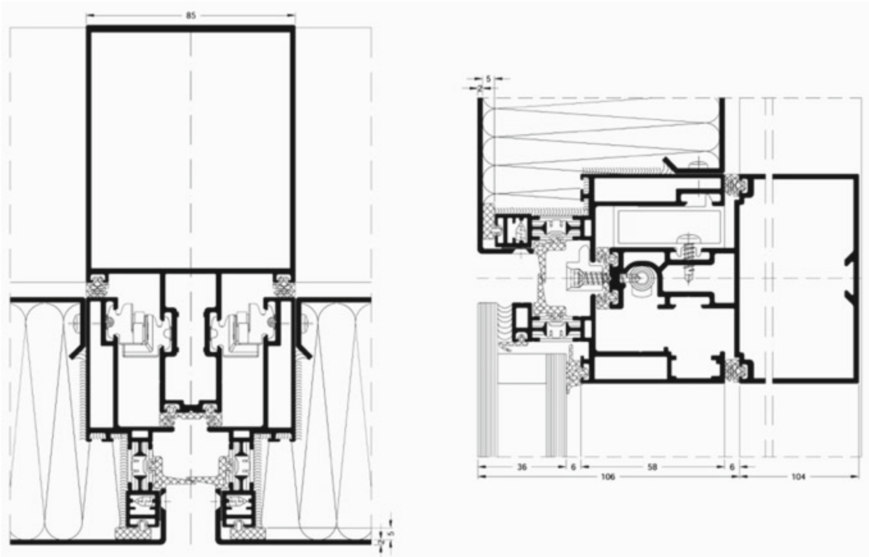

Fig. 3.20 Application of the *spandrel* panels, in sandwich construction with interposed thermal insulation layer or with external glass sheet cladding and interposed thermal insulation layer, which comprises, for the mullions, the fastening of the inner sheet to the frame profile and the fastening of the outer sheet according to the flap beyond the outer laying profile, and, for the transoms, the fastening of the inner sheet to the upper frame profile and the fastening of the outer sheet according to the flap beyond the outer laying profile. © Courtesy of Schüco

3.3 The Functional, Constructive and Coordination Procedures Between the Façade System and the Main Interfaces

The composition of the mullions for the corner interfaces is realized by the projections, on two orthogonal sides, culminating in the tubular profile sections beyond which the cavities for the internal central gaskets extend: according to the arrangement produced in specular form with respect to the longitudinal axis of the mullion, or in misaligned form due to the use of a tubular profile with longitudinal development, the connection of the frame profiles (enclosed within the internal gaskets) to the tubular sections extended beyond the body of the mullion is noted. The frame profiles determine the extension of the planar rib to the façade (up to the external seal extended from the mullion) in relation to the external sealing elements. The assembly of the angular interfaces to the façade plane reveals the use of the combined mullion type, whose sections, aggregated in specular form, are composed of:

- the tubular portion according to the connections, inside and outside, made by means of the cavities provided for the insertion of the vertical connection gaskets with the interposition of the continuous aluminium sheets;

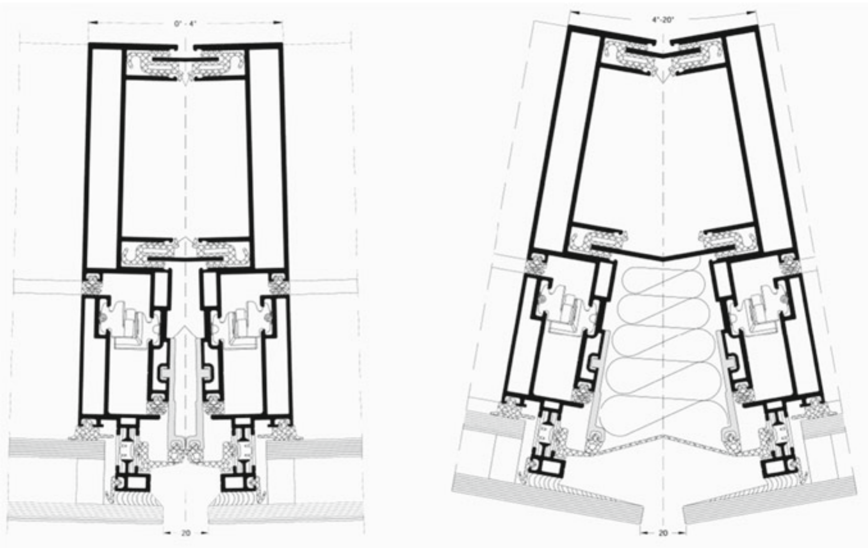

Fig. 3.21 Assembly of the corner interfaces that involves the use of the combined mullion type, the sections of which are composed of the linear tubular section, provided with the cavities necessary for the insertion of the vertical connection gaskets. © Courtesy of Schüco

- the central longitudinal rib, normal to the façade plane, defined by two tubular sections with the interposition of:
  - the cavity for the threaded bushings (for connection to the frame profiles);
  - the cavity for the support devices for the central rebate gaskets;
- the insertion of the thermal insulating layer within the corners, contained between the external aluminium foil, grafted to the cavities connected to the tubular sections of the mullions, and the extension of the rebate gaskets (Fig. 3.21).

The execution of the angular interfaces is determined through the use of two coupled sections of mullions, composed of the median cuts of the tubular structure: this is achieved through both the internal connection carried out by means of the relationship between two circular projections (capable of producing the angle by rotation), and the interposition, as the closure defined by the press device, of the shaped sheet metal wrapping the dowel (of a configuration suited to the established angle). The tubular profiles assume the extension, beyond the cavities for the internal gaskets, of the rib integrated by the linear pins (on which the insulating insert is placed) that realize the jointing elements (by screwing) towards the frame profiles. These, in particular, determine the correlation towards the glazing beads (by means of the front rib pronounced in a planar form to the façade), from which the gaskets are projected (on the rib normal to the façade), the fins of which interface with the central bellows gasket for the frontal enclosure of the system (Fig. 3.22).

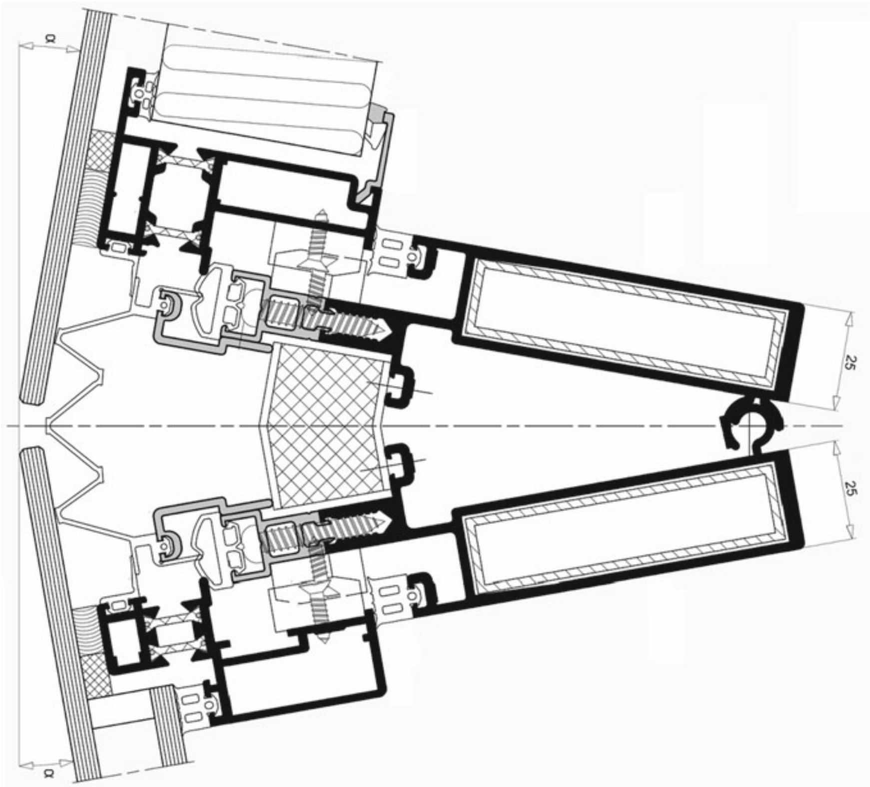

Fig. 3.22 Execution of the corner interfaces, according to the use of the combined mullions, that observes the internal connection by means of two circular projections, the extension, from the tubular profiles, of the linear pins (equipped with the insulating insert), the joining of the frame profiles, the interposition of the shaped sheet metal to close the pressure device and the application of the central bellows gasket for the front enclosure. © Courtesy of Metra

The internal corner interface between the closing planes detects the use of two mullions, executed in the normal manner, directed to the realization of the assembly profiles on the side sections outside the central pivots (according to the assembly to the cavities by means of the threaded bushing engagement): these, by means of the surface planar to the façade, fulfil the support to the fixing (by bolting) to both the central gaskets and the PVC device. This profile is intended to complete the corner, to receive the rebate from the central gaskets and to contain the thermal insulating layer (wrapped, towards the inside, by the aluminium sheet connected to the cavities related to the mullions). The internal angular interface between the closing planes observes the application of the combined mullions, for each of the two sides normal to each other, whose cavities (internal and external) lead to the insertion of the connection gaskets and the aluminium sheets. Specifically, the construction involves:

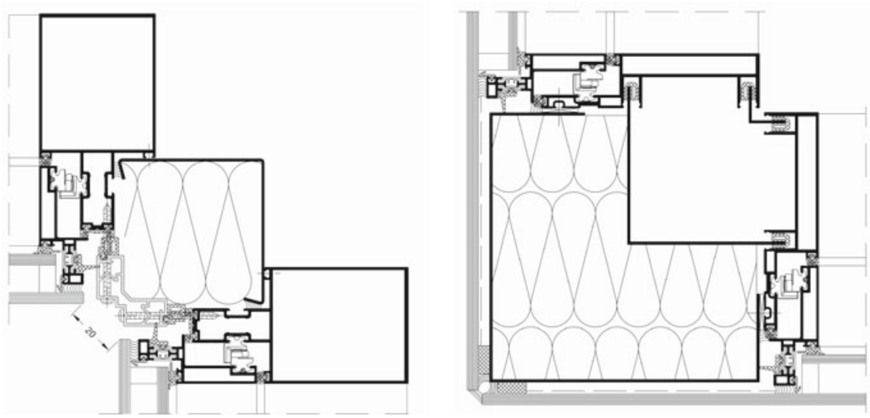

Fig. 3.23 Internal angular interface between the closing planes which observes the use of two mullions that, through the linear pins, realize the fastening to the central internal seals and the fastening to the PVC device, aimed both at the rebate of the central closing seals and at the containment of the heat-insulating layer. © Courtesy of Schüco

- the fixing of the external aluminium sheet, containing the heat-insulating layer, according to the screwing to the cavities arranged on the lateral ribs of the pins projected beyond the tubular sections;
- the assembly of the double-glazed glass panes according to the structural silicone fixing to the installation profiles (projected beyond the frame profiles, by means of the couples of polyamide bars, to which the central closing gaskets are joined in rebate on the external sheet), noting the extension of the external panes up to the silicone corner closure (Fig. 3.23).

The same corner enclosure configuration is defined according to the use of the mullion profile provided with the projection, on the external rib of the tubular section, of the two linear pins directed to accommodate the insulating insert, beyond which the capsule is applied for the connection (by screwing) of the wing extension (planar to the façade) of the glazing beads turned towards the corner (Fig. 3.24).

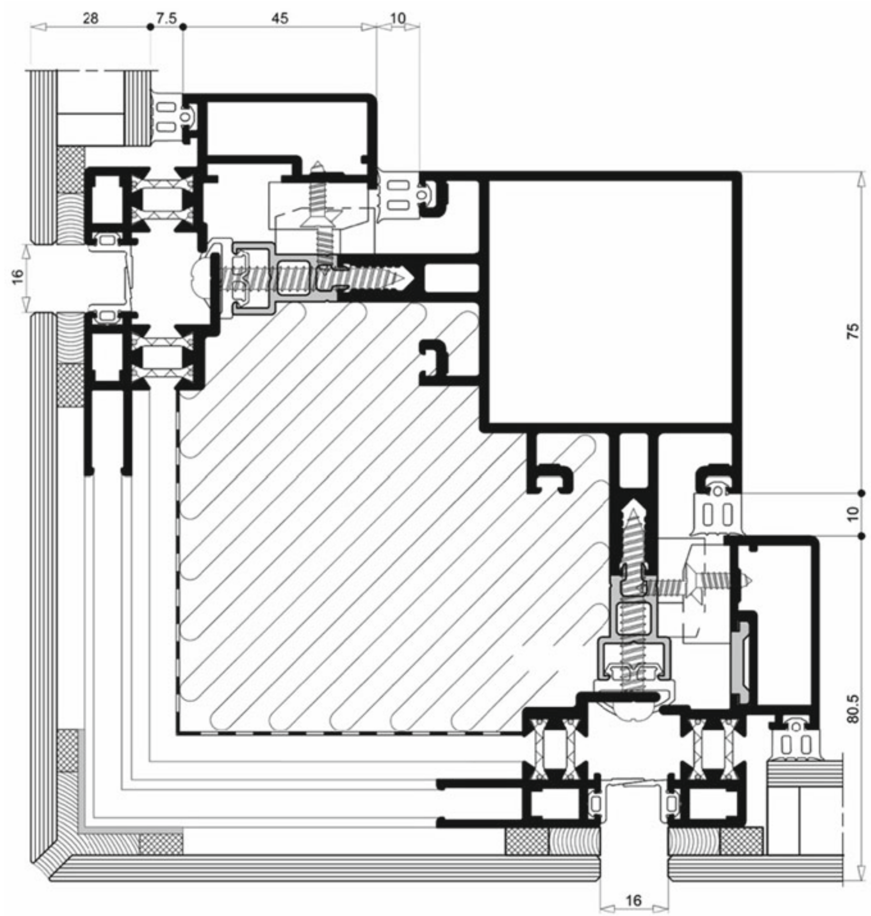

Fig. 3.24 Composition of the mullions for the corner interfaces realized by the projection of the linear pins (fitted with the insulating inserts) on the outer ribs of the tubular section, the connection of the frame profiles and the wing extension of the laying profiles, for the configuration of a frame for attachment to the closing panels. © Courtesy of Metra

Chapter 4
The Typology of the Unit Façade System

4.1 The Geometrical, Executive and Connective Configuration of the Unit Façade Framing and Joints

The curtain wall system in the cellular type (*unit system*) is determined by the load-bearing mullion and transom frame (in general, in aluminium) at bay height and complete with the closing elements. The cells are structurally independent and are connected to each other with telescopic joints (capable of allowing, after the installation, movements for the calibration on the façade plane), executed by means of vertical and horizontal profiles of such a configuration as to make the contiguity connections:

- at a vertical level, by means of "male-to-female" or "female-to-female" construction typologies (with the addition of gaskets);
- at a horizontal level, by means of the connectors equipped with continuity covers that allow water to be conveyed outwards (through the "tile" overlap created by the joining of profiles) (Fig. 4.1).

The system consists of prefabricated elements (such as structural profiles, glazing, jointing and anchoring devices), the installation of which takes place on site for the execution of single-component or predefined series of façades, involving the combined aggregation of mullions and transoms.

The constitution of the system assumes, in the profile aggregation criteria, the structural and thermo-insulated connection modes between linear composite elements (in a specular key, with a double chamber section and a couple of "U"-shaped clutches for fixing the ribbed laths). The system makes explicit the paradigms of flexibility and of executive rationality: this by observing the resolution of the grafts of the double bars (with double or triple chambers) projected towards the glazing beads, as well as the procedures for absorbing the deformations of the horizontal elevation structures (for the geometries and dimensions of the head joints equal to 10–20 mm). The system, from a structural point of view, makes it possible to accommodate the different types of movement and expansion typical of the main structures,

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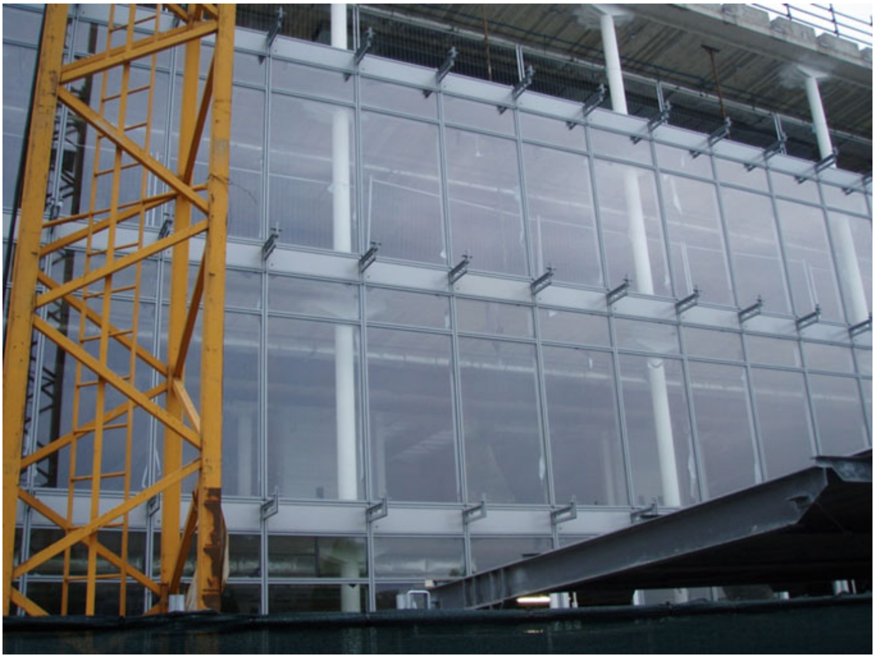

Fig. 4.1 Maurizio Varratta, *iGuzzini Lab*, Recanati. Assembly sequences of the prefabricated cellular façade components through the mechanical connections of the complete modules to the horizontal structures. © Courtesy of Pichler Projects

avoiding the transmission of vibro-acoustic stresses between adjacent spaces on the same level or on overlapping floors (Fig. 4.2).

The construction is carried out by applying the brackets (at the deck connections) to the vertical plane, on which the couples of hooks necessary for the fastening of the cells are inserted for each vertical mullion: in particular, the assembly procedures foresee the insertion of screws from the upper and lower wings of the hooks to the internal sections of the vertical profiles. In addition, the cells are provided, in the pronounced sections of the vertical profiles, with holes for the connection to the pins intended both for lifting and placing in place, and for the vertical joint to the upper panels (Fig. 4.3).

The adjoining connections also act as an air gap to balance the pressure conditions between the outside and the inside. The execution is carried out progressively from the bottom to the top of the façade (by means of a crane or winch, placed in the levels above the assembly level and positioned on rails parallel to the perimeter of horizontal structures), following the installation of the anchoring brackets (in aluminium or steel, on the halfen profiles arranged in the slabs) (Figs. 4.4, 4.5 and 4.6).

The composition of the system notes the aggregation, vertical and horizontal, of the mullions (for the lateral dimensions between 65–85 mm and for the longitudinal

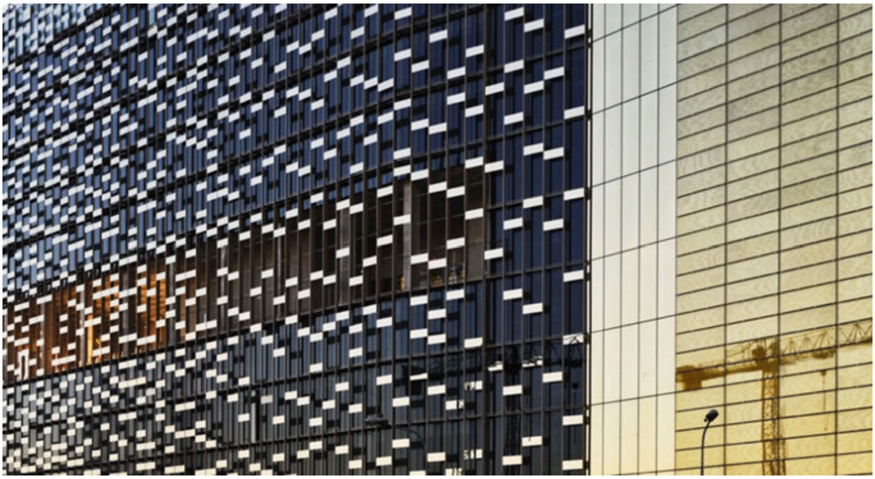

Fig. 4.2 5+1AA with Jean-Baptiste Pietri Architectes, *Fiera Milano* Office Building, Rho (Milan). Unit system developed in a homogenous form through the application of the double-glazing enclosures (equipped with the interposed metal mesh in "gold" colour) according to the geometric modulation of the horizontal elements. © Courtesy of Pichler Projects

Fig. 4.3 Massimiliano and Doriana Fuksas, *Regione Piemonte* Headquarters, Turin. Typological and functional sequence of the cellular modules, detecting the detachment with respect to the junction between the different horizontal structures. © Courtesy of Schüco

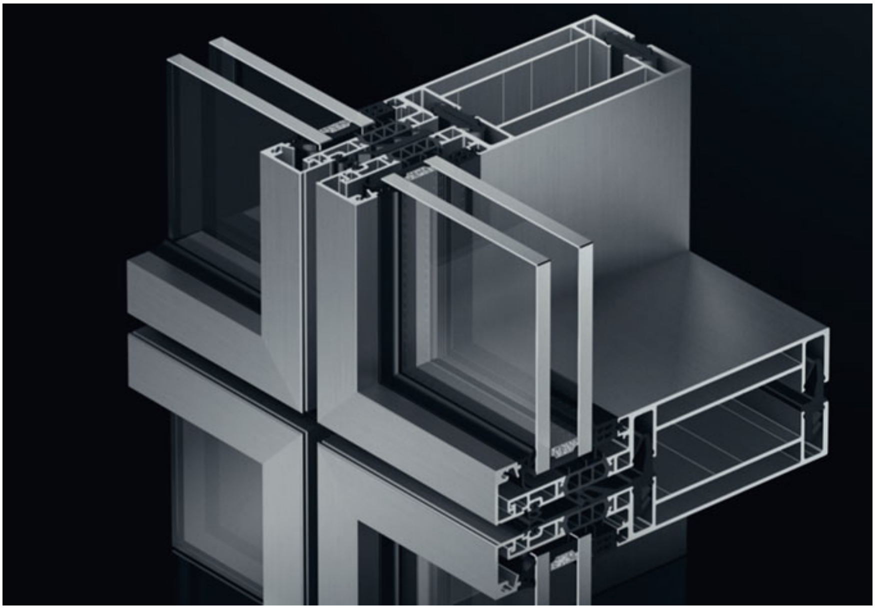

Fig. 4.4 Unit façade system defined by the constitution of prefabricated components, realized by the mullion and transom load-bearing frame, generally combined by means of "female-to-female" type interfaces of contiguity. © Courtesy of Schüco

dimensions between 125–150 mm) according to the combined and parallel assembly of the vertical gaskets (defined as coupling gaskets): these are inserted within the cavities made in the two "U"-shaped sections at the ends of the longitudinal development, beyond the tubular section (capable of containing the stainless steel stiffeners). The mullion continues the front extension by means of:

- the cavity for the internal rebated gasket on the inner surface of the double-glazing panels;
- the insulating profile with two or three chambers, projected according to the constitution of two ribbed partitions and facing the tubular section with the cavities for the central seal (rebated, on the opposite and mirrored seal, through the vertical assembly between two mullions). On the vertical surfaces, defined by the tubular section connected to the mullion, the insulating profile and the outer tubular section, the intermediate gasket with two or three sockets is applied against the opposite and specular surface;
- the connection, to the tubular section at the external end, of the mechanical retaining profile or of the glazing bead necessary for the assembly of the enclosure panels for the structural silicone joint (Fig. 4.7).

The type of executive interfaces of the mullions allows for the creation of angled and segmented surfaces with respect to the façade plane, through the slight opening (according to contained angles, on the horizontal axis of connection between the

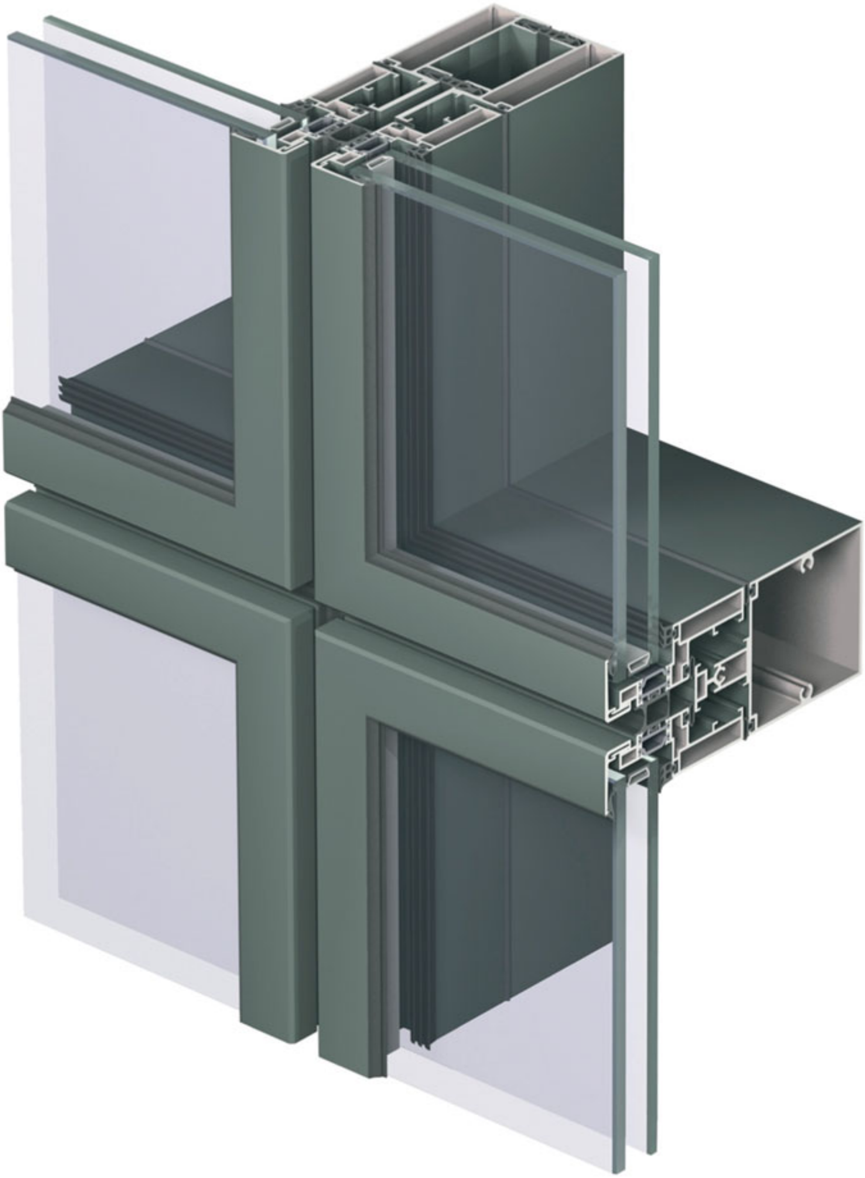

Fig. 4.5 Unit façade system that observes, specifically, the realization by means of aluminium profiles with a double tubular section, the application of the frame profiles, on the sides of the central linear partitions, the application of the thermal break fittings in polyamide bars and the application of the glazing bead profiles, according to the external mechanical retention devices of the enclosures. © Courtesy of Reynaers

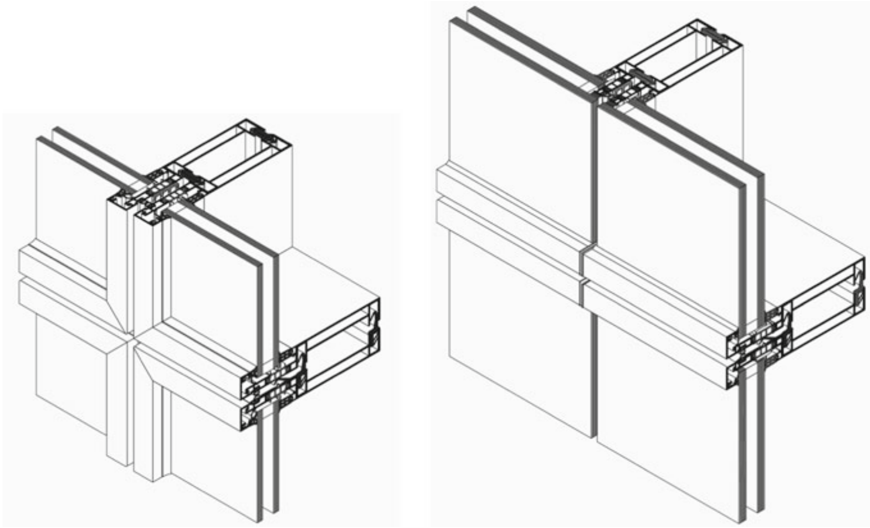

Fig. 4.6 Unit façade system, in prefabricated components, determined by the load-bearing mullion and transom frame at bay height, by the complete execution of the closing elements, the jointing and anchoring devices, by the structural and thermo-insulated aggregation criteria between linear profiles, composed in specular form, and by the assembly according to the detection of the vertical or horizontal lines of the external profiles. © Courtesy of Schüco

profiles) aimed at the continuity of action to the gaskets (internal and external) and the gripping by the central closing gaskets (Fig. 4.8).

The mullions, by means of the extension of the central rib extended in a perpendicular manner to the curtain plane, create the interface towards the frame profiles (of tubular section, connected to the mullions themselves according to the grip of the internal gasket), to which the polyamide fittings are connected: these are aimed at the junction of the laminar profiles supporting the mechanical retainers, supporting both the central closing gaskets and the *spandrel* panelling and double-glazed panels. The composition of the system, according to the aggregation of the mullions, detects the interfaces to the frame profiles, through the connection to the ribs extended perpendicular to the façade plane: the profiles are made in continuous tubular form or articulated in two sections, containing the intermediate gripping gaskets, the central closing gaskets (with double rebate) and the polyamide joints facing the surface of the external slabs (fixed by means of structural silicone). The typology of the mullions with tubular section and "U"-shaped cavity for the insertion of the vertical connective gaskets observes the combined use of extended geometries to the further tubular section and interfaces to the frame profiles: this entails, for both situations, the coupling of the polyamide fittings protruding towards the tubular profiles supporting the mechanical retainers for the *spandrel* panelling and for the double-glazed panels. The composition of the system examines the opportunity of using

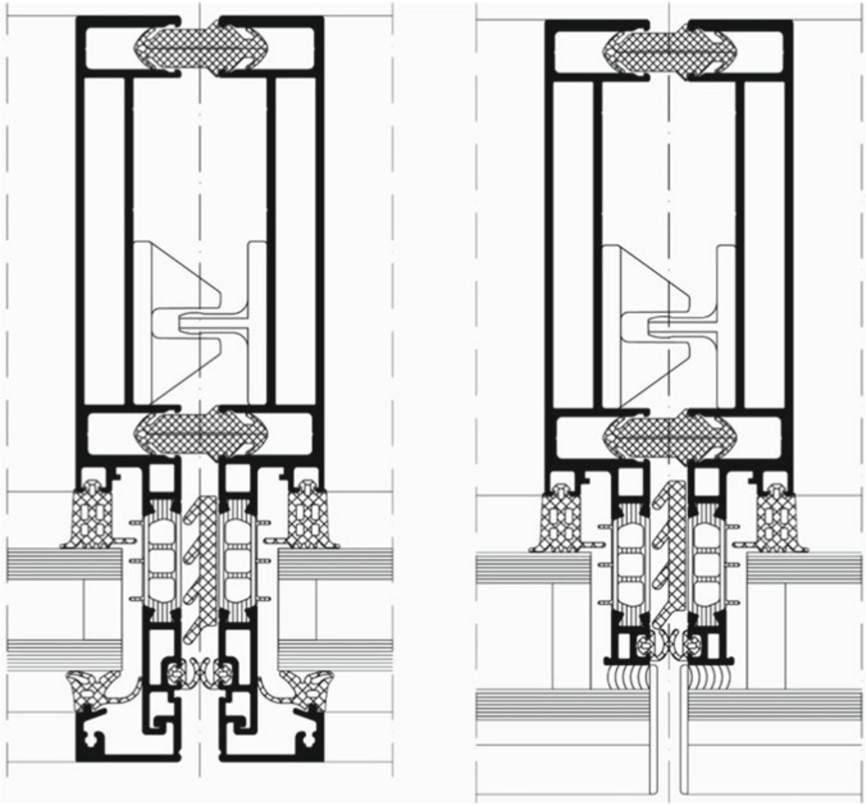

Fig. 4.7 Composition of the unit façade system that expresses the combined aggregation of the mullions, according to the "female-to-female" type assembly with the insertion of the vertical gaskets in the front and rear cavities: this is noted in the execution of the cavity for the internal gaskets, in the rebate on the double-glazed units, the polyamide insulating profiles (with two or three chambers) and the vertical intermediate gasket (with multiple grip). © Courtesy of Schüco

a traditional mullion and transom structure for the production of modular components, on the basis of the tubular section from which the central pivot (with double rib perpendicular to the curtain wall plane) is projected, facing the interface with the frame profiles (with tubular section), involving:

- the connection (by means of the polyamide thermal break joint) with the retaining profiles to the *spandrel* panels and the double-glazing enclosures;
- the application of the mirrored couple of central closing gaskets, integrated into the cavities provided on the mechanical retaining profiles (Fig. 4.9).

The typological set-up of the system based on the use of traditional element framing examines the geometrical and relational constitution of the frame profiles which, aggregated with respect to the mullion, are articulated according to a further tubular section from which the couple of polyamide ribs is projected, aimed at:

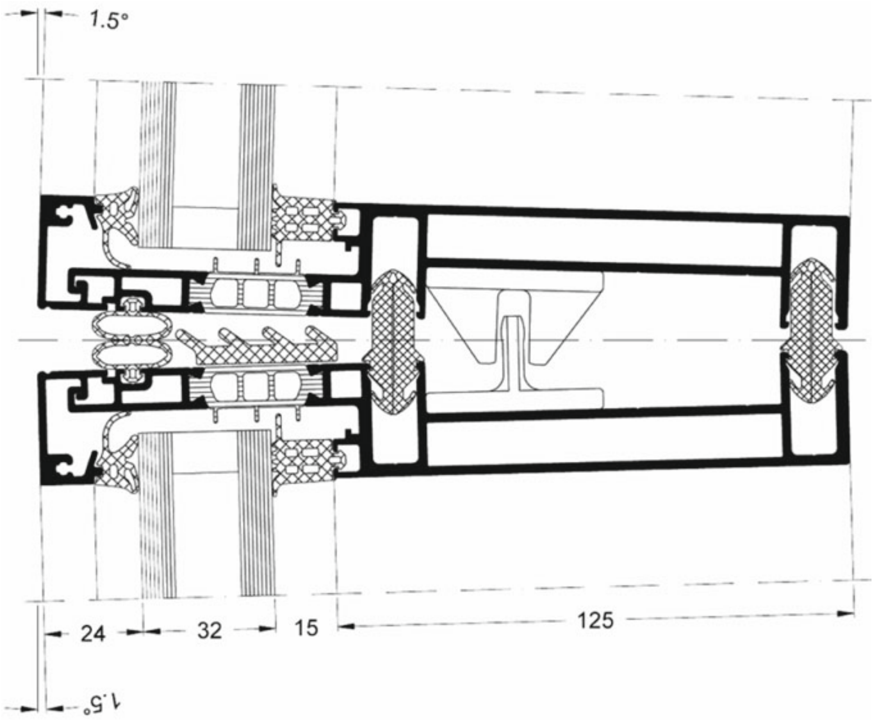

Fig. 4.8 Application of the cellular components in relation to the installation profiles, which are defined by the cavity spaces for the central closing gaskets, the glazing bead profiles and the structural silicone joint on the outer sheets: this is achieved by creating angled surfaces on the façade plane, through the opening contained on the connection between the profiles and the rebate of the central closing gaskets. © Courtesy of Schüco

- the connection to the external tubular profile, from which the mechanical retention extends to the *spandrel* panelling and the double-glazed panels;
- the inclusion of the cavity for the central sealing gaskets (Fig. 4.10). The application of the frame profiles with respect to the mullion is determined according to a tubular geometry extended from the internal gaskets to the external gaskets, pronouncing towards the central interface: this is to accommodate (in the case of *spandrel* panelling and double-glazed panes, with structural silicone fixing), within the linear cavities, the central gaskets with double rebate and extended up to the grip towards the central pin protruding from the mullion itself.

On the basis of the mechanical, executive and morphological requirements of the system, the application of the intermediate mullions is determined according to:

- the cavities for the internal gaskets on the internal surface of the insulating glass panes, or for the insulating inserts intended to contain the cavities for the gripping gaskets on the glass panes on the outside of the *spandrel* panels;

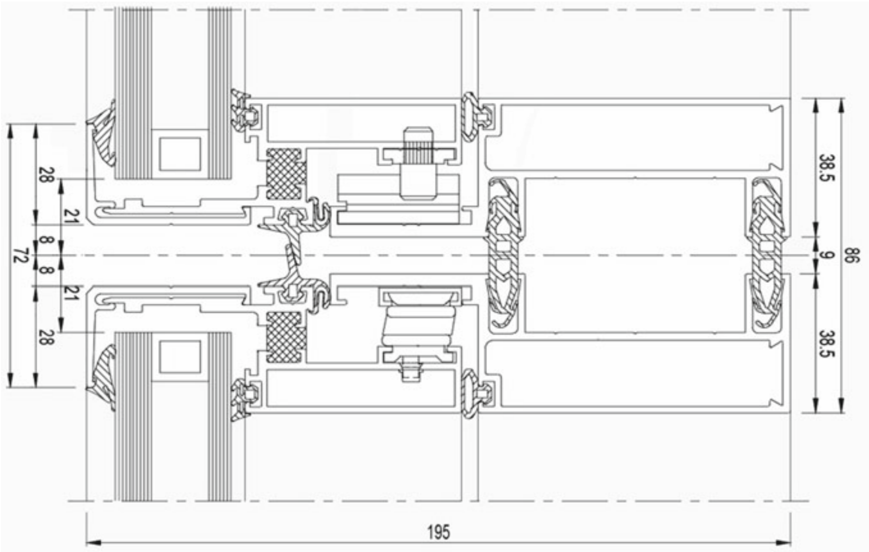

Fig. 4.9 Composition of the unit system that expresses the typological articulation according to the extension of the linear partitions perpendicular to the façade plane, the polyamide thermal break fittings and the glazing bead profiles, with external gaskets, in rebate on the double-glazed units. © Courtesy of Reynaers

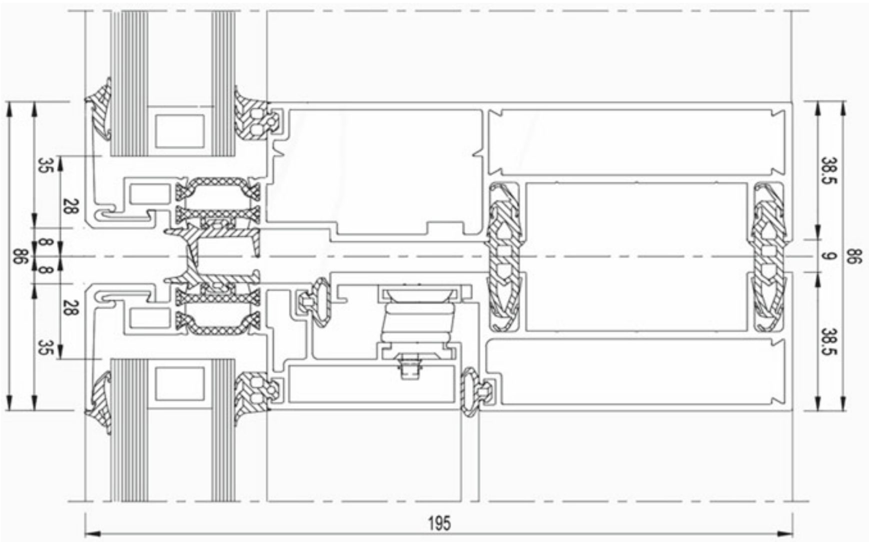

Fig. 4.10 Typological arrangement of the system that examines the geometrical and relational constitution of the frame profiles which are articulated according to the application of the polyamide bar fittings, the application of the glazing bead profiles, with external gaskets, in rebate on the double-glazed units. © Courtesy of Reynaers

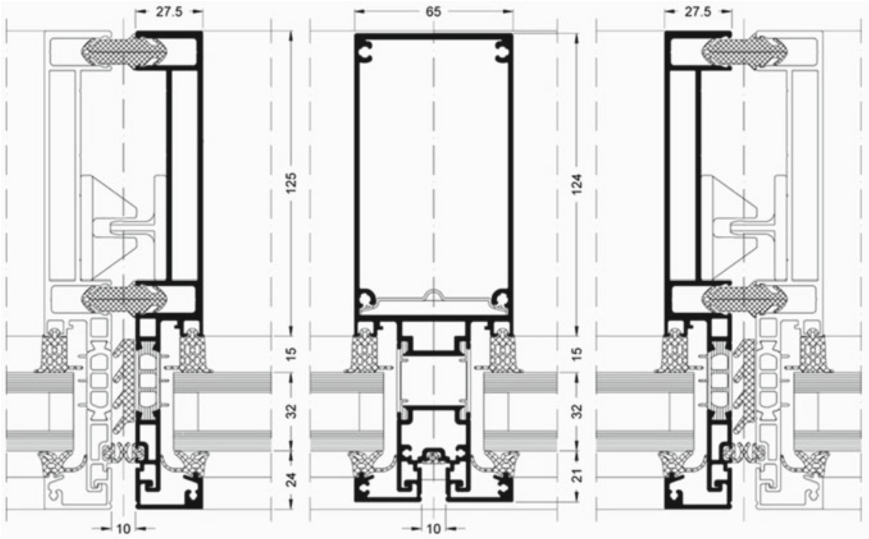

Fig. 4.11 Application of the intermediate mullions based on the mechanical, executive and morphological requirements of the system, with respect to the main frame, according to the quadrangular tubular section, equipped with homogenous ribs, and the central pivot with thermal break, with polyamide bar connections. © Courtesy of Schüco

- the extension of the two central ribs, extending up to the specular cavities intended to contain the mechanical retaining profiles or glazing beads (Fig. 4.11).

4.2 The Functional, Constructive and Applicative Coordination Procedures of the Mullions and Transoms Framing

The unit façade system consider the corner connection that involves the use of the mullion with a homogenous and concentrated tubular section to determine:

- at the front, the cusp from which branch off the cavities for the internal gaskets and the central threaded pin, which is necessary for the fastening (according to the pressure procedure) of the glazing beads. The same pressure offers two ribs for the insertion of the segmented cover so as to complete the external edge in a perpendicular form with respect to the facade planes;
- at the rear, the perpendicular cut (with stiffening ribs) facing to complete the inner edge in perpendicular form with respect to the façade planes (Fig. 4.12).

The corner solution, in the case of the system variant defined by the structural application of the double-glazing, provides for the installation of the perpendicular

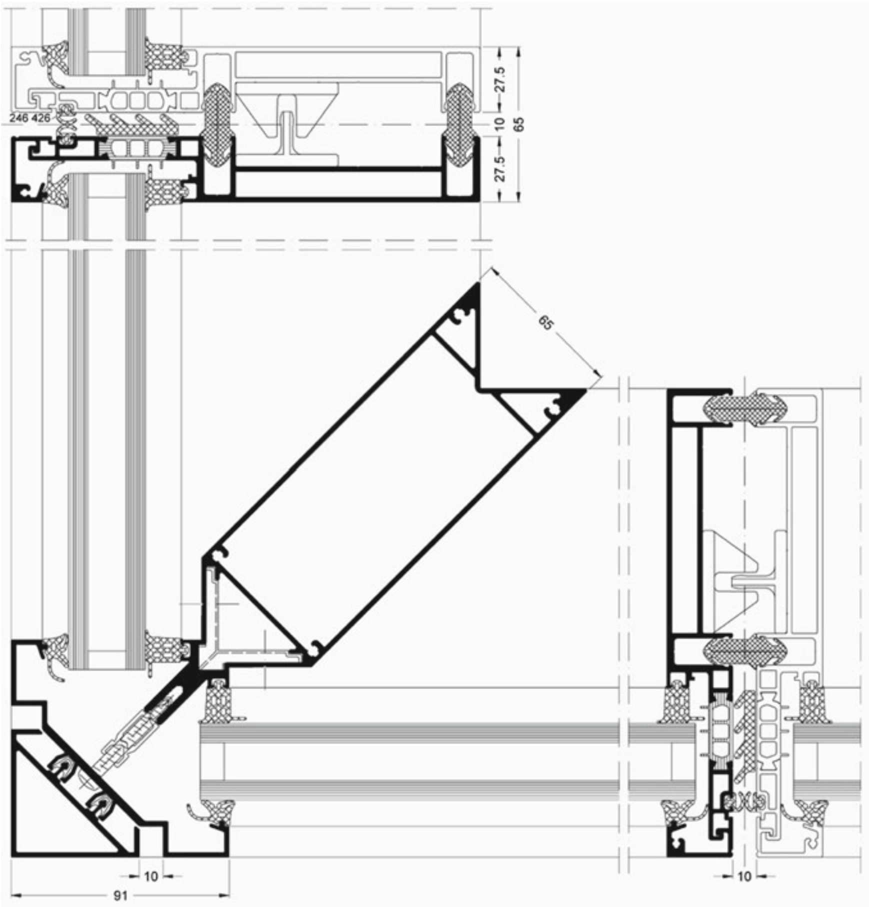

Fig. 4.12 Assembly of the corner interfaces that involves the use of the mullion with a homogenous tubular section, in order to make the central pivot for the fixing of the glazing units by means of the pressure device, the cavities for the internal gaskets and the insertion of the segmented cover, for the perpendicular connection of the façade planes. © Courtesy of Schüco

panes even without the interposition of the corner mullion, involving fixing by means of the double structural silicone joint (Fig. 4.13).

The composition of the system observes the geometries and sections of the transoms, similar to the configuration of the mullions: the tubular section (capable of containing the stainless steel stiffeners) is equipped, at the ends, with the cavities made in the two "U"-shaped sections for the insertion of the gaskets, characterized by the transversal shape aimed at performing the complete seal following assembly. The transom continues the front extension by means of:

- the cavity for the internal seal against the surface of the double-glazing panels;

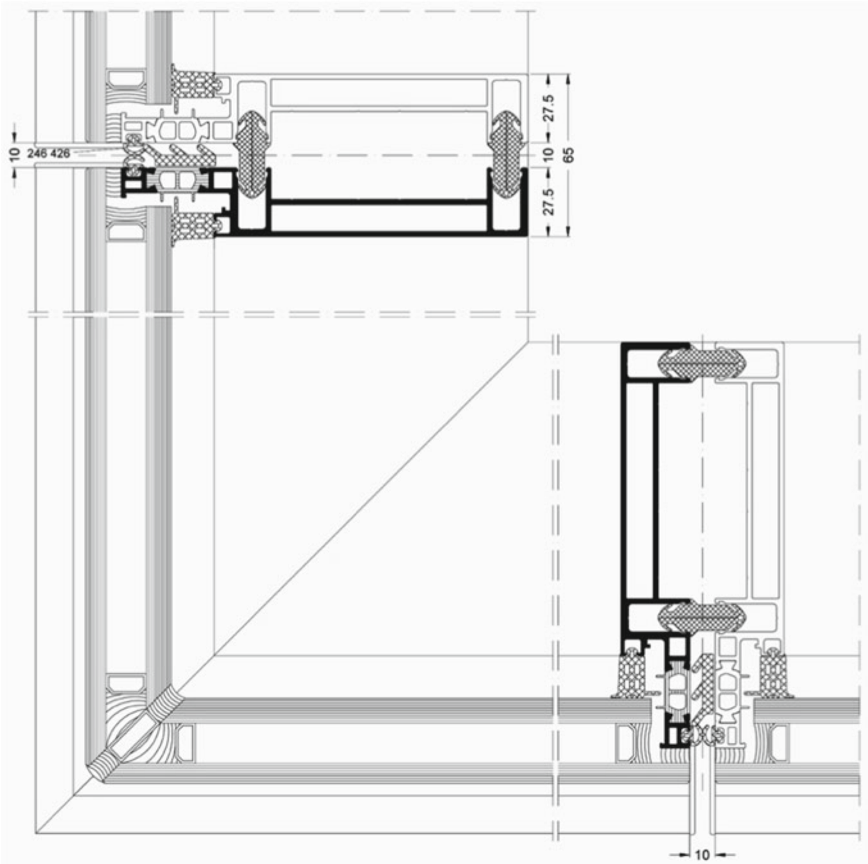

Fig. 4.13 Assembly of the corner interfaces (observing the "female-to-female" coupling combination), in the case of the structural application of double-glazed units, that involves the execution of the transoms, parallel to the façade planes, and the procedures for fixing the panes by means of the double structural silicone joint. © Courtesy of Schüco

- the insulating profile with two or three chambers, projected according to the constitution of two ribbed partitions, and facing the tubular section with the cavities for the central seal (in rebate, on the opposite and specular seal, through the horizontal assembly between transoms). On the horizontal surfaces (referring to the upper transom), defined by the tubular section connected to the transom, the insulating profile and the outer tubular section, the extension of the front gasket is noted, according to the bulge offered for the connection towards the opposite and specular surface (referring to the lower transom of the upper cell);
- the connection, to the tubular section at the outer end, of the mechanical retaining profile or of the glazing bead (for the structural silicone joint) necessary for the assembly of the enclosure panels (Fig. 4.14).

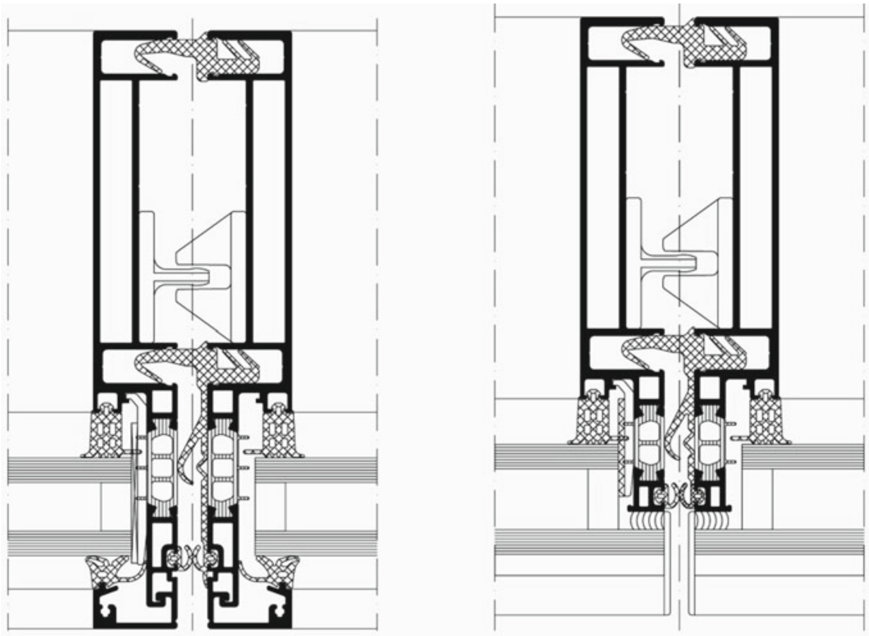

Fig. 4.14 Composition of the system that assumes the horizontal load-bearing apparatus through the combined aggregation of the transoms, according to the "female-to-female" type assembly with the insertion of the horizontal gaskets in the front and rear cavities: this takes on the interposition of the stainless steel stiffening profiles in the connection section, the housing slots for the internal gaskets, in rebate on the double-glazing sheets, and the polyamide insulating profiles, with two or three chambers. © Courtesy of Schüco

The configuration of the transoms is expressed according to:

- the intermediate type, with a traditional tubular profile and a central pivot (with double rib, extended to receive the rebate from the intermediate gaskets), to which the frame profiles are interfaced (according to the internal gasket socket): these are connected, according to the polyamide fittings, to the laminar profiles (perpendicular to the façade plane) to support the mechanical retainers;
- the tubular type equipped, at the ends, with the cavities made in the two "U"-shaped sections for the insertion of the horizontal gaskets, and, at the front level, with the ribs perpendicular to the façade plane turned to receive the rebate from the intermediate gaskets (as part of the central closing gaskets, inserted in the profiles of the mechanical retainers). The transoms, according to the geometry and general dimensions of the façade components, may provide, in the lower arrangement of the frame, for the use of tubular profiles (capable of containing the stainless steel stiffeners) shaped to increase the mechanical capacity: these profiles are defined by the increase in height in the tubular section, in compliance with the geometric and connective coordination with the basic typology of the transoms.

The assembly between the mullions and transoms, in production, takes place by means of the angle brackets inserted and assembled (by screwing) to the tubular sections, cut at the ends in diagonal form to determine the perpendicular connection at the corners of the frame (Fig. 4.15).

The assembly between the cells involves the geometric and functional overlapping of the vertical seals and the horizontal seals (internal and external): in particular, these are applied continuously and homogeneously above the upper transoms for several cells during the construction phases (Fig. 4.16). According to the morphological,

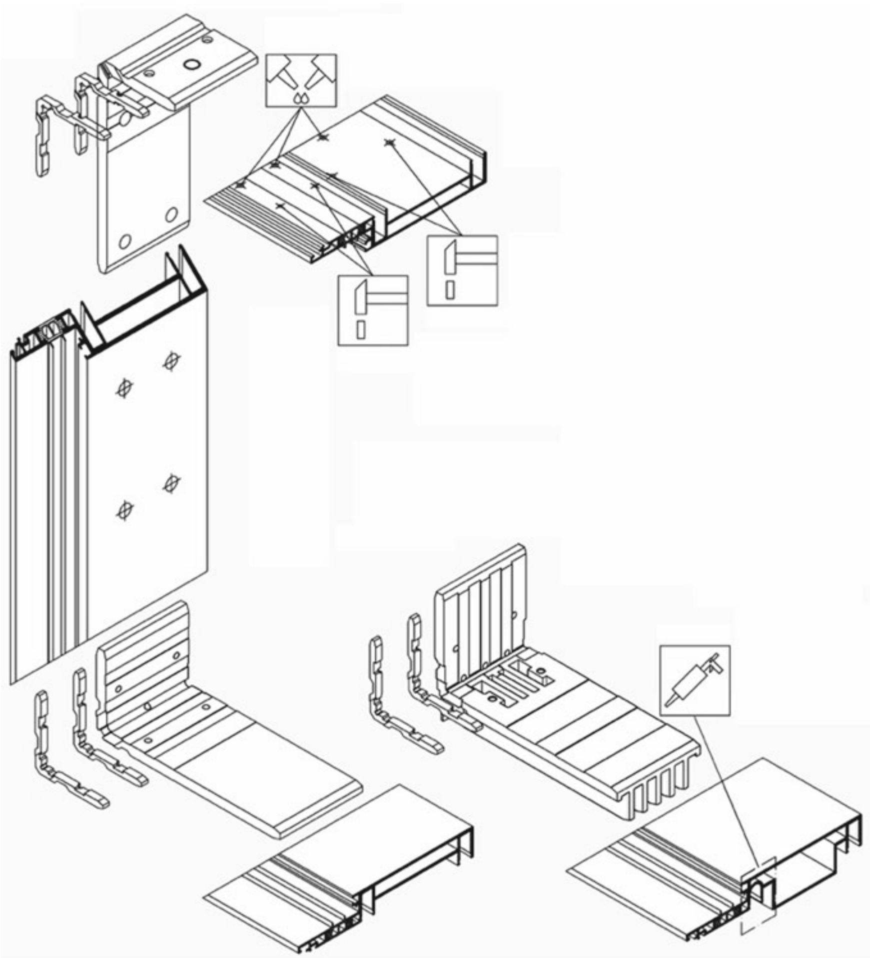

Fig. 4.15 Production phase of the cellular components that considers the assembly between the mullions and transoms, by means of diagonal cutting for the angular connection and the insertion of the brackets, within the tubular sections: this takes over the practices aimed at providing the coordination and geometric, dimensional and connective continuity of the frames in order to comply with the mechanical, sealing and construction requirements. © Courtesy of Schüco

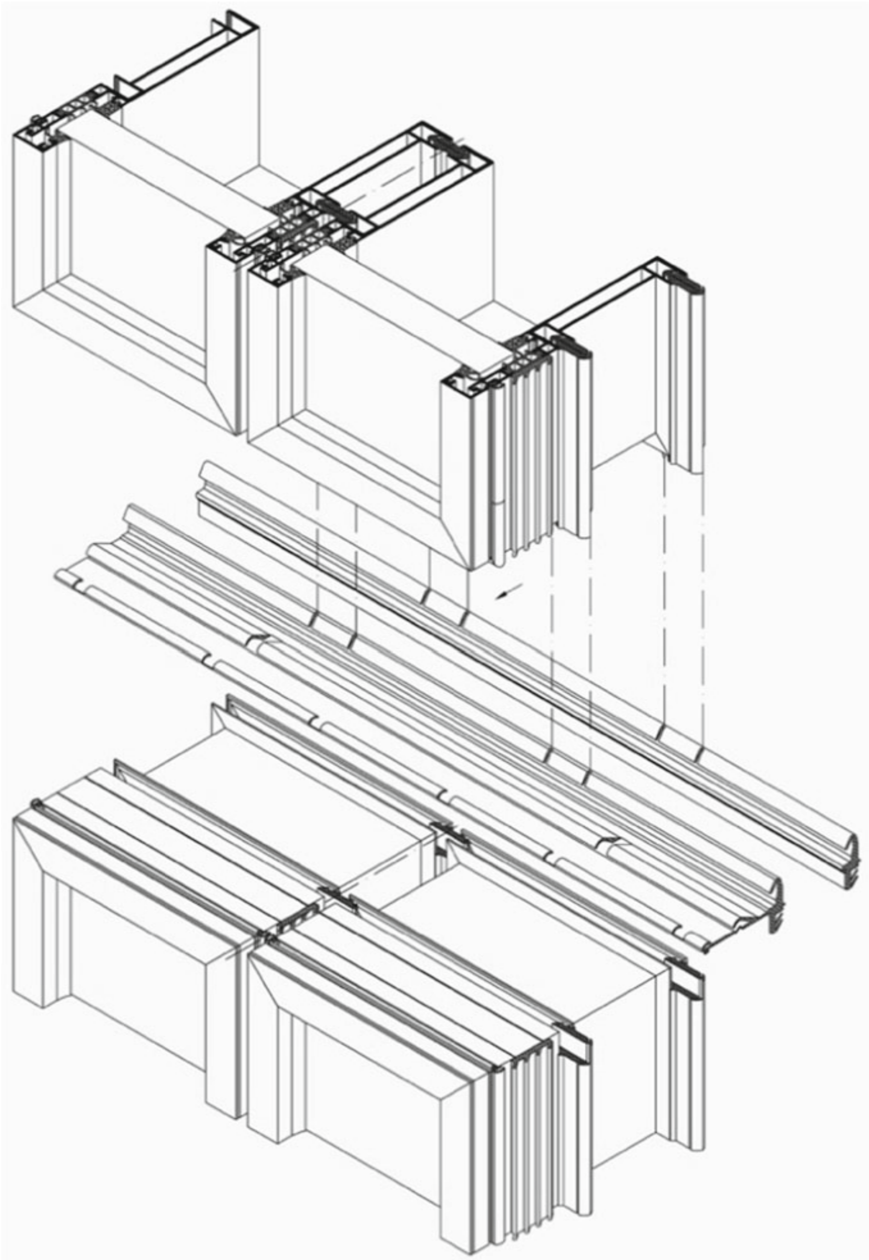

Fig. 4.16 Assembly on site between the cells that involves the homogenous application of the horizontal gaskets, above the transoms related to the assembled components, the combined aggregation of the mullions, according to the "female-to-female" type connection with the vertical gaskets inserted in the front and rear cavities, and the fixing between the vertical gaskets and the horizontal gaskets. © Courtesy of Schüco

mechanical and executive requirements of the system, the application of the intermediate transoms is determined. These, defined by the main tubular section, are configured through:

- the cavities for the internal gaskets on the surface of the insulating glass panes, or for the insulating inserts aimed at containing the cavities for the gripping gaskets on the glass panes on the outside of the spandrel panels (involving the same inclusion for the upper transom of the cellular component);
- the extension of the two parallel central ribs (with intermediate stiffeners, provided with the necessary ribs for the interposition of the insulating inserts), extending up to the specular cavities intended to contain the glazing beads.

The intermediate transoms provide support to the insulating parts, enclosed by the aluminium claddings, of the spandrel panels by means of the support and the upper connection to the tubular section, also requiring fastening (by screwing) at the interface of the rear "U"-shaped cavity relative to the upper transom (Fig. 4.17).

The arrangement of the transom, within the unitary composition of the system, realizes the interface to the frame profiles according to the grip made by:

- the internal gaskets, applied in the slots exposed on the front rib of the tubular section;
- the external gaskets, applied in the cavities included by the tubular section aggregated to the frame profiles themselves. From this are projected the double couples of polyamide bars for connection to the profiles aimed at the aggregation of the mechanical retaining elements to the *spandrel* panels and the double-glazing enclosures. This is done by noting the arrangement of the support dowel to the upper panes above the polyamide bars and the tubular profile (Fig. 4.18).

The system considers the insertion of the opening frames according to the connection of the rebate frame profiles (with articulated tubular section) to the side and intermediate mullions of the cells. This is achieved through:

- the connection (by screwing) to the tubular sections, in contiguity between the ribs perpendicular to the façade plane;
- the connection of the cavity (pronounced on the outside of the rebate profiles) to the "Z"-shaped profile, with interposed chambers, aggregated to the mullions according to the assembly in the geometric and dimensional space established by the double-glazing enclosures.

In this respect, the connection of the opening frame, on the rebate frame, detects:

- the projection of the internal and external sealing gaskets, this extended from the glazing bead profile to the enclosure on the "Z"-shaped profile device;
- the manner in which the double-glazed units are assembled according to the attachment of structural silicone to the glazing beads (Figs. 4.19 and 4.20).

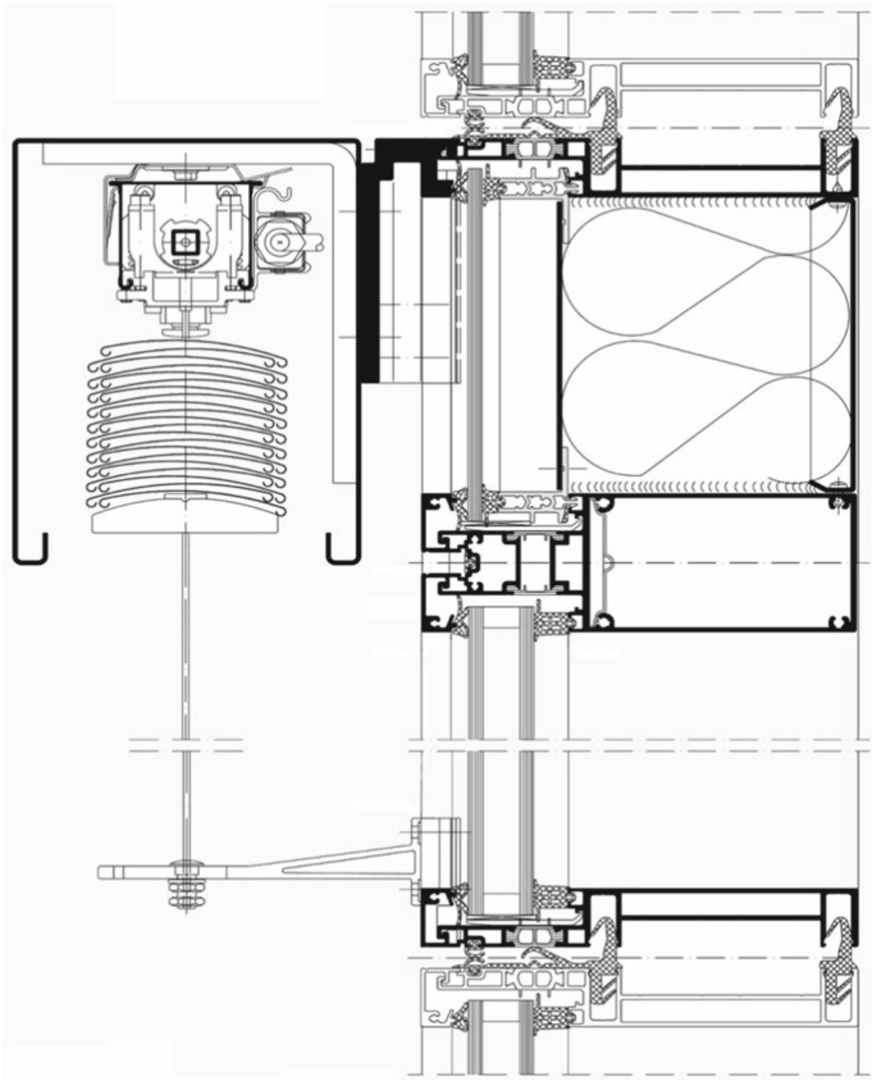

Fig. 4.17 Assembly of the intermediate transoms delineated on the basis of the mechanical, executive and morphological requirements of the system, according to the quadrangular tubular section, equipped with homogeneous ribs, the cavities for the internal gaskets, rebated on the double-glazing panes, the front joint to the PVC connection insert and the central thermal break pin, with the polyamide bar connections. © Courtesy of Schüco

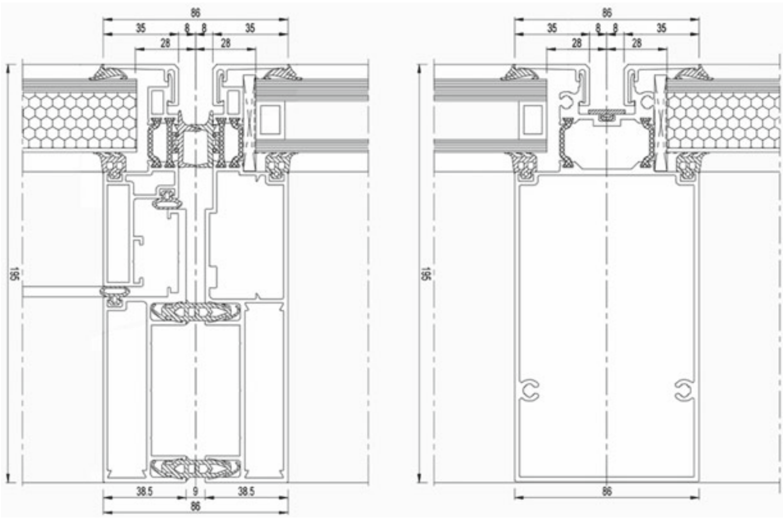

Fig. 4.18 Configuration of the transoms articulated according to the structural and executive coordination between the combined typology, related to the application of the frame profiles, the extension of the tubular section, the polyamide bar connectors and the application of the glazing bead profiles: this takes over the construction criteria of the intermediate typology, according to the polyamide bar connectors and the glazing bead profiles. © Courtesy of Reynaers

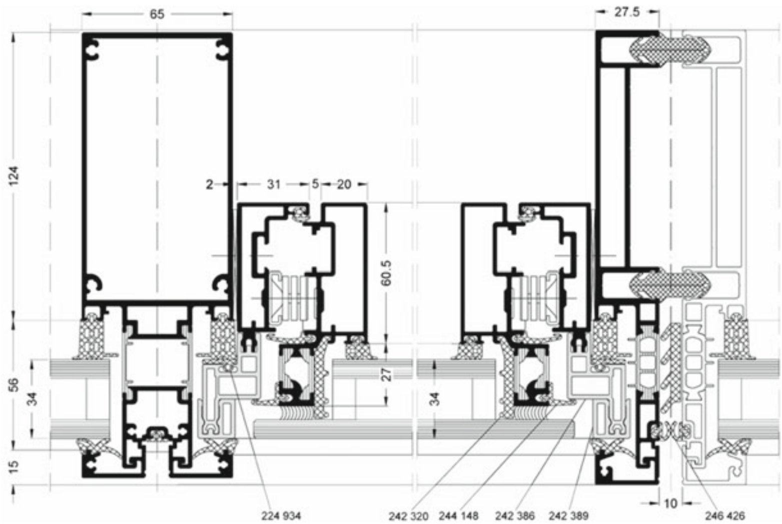

Fig. 4.19 Unit façade system that considers the insertion of the opening frames through the assembly of the rebate frame to the side and intermediate mullions and the external PVC "Z"-shaped connection device to the side and intermediate mullions, in the geometric space established by the double-glazed units: this is achieved by taking over the connection of the opening frame, by projecting the gaskets from the installation profiles and the assembly of the double-glazed units to the installation profiles, according to the fixing with structural silicone. © Courtesy of Schüco

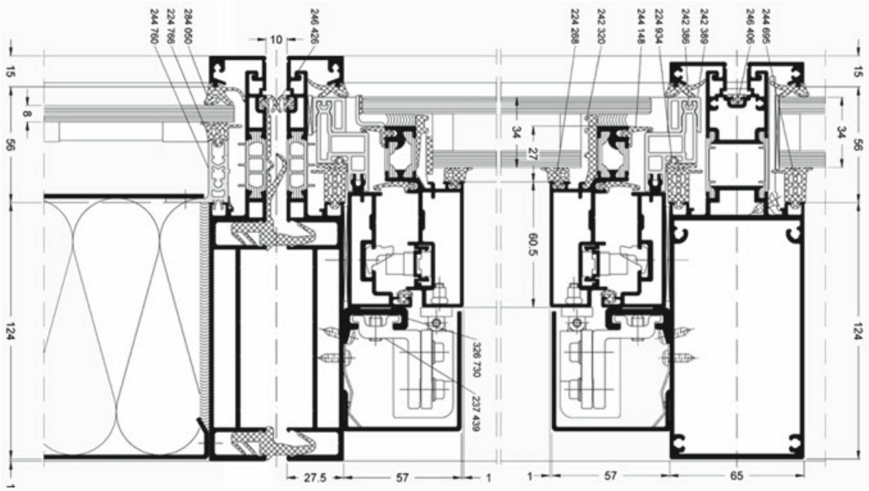

Fig. 4.20 Application of the openable frames that observes the executive interfaces at the extrados and intrados of the frame and intermediate transoms of the cellular components, according to the connection of the rebate frame to the tubular sections and the engagement of the support devices to the sash profiles, in the casings fixed to the tubular sections of the transoms: this is by noting the assembly of the “Z”-shaped PVC external connection device to the side and intermediate mullions, in the geometric space established by the double-glazed frames. © Courtesy of Schüco

Chapter 5
The Typology of the Suspended Façade System

5.1 The Geometrical, Executive and Connective Configuration of the Suspended Façade Framing and Joints

The suspended façade system (or *structural glass façade*, *suspended curtain wall* or *point fixed curtain wall*) is determined by the use of glass enclosures (composed in vertical groups) by means of point fixing devices, with mechanical support: these in turn are connected to steel cable frames anchored to the main load-bearing structure of the architectural organism (or to a steel frame, usually tubular).

The application of the glass enclosures for the suspended façade system is done by means of the mechanically supported fixing devices jointed at the corners of four converging panes: these devices, composed of bolts or *rotulles*, punctually “suspend” the glass panes and transmit the stresses (such as their own weight, wind loads, expansion and differential movements) to the steel cable frames (anchored to the main load-bearing structure or to a steel frame structure). Again, these devices are capable of absorbing the torsion and bending stresses transmitted by structural movements: in particular, they are equipped with a sphere that rotates inside the sheets, through semi-spherical teflon-coated soft aluminium cavities, and they have joints capable of absorbing any movements of the cables.

This type of façade allows the configuration of completely transparent surfaces, with no visible profiles, providing for the distribution of the loads of the closing modules: the application of the fixing devices takes place against the holes placed on the glass modules or through the use of elements that allow the sheets (of various thicknesses) to be inserted inside them (in this case avoiding the use of the *rotulles*).

The glass panels are assembled by means of *rotulles* (countersunk or overhead), which are articulated to allow for expansion and free movement, involving:

- the insertion into the perforations and locking by means of the threaded ring nut: contact with the glass surfaces is not direct, providing for insulation by means of nylon or aluminium bushings and/or washers;

I. Paoletti and M. Nastri, *Executive Design of the Façade Systems*,
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- the insertion of aluminium bushings between the two panes into the holes of the double-glazing sheets: millings are made on the bushings (at the glass surfaces), insulated with a layer of butyl or silicone;
- the fixing of the *rotulles* in the glass panes, which are then mounted on the main supporting structure in relation to the arrangement of the crosses: specifically, the operation is carried out by inserting the *rotulles* in the appropriate cavities and fixing them with bolts.

The panes are perforated on both faces at the four vertices, observing that:

- in the case of single panes, the holes may be smooth or threaded, in order to receive the fixing points in the form of bolts (formed by a flat stainless steel cylinder, raised in relation to the façade plane) or in the form of *rotulles* (with a conical head, inserted inside the countersink of the holes);
- in the case of double-glazing sheets, the holes in the outer pane have a countersink capable of accommodating the heads of the threaded screws, which are tightened by means of adjustable bolts: in this case, the integrity of the thermal and acoustic insulation is ensured by the use of appropriately sealed coaxial circular crown spacers (Fig. 5.1).

The execution of the structural glass façade system involves:

- the suspension of the glass panes at the two upper fixing points, with the task of supporting their own weight, and at the lower fixing points, with the task of absorbing the differentiated movements in the façade plane due to the movements of the supporting structure;
- the suspension of the glass panes in a stress-free manner, by means of oscillating bearings;
- the use of *rotulles* by means of the four-point "rocker" fixing procedure (*spring plate* or *spider*), with direct connection to the mullions or to the cable frame;
- the construction of the adjoining joints between the glass panes by means of extruded and silicone sealants (cohesive and non-adhesive, without the use of structural sealants), sealed against atmospheric agents and with the task of both absorbing differential expansion and the movements of the supporting structure.

The application of the glass enclosure elements for the façade system with point fixing takes place (in the corner areas at the perimeter) on metal supports (in general, steel), which are in turn connected to the main supporting structure or to a steel frame structure, with or without perforation. The assembly of sheets with perforations is solved by means of connections intended to prevent:

- the interlocking between the load-bearing structure and the sheets, so that the latter can follow their natural bending line;
- contact between the supporting structure and the sheets, through the interposition of intermediate layers.

Assembly of the sheets without perforation is solved through connections:

Fig. 5.1 Type of external enclosure composed of tubular profiles supporting steel crosses: these connect the steel *rotulles* (consisting of a cylindrical body, inserted into the flared hole in the glass, a threaded spherical-headed axle, a polyethylene washer and a steel washer) for fixing the sheets according to a variety of expressive and executive possibilities. © Courtesy of Faraone Sistemi

- without interlocking works, involving the sheets being supported by dowels on steel pins (acting as brackets), welded to the supporting structure;
- with pressure closure by means of plates (with screws passing through the threaded pins) (Figs. 5.2 and 5.3).

The design of the structural glass façade system considers:

- the physical and structural characteristics of glass, which does not allow plastic deformations, so the use of tempered panels is determined in order to increase the resistance characteristics and to correct the states of tension generated during cooling: the glass is heated to 500–700 °C and then cooled rapidly (by blowing on the two surfaces), allowing the inner layers (resulting in tension) to contract slowly and, therefore, to compress the outer layers that have already hardened (resulting in compression). Through the tempering process, tensile strength values increase

Fig. 5.2 Nicholas Grimshaw and Partners, *The Western Morning News*, Plymouth (Great Britain). Type of external vertical enclosure composed of the structural apparatus in hollow steel profiles, supporting the brackets (in cast ductile iron) at the ends of which are assembled both the vertical tie rods and the crosses integrated by the articulated bolts for fixing the glazed sheets. © Courtesy of Nicholas Grimshaw and Partners

from 400 kg/cm^2 to 2000–3000 kg/cm^2, reaching a strength value that makes suspended application possible;

- the application of the tempered glass panes in modules hanging from each other (capable of resisting tensile stress), as a whole suspended from a main linear structure (in the form of a continuous, perimeter-type truss), to which the vertical loads are transferred. This is observed by sealing with silicone gasket on the inside and with structural silicone on the outside;
- the transfer of horizontal stresses to the bracing structure, according to the transfer of loads through:
  - the fixing devices, designed to support both the weight of the sheets (as a vertical load) and the horizontal loads in the direction perpendicular to the façade plane;
  - the articulation of the horizontal connecting rods;

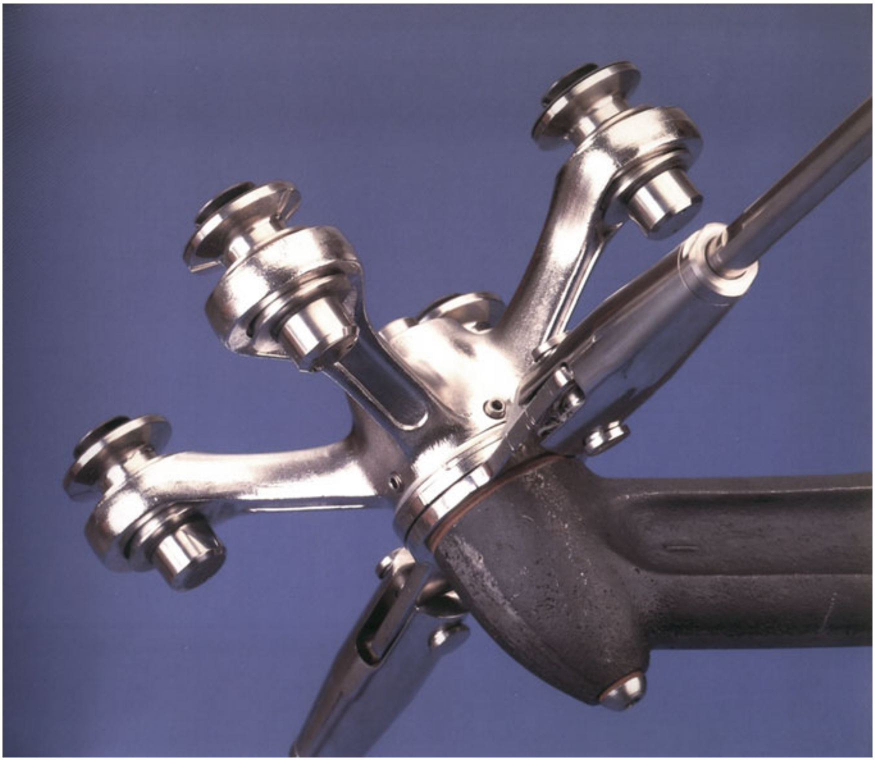

Fig. 5.3 Nicholas Grimshaw and Partners, *The Western Morning News*, Plymouth (Great Britain). Point fixing device with four-way *rotulles*, articulated in relation to the central pivot supported by the brackets, with steel cable reinforcement. © Courtesy of Nicholas Grimshaw and Partners

- the drilling of the glass modules at the four corners, within which the insertion of the fixing devices (configured as "star" blocks) capable of connecting four distinct sheets and defined, at the point of contact, by an articulated bolt: this is realized by a spherical hinge capable of rotating within the head of the bolt allowing differential movement between the façade plane and the structure. The drilling of the sheets involves a procedure to avoid fraying, which would result in an uneven distribution of stresses and encourage the formation and progression of micro-fractures (Fig. 5.4).

The composition of the system is constituted according to:

- the upper main load-bearing structure, which must support the vertical loads due to the suspended modules and aggregate devices, in addition to the tension related to the stabilizing cables of the trusses themselves;
- the action of the horizontal loads, for which the stresses directed perpendicularly to the façade plane determine, towards the modules, the bending loads both in the vertical plane and in the horizontal plane: the operation of the spherical hinge

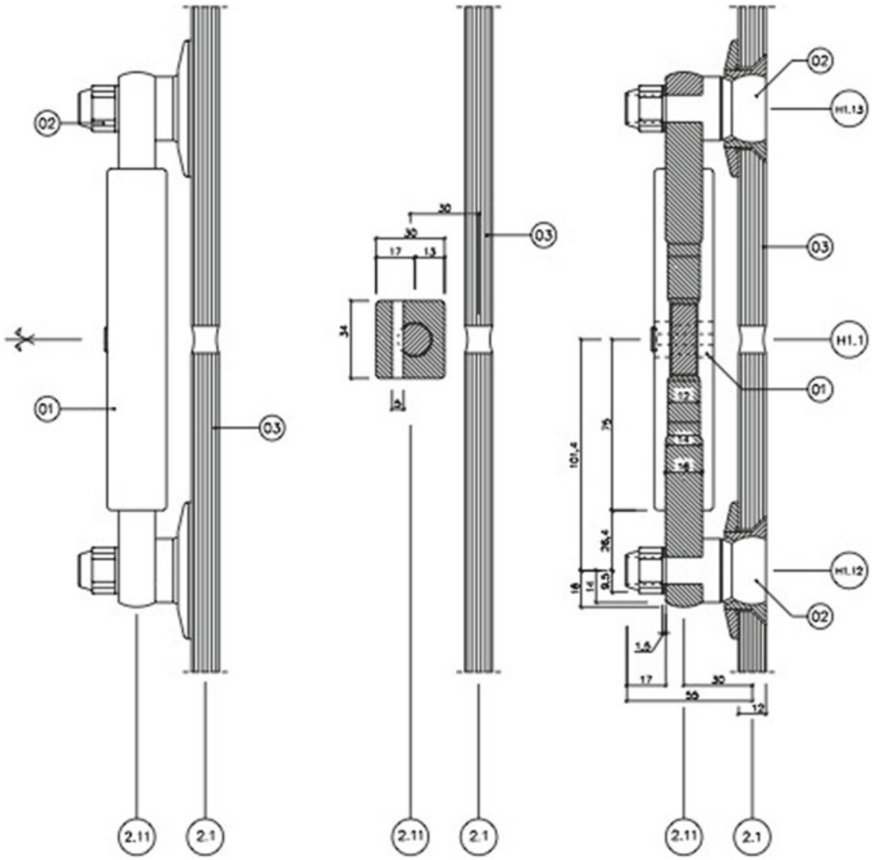

Fig. 5.4 Productive design of point fixing devices with respect to the junction of perforated and adjoining glass panes: sections and connections of the support brackets to the *rotulles* inserted in the sheets. © Courtesy of Andrea Giuradei and Andrea Costa

of the fixing devices makes it possible for the modules to move and rotate out of their plane;

- the action of the lateral loads, whereby the stresses directed laterally to the façade plane result, through the operation of the spherical hinge of the fixing points, in the mobility of the modules in their own plane, rotating around the axis of the bolt (Figs. 5.5 and 5.6).

The composition of the articulated bolt, i.e. the fixing block, is constituted according to:

- the first design formulation, through an "H" configuration, characterized by the articulation of the horizontal bracket with respect to the vertical brackets due to the presence of two hinges: in this way, the glass panes can slide with respect to

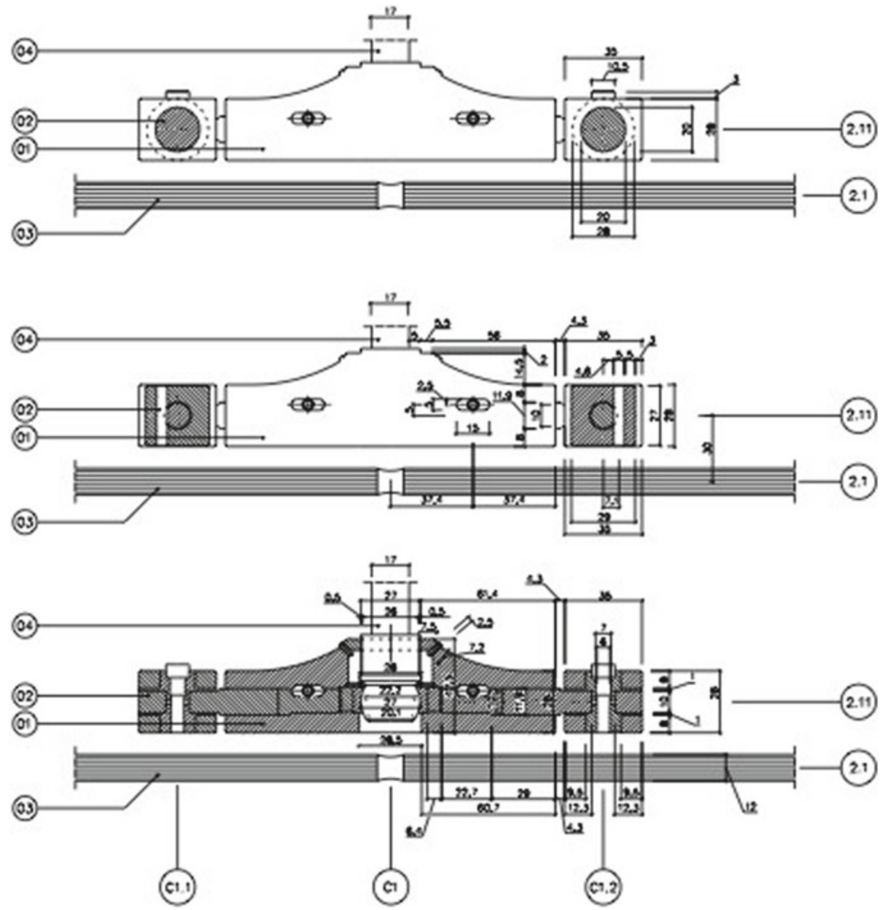

Fig. 5.5 Productive design of point fixing devices with respect to the junction of perforated and adjoining glass panes: connections of the steel cables and of the reinforcement brackets around the *rotulles* inserted in the sheets. © Courtesy of Andrea Giuradei and Andrea Costa

each other, both vertically and horizontally with respect to the direction of the loads;

- the subsequent design formulation, by means of a "X" configuration (following the analysis whereby the loads are not such as to determine the need for movements of this magnitude with respect to the arrangement of the modules), articulated only in the bolt and hinge connecting with the connecting rod directed to the bracing structure. In this regard, it is specified:
  - the assembly, with respect to the central hole of the "star" block, of the spherical head with through thread for the connecting rod connection;
  - the constitution of the point joint according to the passage of the bolt shank tautened by the screwing of the spherical head, directed to the insertion in the

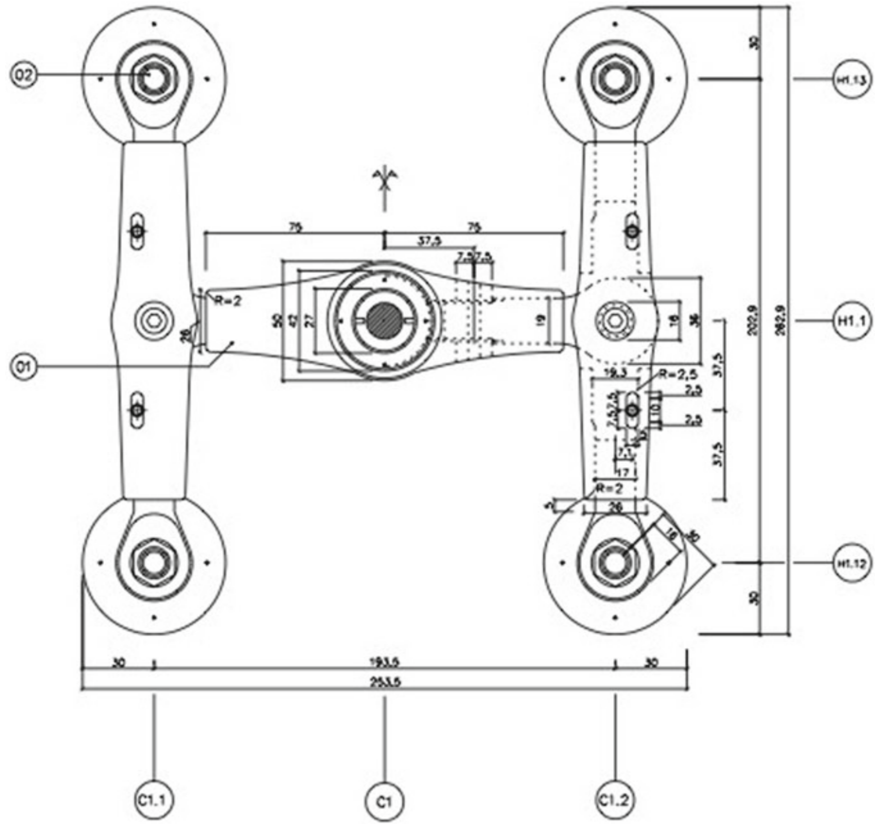

Fig. 5.6 Productive design of point fixing devices with respect to the junction of perforated and adjoining glass panes: mechanical elaboration of the central joint bracket, ball joints and circular joints to achieve façade movements. © Courtesy of Andrea Giuradei and Andrea Costa

drilled head (in thermoplastic material within the cylindrical aluminium body) arranged in the glass plate drilling.

The design of the fixing points generally examines:

- the physical behaviour of the glass modules which, due to their rigidity, do not allow the stresses generated within them (caused by the action of the fixing points) to distribute themselves uniformly;
- the physical behaviour of steel elements (produced in fusion, necessary for the manufacture of elements of rigorous precision), which are plastic in nature, whereby the uniform distribution of stresses is determined, and defined by a high degree of hardness: the junction towards the modules observes the interposition of both a thermoplastic element and an aluminium element (aimed at preventing slippage that could reduce the tightness of the fixing points).

5.2 The Functional, Structural and Constructive Procedures of the Suspending Framing and Devices

The façade is suspended from the main horizontal load-bearing structure by means of a spring system, which ensures that the weight of certain enclosure sections (consisting of the glass modules) is equally distributed between all suspension points (even if one module breaks). The spring system remains at rest until it is subjected to loads greater than the weight of the glass: in this case, the spring extends until the additional load is absorbed by the other connection points. The construction of the façade system involves:

- the centrality of the suspension point, so that, even in the case of a lateral load, the glass module does not oppose the load itself, but can hang vertically and independently of the horizontal arrangement of the main supporting structure;
- the application of two helical springs (on a cylindrical guide), connected to a fixed upper plate and a movable lower plate, in order to allow the springs themselves to stretch. The forceps geometry makes it possible to divide the weight of the modules into two components, an oblique one, which passes through the spring box, and a horizontal compression one, which passes through the rear bar;
- the connection with the structure through two bars with a perforated head (with a ball bearing in between), an upper one passing between the springs (connecting two plates, in the form of a slip guide) and a lower one (starting from the lower plate). The two bars are joined to an element designed to transmit the loads tangentially to the load-bearing truss. The structural apparatus of the façade system is generally executed by means of vertical steel profiles (e.g. in tubular form), possibly reinforced with grid structures (as in the case of interventions with a height $h \geq 6000$ mm), on which the transverse passage of the spacers (to which the fixing points are connected) takes place, or is executed directly by the stainless steel cross braces. The stainless steel cross fixing devices are produced in investment casting and with a polished or satin finish (Figs. 5.7 and 5.8).

The connection to the main load-bearing structure involves the use of special accessories (in the form of a base, welded or mounted on the structure, and a calibrated internal ring nut) for depth adjustment, to compensate for any dimensional differences in relation to the planar arrangement of the façade. Specifically:

- the aluminium structures concern, for example, the constitution according to shaped tubular profiles, integrated by internal stiffening baffles and characterized by the use of accessories for the junction of the crosses and for the passage of the extrados and intrados anchoring elements;
- the stainless steel structures concern, for example, the constitution according to tubular profiles anchored to the extrados and intrados by means of tubular section brackets, also capable of telescopic adjustment. The direct application of the cross brackets involves the insertion (by welding) of a transversal (galvanized) steel pin, of threaded cylindrical section, for the insertion of the mechanism to accommodate the shaft of the longitudinal bolting projected by the cross brackets themselves;

Fig. 5.7 Francesco Cocco, *People Mover*, “Tronchetto” and “Piazzale Roma” Stations, Venice. Structure with the fixing devices (in spider form) with four or two brackets, depending on the position of use, with the possibility of orbital adjustment. The *rotulles* have a cylindrical head to be inserted into the drilled and tempered glass modules, equipped with the nylon bushings to avoid direct contact between the metal couplings and the drilled holes. © Courtesy of Oskar DaRiz

Fig. 5.8 Francesco Cocco, *People Mover*, “Tronchetto” and “Piazzale Roma” Stations, Venice. Pillars supporting the spherical joints from which the diagonal struts branch off to the transverse struts, on which the couplings for the parallel attachment of the upper tubular beams are set: above the spherical joints the pin for the assembly of the beams is applied, on which the connection of the *rotulles* takes place. © Courtesy of Oskar DaRiz

Fig. 5.9 EFA, *Collodi Butterfly House*, Collodi (Pistoia). Vertical mullions made of glass plates to support the *spider*-glass joining devices for the mechanical assembly of the glass plates, taking into account the connection of the stainless steel crosses necessary for the attachment of the *rotulles* (equipped with an internal rotating ball). © Courtesy of EFA

- the tempered glass structures concern, for example, the constitution of second mullions (of variable width between 400–600 mm) drilled for the direct fixing of the crosses, of the connection accessories to the masonry and of the extrados and intrados anchoring brackets (in the form of pairs of stainless steel "L" profiles). The glass mullions may include intermediate perforations for the passage of horizontal structural elements, e.g. in the form of stainless steel tubular profiles (Figs. 5.9 and 5.10).

The constitution of the main load-bearing structure, over extended heights of the façade, is equipped with the bracing apparatuses, for the regulation of normal loads in the vertical plane, composed of:

- the spacers (in stainless steel, for variable dimensions of between 500–800 mm), directly connected to both the crosses, passing transversally to the main frame in tubular profiles (within the cavities arranged in the sections or through the sleeves), and to the system of tensor cables (in stainless steel);
- the tensor cables (in rope or stainless steel rods), assembled to the extrados, intrados or directly at the upper and lower points of the vertical profiles, executed in single, simple double specular form or with diagonal passages.

The connection between the façade and the bracing structure is made by the application of a system of connecting rods which, extended by the articulated bolt of

Fig. 5.10 EFA, *Collodi Butterfly House*, Collodi (Pistoia). Modular glass sheets, to be assembled to the structural grid at multiple connective points (comprising laminated and tempered glass panels for the roof), which are jointed to the vertical blades by means of *rotulles* designed to transmit the stresses of self-loading, external loads and torsion and bending stresses. © Courtesy of EFA

the fixing devices, are arranged in succession towards a horizontal beam. According to the general formulation of the system:

- the horizontal beams are realized by a central longitudinal profile (operating in compression), by the series of spacers (operating in compression, aimed at holding the cables in tension) and by the double series of cables (linear, outside the longitudinal profile, and diagonal, between the linear cables and the central profile, all operating in tension);
- the trusses, which, as a whole, react against both the action of wind pressure and the action of depression, are applied successively at each horizontal interface between the glass modules;
- the integration of the forceps cables between the trusses takes place with the function of connection and stabilization with respect to the loads lying on different planes (due to the rotation of the connecting rods due to the vertical movements of the façade, which could cause the rotation of the trusses themselves, losing their stability) from the horizontal one (referring to the beams). The beams are

then connected to the upper beams by means of forceps, which are subjected to traction in order to prevent rotation;

- the spacers are configured in the form of a cantilever beam loaded at the ends, resistant to the bending induced by the tension of the cables. The beams are connected via the lateral struts, which in turn are connected to the main load-bearing structure via the connecting rods, ensuring the overall stability of the system (according to the generation of an isostatic three-hinged arch). The mullions, subjected to shear and bending action, must consider a larger dimension in the direction of the main stress (i.e., adopting a section characterized by a high moment of inertia) (Figs. 5.11, 5.12 and 5.13).

The load-bearing sections of the system are carried out by means of the interposition of the series of horizontal supports, according to the combination with the load-bearing devices, i.e. characterized by the mechanical behaviour according to:

- the main structure, lower and upper, in the form of a perimeter truss with cross-sections made of steelwork, designed to support the vertical loads due to the suspended modules and aggregate devices, in addition to the tension related to the stabilizing cables of the beams themselves;
- the action of the horizontal loads, for which the stresses directed perpendicularly to the façade plane determine, towards the modules, bending loads both on the

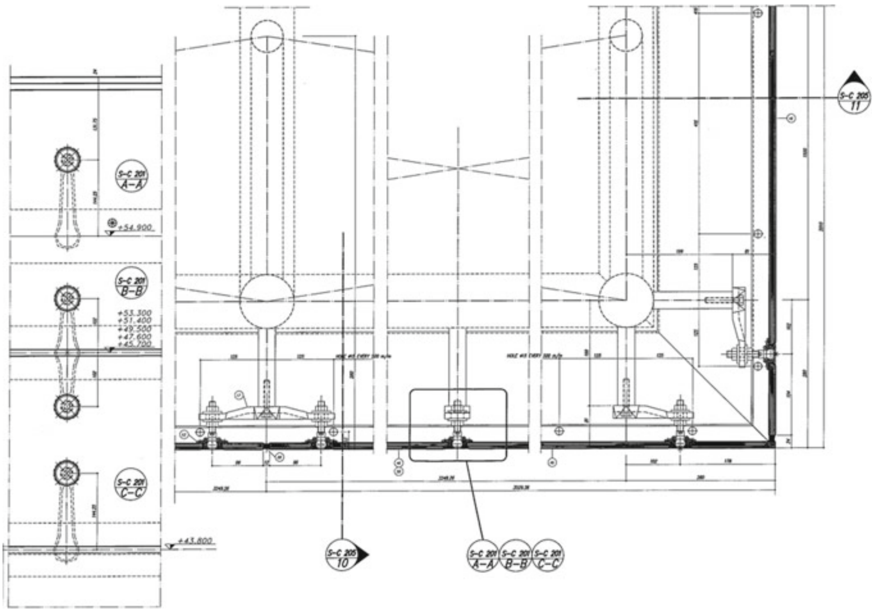

Fig. 5.11 BDP, *Marks & Spencer Store*, Manchester. Construction of the skin in single toughened glass through mechanical assembly to point devices in the angular proximity of the panes, with the aim of bearing their weight (as a perfectly vertical load to be transferred to the inner secondary structure), resisting horizontal stresses and supporting deformations. © Courtesy of Focchi

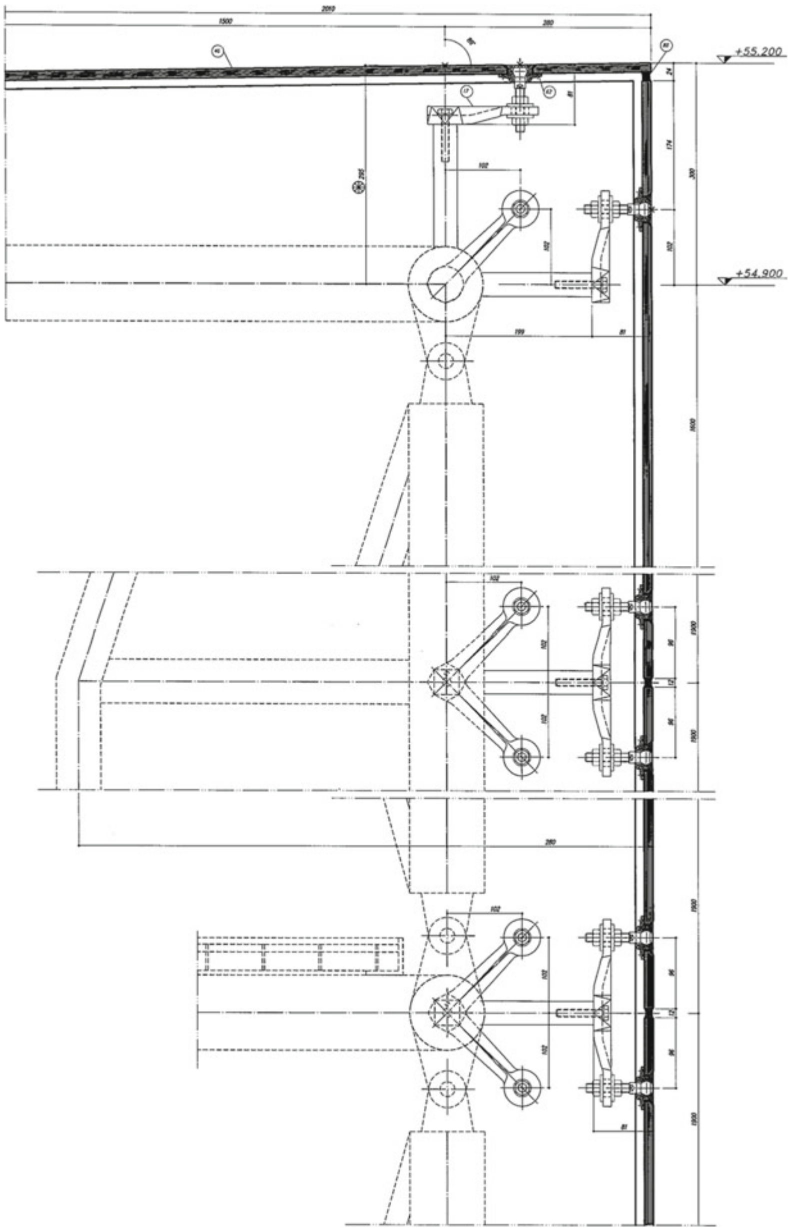

Fig. 5.12 BDP, *Marks & Spencer Store*, Manchester. Joints made up of the stainless steel spherical hinges within the conical holes in the double-glazing and applied to the four brackets of each "cross" connector (capable of absorbing, with its own slots and holes, the processing tolerances of the glazing and supporting structure). © Courtesy of Focchi

Fig. 5.13 BDP, *Marks & Spencer Store*, Manchester. Planar construction of the external skin of glass panes supported by regulated brackets, which are assembled to the frame through related profile branches up to the secondary load-bearing structure and accommodate the point jointing devices (*rotulle* type). © Courtesy of Charlotte Wood Photography

vertical plane and on the horizontal plane: in this regard, the functioning of the punctual joining devices makes possible the mobility and rotation of the modules outside their own plane;

- the action of lateral loads, whereby the stresses directed laterally to the façade plane result, through the operation of the punctual jointing devices, in the mobility of the modules in their own plane, rotating around the axis of the bolting.

The structural solution consists in the use of a grid of pretensioned tie-rods, with the vertical beams in rope assisted by cross-tie-rods (also in rope, but with a smaller diameter in the central part of the vertical development), and a round profile in the two end zones, upper and lower, of each truss. The horizontal connections between the trusses placed in the central rows of the struts consist of the round profile ties with the insertion of appropriate "St. Andrew's" crosses. The structure is designed and verified by conducting a non-linear analysis, making it possible to identify the correct tie rod diameters and to optimize the pretensioning loads, which are different according to the type of tie rod. In other words, the mechanical processing of the tensile structure is based on the finite element analysis method, through the discretization of the interfaces and the subdivision into an equivalent system of smaller structures or units, such that their assembly generates the actual composition.

5.3 The Functional, Constructive and Coordination Procedures Between the Façade System and the Main Interfaces

The load-bearing tensile structure is studied with the objective of examining the conditions of maximum axial load, which induces the deformation of the reticular sections with respect to the planar configuration, producing a state of pressure-bending concentrated, in particular, along the intermediate portion of the façade. The modelling, then, deepens the conditions of maximum displacement that, in the development of the tensile structure, are concentrated within the central sections: on these bands the bracing apparatuses are arranged, characterized by the series of bays defined as stiffening cores by means of the intersections between the cables. In addition, the modelling focuses on the particular load situations inherent in the individual cables of the tensile structure, noting the pre-load state for the linear and diagonal passages. The vertical trusses are connected by the horizontal ties in the central rows of the struts, while the glass panels are installed by vertical rows and connected to the trusses via the point supports (Fig. 5.14).

The connection between the façade and the bracing structure is made through the application of the system of connecting rods which, extended by the articulated bolt of the fixing devices, are arranged in succession towards the horizontal truss (of the bracing structure itself). According to the general formulation of the system:

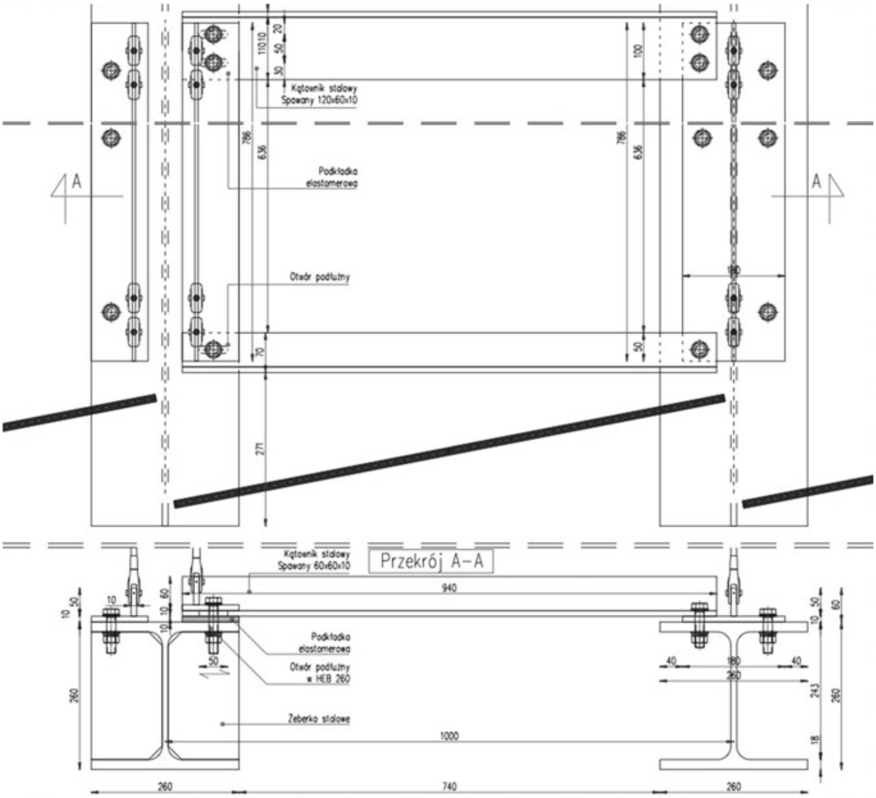

Fig. 5.14 Stelmach & Partners, *CSK*, *Centrum Spotkania Kultur* ("Centre for Encountering Cultures"), Lublin. Application of the façade system set up according to the arrangement of the series of steel profiles as the basis for the assembly of the steel angle brackets: these are intended to make the fixing points to the end pins of the ropes that make up the tensile structure, in accordance with the arrangement of the holes and point fixings from the beams. © Courtesy of Lilli Systems

- the horizontal beams are formed by a central longitudinal profile (operating in compression), by the series of spacers (operating in compression, aimed at holding the cables in tension) and by the double series of cables (linear on the outside of the longitudinal profile and diagonal, between the linear cables and the central profile, all operating in tension);
- the trusses, which, as a whole, react against both the action of wind pressure and the action of depression, are applied in succession at each horizontal interface between the glass modules;
- the integration of the forceps between the beams takes on the function of connection and stabilization with respect to the loads lying on different planes (due to the rotation of the connecting rods due to the vertical movements of the façade, which could cause the rotation of the beams themselves, losing their stability) from the horizontal one (referring to the beams). The beams are then connected

to the upper beams by means of forceps, subjected to tension, in order to prevent their rotation;

- the spacers are configured in the form of a cantilever beam loaded at the ends, resistant to the bending induced by the tension of the cables (Fig. 5.15).

With respect to the horizontal planar configuration of the brackets, the articulation due to the aggregated flanges leads to the development of the linear series of tensor cables, vertical and horizontal, in the perimeter sections, external and internal, of the tensile structure. The connective arrangement of the ends accommodates, in

Fig. 5.15 Stelmach & Partners, *CSK*, *Centrum Spotkania Kultur* ("Centre for Encountering Cultures"), Lublin. In-situ adjustment of steel segments protruding from the brackets to support spacers for mechanical jointing of the fixing devices. © Courtesy of Lilli Systems

the vertical plane, the flanges arranged for the attachment of the transverse diagonal tensors, which cross at the centre-line of the span; similarly, in the horizontal direction, the interfaces due to the diagonal cables in the stiffening sections for the bracing structures are determined. This is while the projections of the brackets accommodate the attachment of the laminar surfaces supporting the spacers.

The mechanical diagram shows the function of the devices projected externally to the brackets, in the form of both devices guiding the passage (vertical or diagonal) of the tensor cables, and as supports to the templates from which the spacers unfold. The support devices to the glass enclosures consist of the geometries directed to accommodate both the engagement and adjustment of the spacers, as well as the connection surfaces with respect to the external tensors, while the brackets normal to the façade plane perform the support base to the enclosures (Fig. 5.16).

The design of the suspended façade system considers:

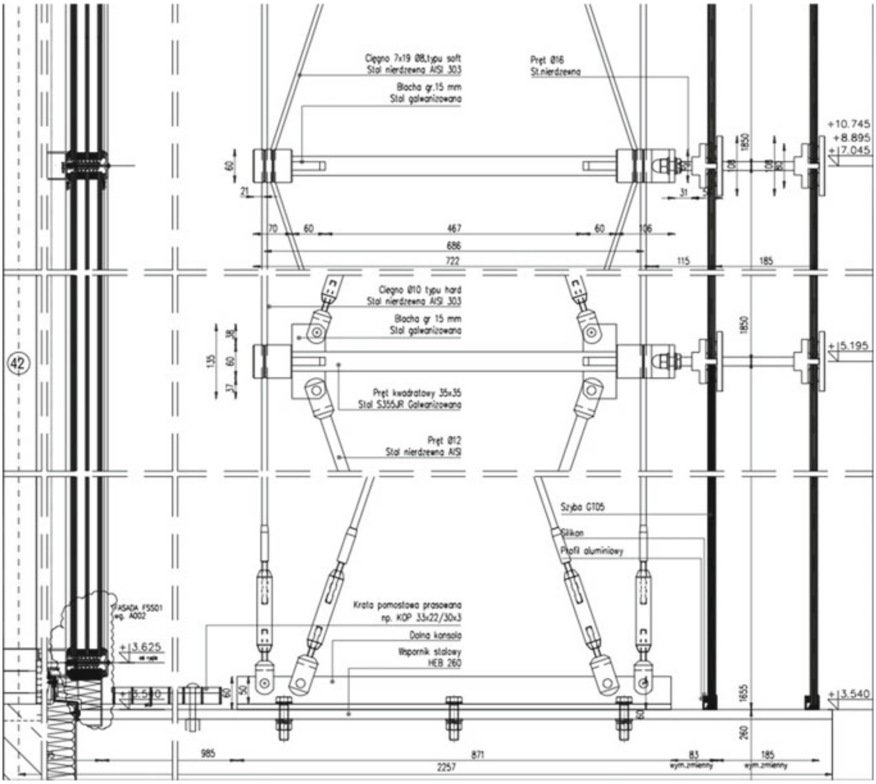

Fig. 5.16 Stelmach & Partners, *CSK*, *Centrum Spotkania Kultur* ("Centre for Encountering Cultures"), Lublin. Articulated rope extension with respect to vertical (inner and outer) and diagonal linear developments, according to the passage through the guiding devices or attachment to the flanges connected to the horizontal steel brackets. © Courtesy of Lilli Systems

- the application of the toughened glass panes in modules associated with each other (capable of resisting tensile stress), as a whole suspended from the rope structure to which the vertical loads are transferred, and the transfer of the horizontal stresses to the bracing structure, according to the transfer of the loads through:
  - the punctual joint devices, designed to support both the weight of the sheets (as a perfectly vertical load) and the horizontal loads in the direction perpendicular to the façade plane;
  - the articulation of the horizontal connecting spacers;
- the assembly of the glass panes according to the coupling of the pairs of punctual joining devices in the horizontal connections, also in the solution that avoids drilling (and the consequences caused by the "fraying" of the material, such as to lead to a non-uniform distribution of the stresses and to favour both the formation and the progression of micro-fractures): the devices are made by a spherical hinge capable of rotating inside the bolt head, allowing the differential movement between the plane of the façade and the structure (Fig. 5.17).

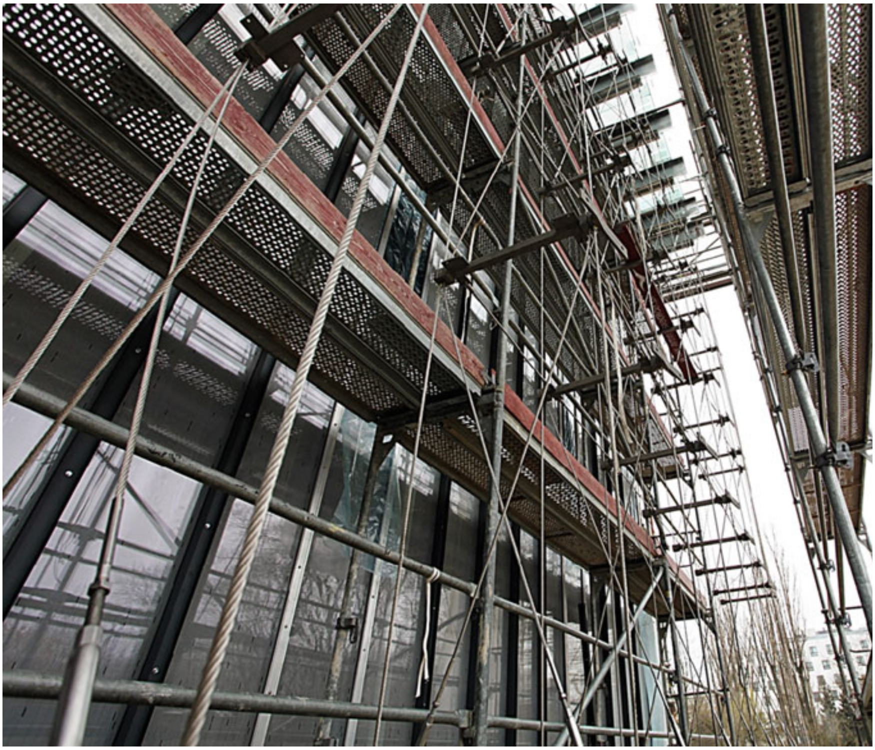

Fig. 5.17 Stelmach & Partners, *CSK*, *Centrum Spotkania Kultur* ("Centre for Encountering Cultures"), Lublin. Executive phase of adjusting the tensile structure of longitudinal and crossing cables with the interposed spacers. © Courtesy of Lilli Systems

Chapter 6
The Typology of the Double Skin Façade System

6.1 The Functional, Executive and Connective Configuration of the Double Skin Façade Composition

The double wall façade system (or "double skin façade") is determined in the transition from the continuous curtain wall to the multilayer type, articulating the specific performance of the levels and the relative technical elements: this with the possibility of realizing the interspace between the two walls for thermal and acoustic insulation, for ventilation and to apply functional devices (such as, for example, sunshades) and also plant ducts. The double envelope constitution provides the use of a screen (or "second skin", in general, made of glass) outside the vertical enclosure, with the aim of optimizing the functions allowed in the cavity: this is through the additional application of a glass enclosure in front of the curtain wall or the external building curtain (in general, equipped with openable frames), in the form of a ventilated cavity that can be used according to certain modes of operation (passive or active type) aimed at controlling external climatic and environmental stresses to regulate the conditions of the internal spaces.

The examination detects the prospects of "dynamic interaction" between the double envelope system and the external environment, observing the criteria aimed at realizing built spaces in a stable and balanced manner, with the possibility of transmitting, modifying or rejecting climatic stresses. The double-envelope system typology is understood as an "interchange" tool for the ability to respond to external loads through the development of different functional levels and the use of means of regulation to manipulate interactions with the environment. Furthermore, this typology is applied as:

- the mediating and reacting apparatus, specifying the "sensitive" type of functioning that acts with adaptive and control capacities, according to the needs of well-being and reduction of energy consumption;
- the "programmable" surface apparatus, capable of interpreting the functions and needs of users in an *eco-efficient*, selective and multi-purpose form, with respect

I. Paoletti and M. Nastri, *Executive Design of the Façade Systems*,
PoliMI SpringerBriefs, https://doi.org/10.1007/978-3-031-44893-5_6

to the control of temperature, humidity and ventilation levels, perception towards the outside and lighting levels.

The technical and typological definition of this system can be calibrated with respect to the activities inside the built spaces, referring to the main external environmental and micro-climatic parameters (such as, for example, the intensity of solar radiation and its distribution) and internal ones (such as the temperature of the air and the perimeter vertical curtains, relative humidity, air speed and its quality). The composition of the double envelope system considers:

- the functioning in the form of a passive solar system (in general, through the capture of radiant energy, the reduction of heat dispersion, the possibility of heat accumulation in the form of a thermo-insulating air chamber and, therefore, of heating the air section by the "greenhouse effect", the increase in lighting performance), based above all on the thermo-building principles inherent in the control of air flows in the cavity (by means of parietodynamic transfer processes). In this regard, the system assumes the use and accumulation of solar radiation for the regulation of indoor thermal comfort conditions, together with the possibility of a reduction in the use of heating systems;
- the functioning in the form of a system for capturing and injecting air flows (whereby the amount of air exchanged between the external environment and the cavity depends on the temperature gradient, wind pressure and the size of the ventilation slots), in general:
  - the passive type, by capturing convective flows close to the façade plane (by means of profiles and devices with aerodynamic geometry and openings), their introduction into the cavity between the internal and external closures and the conduction of convective flows by the "chimney effect" (due to the rise in temperature due above all to solar radiation) in an upward direction until they reach the internal spaces (considering the possibility of reducing the use of air-conditioning systems for cooling)
  - of the active type, with the use of electro-commanded equipment to generate the aeration of convective flows in the cavity between the internal and external enclosures (such as, for example, fans for the conduction of air flows) (Fig. 6.1);
- the calibration of solar radiation, in an integrated manner with the use of shading or diffusing devices, in order to obtain diffused lighting conditions in interior spaces (capable of limiting the use of artificial light, achieving energy savings of 60–70%). These devices, placed in the cavity (protected from atmospheric pollution and bad weather), keep the heat absorbed by solar radiation outside the built spaces and determine:
  - the accumulation of heat aimed at increasing the temperature of the air in the cavity, the flow of which is directed upwards, until it is expelled (through the ventilation devices);
  - the accumulation of heat outside the built space, limiting air conditioning loads and reducing the need for cooling.

Fig. 6.1 Renzo Piano Building Workshop, *Debis-C1* Building, Potsdamer Platz sector, Berlin. Functional and environmental expression of the façade components: the outer membranes made of glass sheets create, when closed, a thermal and sound-absorbing storage cavity and, when open and regulated, a filtering function with respect to incident wind loads. © By the Authors

In addition, the calibration of solar radiation can be specified through the use of devices capable of transmitting, reflecting and diffusing natural lighting in interior spaces (Fig. 6.2).

The application of the double-glazed surface makes it possible to reduce thermal losses from internal spaces, by reducing the speed of the air flow in contact with the internal curtain, increasing thermal insulation: therefore, the reduction in thermal transmission makes it possible to maintain the glass surfaces at a temperature close to the values of the average internal ambient temperature, so as to make the adjoining spaces more comfortable.

The change of air inside the cavity increases in direct proportion to solar radiation, since the airflows that lap the façade are heated by the elements that make it up (the glazed panels and metal profiles): therefore, convective circulation and the amount of evacuated heat increase according to the intensity of solar radiation, so that the interior spaces are ventilated even in difficult climatic conditions. During the winter season, the cavity inside the double envelope systems acts as a passive heating device through

Fig. 6.2 Norman Foster and Partners, *Swiss Re* Tower, London. Type of enclosure enveloping the cylindrical tower, streamlined and tapered according to a progressive double-curved conical winding (double-curved geometry). The closure, warped by the diagonal lattice construction, is composed of the double envelope system that generates an upward air flow (stimulated by the "chimney effect" and increased by the thermal gradient between the temperature in the cavity and the temperature of the incoming air). © By the Authors

the accumulation of heat (due to solar radiation), sheltering the internal surface from the effects of low temperatures and improving (by approximately 20%) the thermal insulation of the curtain wall (Figs. 6.3 and 6.4).

- the solar shading devices (in an adjustable form), placed inside the cavity and, therefore, protected from atmospheric agents and external pollutants: these devices reduce the heat input according to the external temperature and solar radiation conditions, being particularly effective when the external temperature is lower than the temperature of the internal spaces and for low values of total radiation (Fig. 6.5);
- the external screen, in the form of a totally or partially transparent façade, made up of monolithic tempered or double-glazed glass panes: this screen, in addition to allowing the creation of a ventilated cavity or as a *buffer strip* for thermal accumulation and insulation, reduces wind pressure and allows the opening of windows

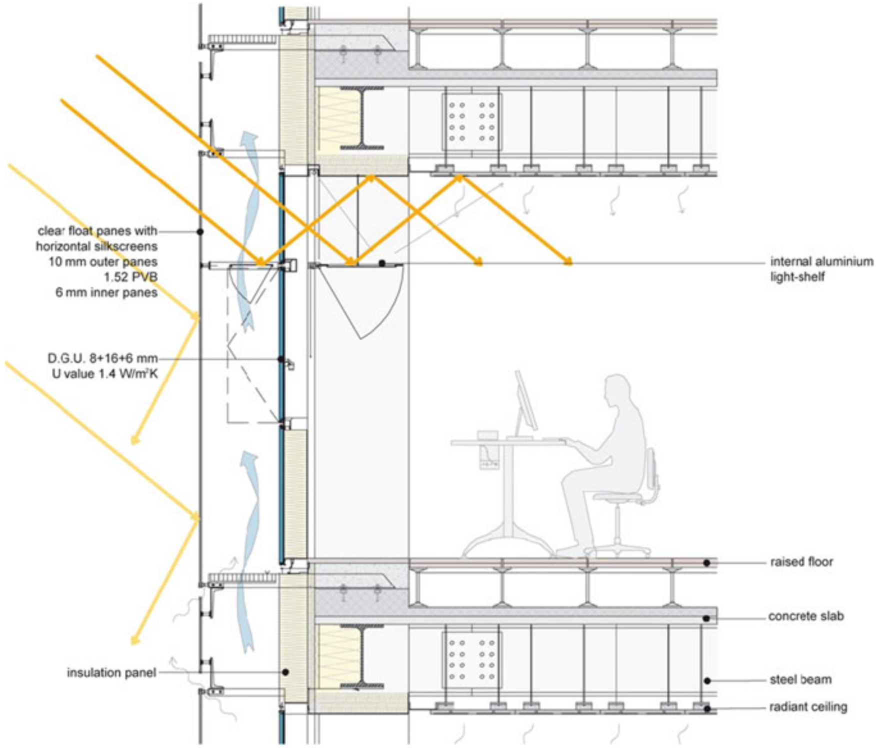

Fig. 6.3 Mario Cucinella Architects, *SIEEB* (*Sino-Italian Ecological and Energy Efficient Building*), Beijing. Application of the "double wall" envelope supplemented by horizontal reflective elements in the form of light shelves, for the calibration and diffusion of natural light into the interior spaces, with respect to the degree of critical exposure to solar radiation (east and west exposures). © Courtesy of Mario Cucinella Architects

relative to the internal curtain (even at high levels of the building, allowing the exchange of air by natural ventilation) (Fig. 6.6).

The functioning of the double envelope system, for example, provides that:

- during the summer season, by the day, the vertical passive ventilation conducts upwards the heat generated in the external cavity, recalling (through the opening of the window relative to the external curtain) the flow of air consequent to the opening of the window in the opposite and parallel curtain;
- during the summer season, by the night, the vertical passive ventilation recalls the flow of air resulting from the opening of the window in the opposite and parallel curtain and conducts it up to the cavity, cooling the internal spaces;
- during the winter season, with the closure of the windows and the covering of the open horizontal grid, the thermal accumulation chamber creates (due to the

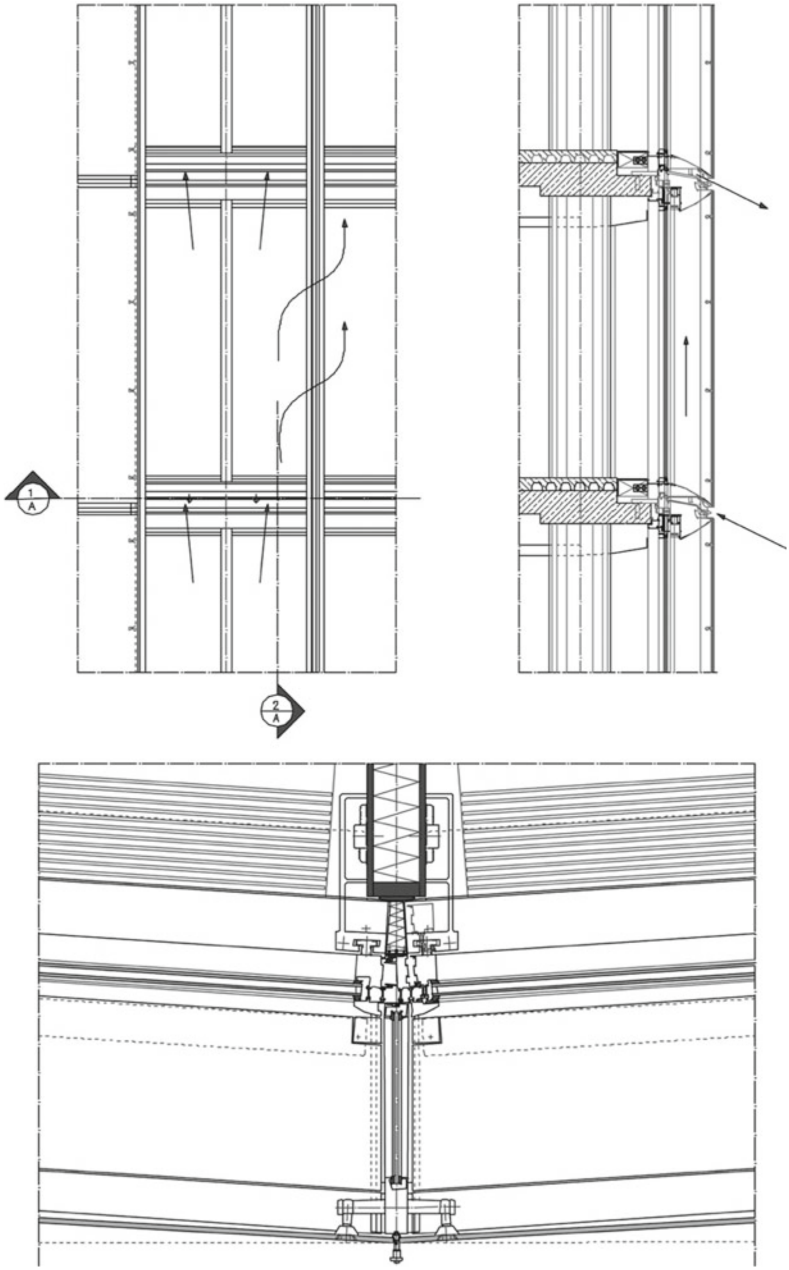

Fig. 6.4 *Ingenhoven Overdiek und Partner*, *RWE* Building, Essen. Assembly of transversal baffles, placed horizontally or vertically to the façade plane, which typologically and functionally delimit the contiguous components of the system. © Courtesy of *Ingenhoven Overdiek und Partner*

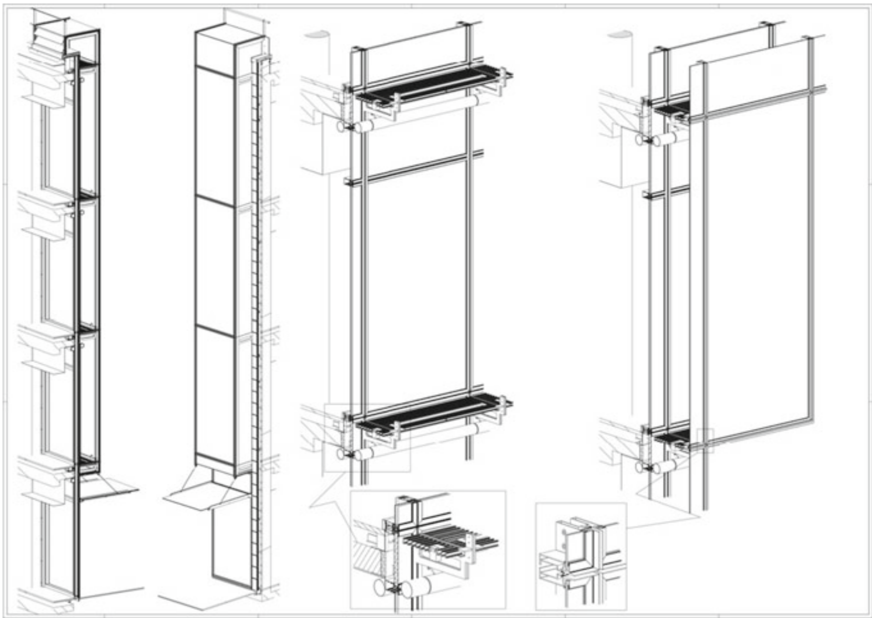

Fig. 6.5 Maurizio Varratta, *iGuzzini Lab*, Recanati. Assembly of solar shading devices inside the cavity, reducing the heat input according to the external temperature and solar radiation conditions. © Courtesy of Pichler Projects

Fig. 6.6 Maurizio Varratta, *iGuzzini Lab*, Recanati. Assembly of the external screen, in the form of a totally or partially transparent façade, made up of monolithic tempered or double-glazed glass panes. © Courtesy of Pichler Projects

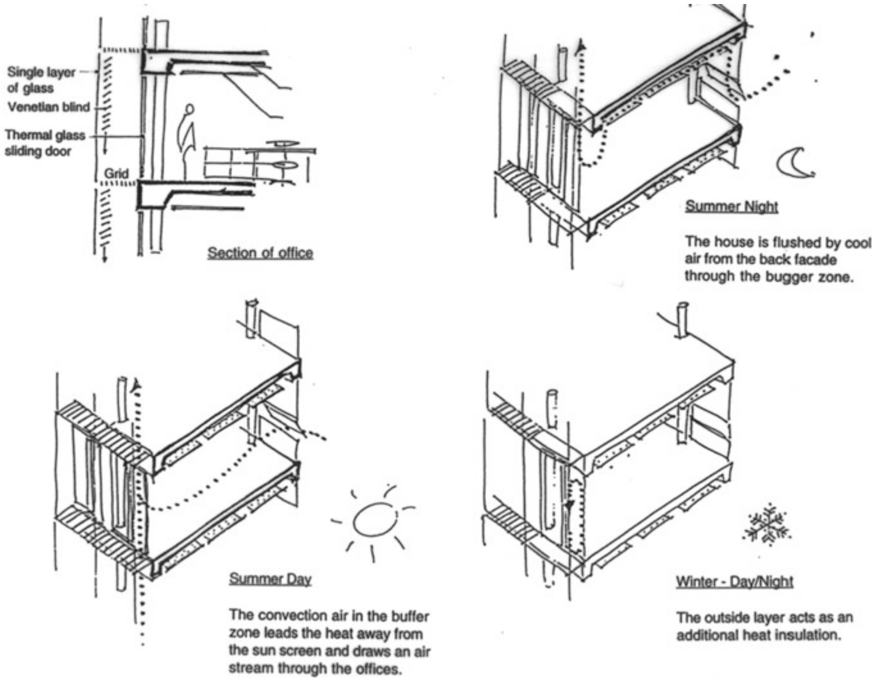

Fig. 6.7 Henning Larsen, *Danish Design Center*, Copenhagen. Functioning of the double envelope system realized through passive ventilation, of a permanent and continuous type (vertically), in the external cavity. © Courtesy of Henning Larsen

"greenhouse effect") a heated air section (directed to the heating of the internal spaces) and thermal insulation (Fig. 6.7).

6.2 The Functional, Constructive and Typological Constitution of the Continuous and Discontinuous Double Skin Façade System

The double envelope façade system with continuous cavity (or *multistorey façade*) is composed according to the homogeneous and progressive development of the cavity interposed between the internal enclosure and the external skin, considering, with respect to the traditional "ventilated wall" configuration, the possibility of segmenting and articulating the façade by means of adjustable openings: this for the introduction and for the expulsion, even partial, of the convective flows contained during the upward flow (in any case generated by the "chimney effect"), on the basis of appropriate geometric adjustments aimed at confirming the dynamic continuity and avoiding the occurrence of intermediate turbulence. The application of the double envelope system, in the case of the continuous cavity façade, is determined with respect to the development of functional and adjustable equipment by means of the activation of mechanical devices, aimed at regulating the transmission of heat, light and natural ventilation, together with the attenuation of external wind and acoustic loads. The double envelope system, by means of the re-radiation phenomena in the cavity (resulting from the absorbed solar radiation), realizes homogeneous upward convective flows, which drive the ventilation of the enclosed air upwards, transporting the heat generated inside (Fig. 6.8).

The double envelope systems operate with respect to two functioning models:

- the winter functioning, with the aim of exploiting the heating of the air mass present in the cavity to transfer the heat to the interior spaces; that is, with the objective of directly distributing the accumulated heat, through the natural thermo-circulation established by vertical convective flows;
- the summer functioning, with the aim of avoiding overheating of indoor air by removing the heat and transferring it outside (Fig. 6.9).

The cavity of the double envelope (as a ventilated duct) reduces the need for heating and mechanical cooling. This equipment generates an upward air flow, which is also increased by the thermal gradient between the temperature in the cavity, the temperature of the incoming air and the "chimney effect" produced by the transparent curtain at the perimeter: this with respect to the objective of reducing heat during hot

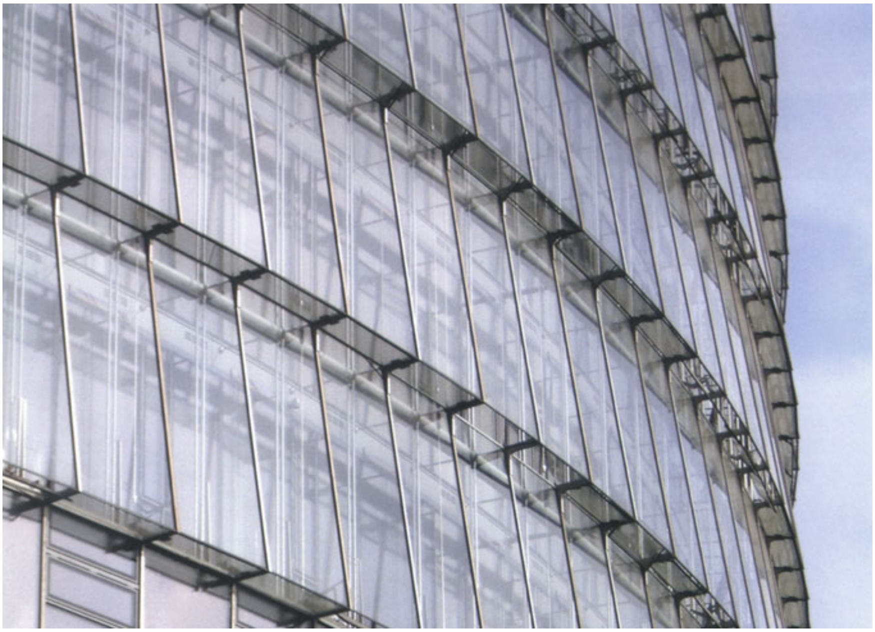

Fig. 6.8 Helmut Jahn, *Post Tower*, Bonn. Segmented external shading skin (south elevation), framed by linear vertical and horizontal aluminium profiles, that creates a visual and functional membrane to the internal curtain wall. © Courtesy of Helmut Jahn

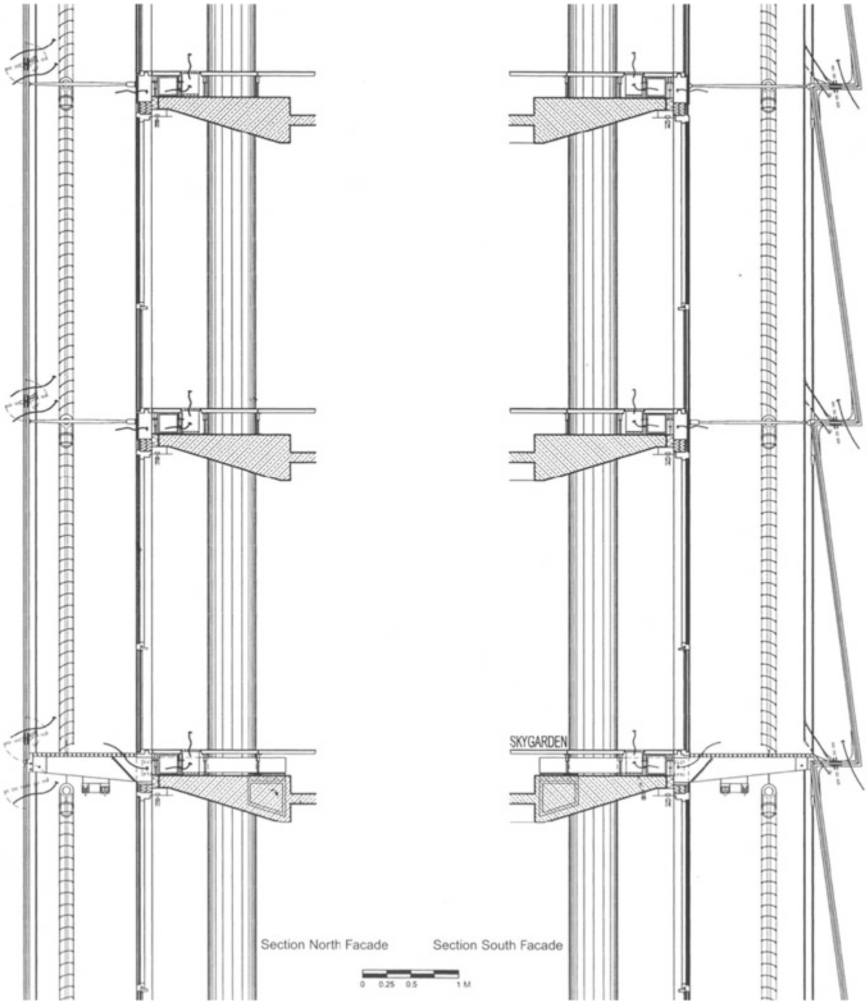

Fig. 6.9 Helmut Jahn, *Post Tower*, Bonn. Double envelope systems, consisting of the inner curtain wall with linear external shading for the north elevation and segmented for the south elevation, that involve the natural ventilation of the cavity by capturing air flows through adjustable louvers applied to the lower sections of the outer screens. © Courtesy of Helmut Jahn

periods and controlling energy losses, water vapour flows and frost formations on the façade plane during cold periods. In the case of the external shading configuration, the functioning of the system provides that:

- during the winter period, the glass blades are closed: the solar radiation, heating the air in the cavity, generates a heat-insulating layer (due to the "greenhouse effect") which contributes to maintaining heat in the interior spaces and reducing energy consumption for heating;

- during the summer period, and depending on the outside temperature level, the glass blades are open, allowing ventilation of the cavity and night cooling of the buildings, acting in combination with the opening of the windows. Even in the open position, the blades assume a filtering function with respect to incident wind loads, the speed of which is high at the highest levels of the towers, allowing the windows of the internal façade to open (Fig. 6.10).

The double envelope system with a continuous cavity determines the control of air exchange and the thermal compensation effect of the façade since, by placing ventilation openings at the base and at the top, it is possible to vary the air inlet and outlet section (Fig. 6.11).

The double envelope façade system with discontinuous cavity is composed:

- with a horizontal-type division, which results in *corridor façades*;
- with a horizontal-vertical division.

The *corridor façade* type has the cavity segmented by horizontal connective elements (in reticular and practicable form) placed in correspondence with the extrados of the structures. The outside air is introduced in the lower strip of each

Fig. 6.10 Helmut Jahn, *Post Tower*, Bonn. Connection of the external shading to the building curtain made either through the assembly, with shaped profiles, to the brackets integrated by the ventilation grilles, or through the connections determined by the linear elements with point joints, extended by the connections to the floors. © Courtesy of Helmut Jahn

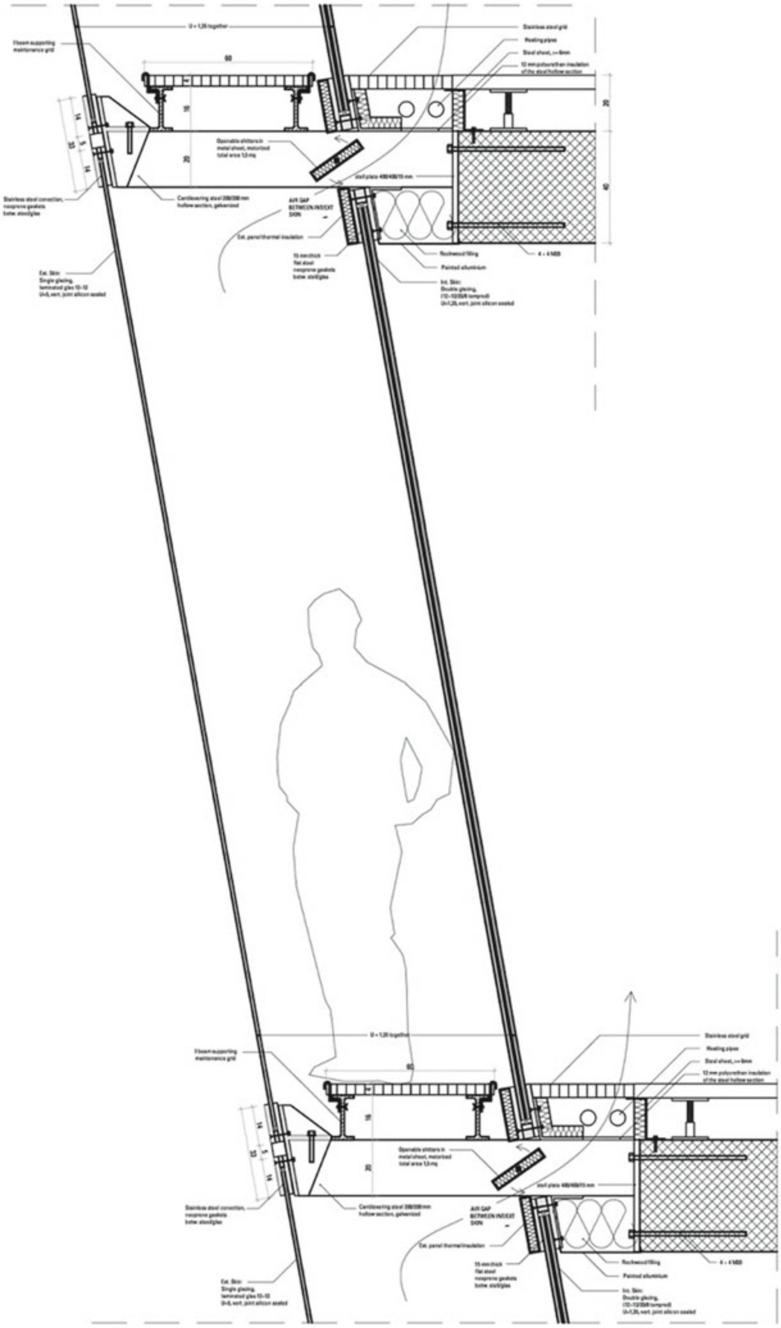

Fig. 6.11 Mario Cucinella Architects, *CSET* (*Centre for Sustainable Energy Technologies*), Ningbo (China). Functional and executive closing apparatus realized by the external screen (in single laminated glass) and by the internal curtain (in double tempered glass), assembled to the external truss and separated by the technical cavity. © Courtesy of Mario Cucinella Architects

inter-floor curtain module, while inside exhaust air is expelled from the "corridor" in the upper strip. At the functional level, the ventilation slots (also of the adjustable type) are staggered laterally or spaced vertically to prevent incoming and outgoing air currents from mixing. The division of the cavity avoids the stagnation of heat in the upper part of the façade.

The application of the double envelope system, in the case of the *corridor façade*, provides for passive ventilation by the "chimney effect" (triggered by the heat radiated by the glazed panels) in the cavity and the capture of external convective flows: this by means of a device articulated through a series of aerodynamic elements aimed at the input of air flows close to the façade plane.

Therefore, the functioning of the double envelope system is realized through the regulation of the ventilation devices, which creates passive ventilation for cooling or heating of the interior spaces (in this case, in combination with the reduction of heat loss by transmission): the calibration of these devices allows the adaptation of the overall operating conditions with respect to the temperatures of the air outside and inside the built environment, to solar radiation and wind stress, limiting the energy consumption necessary for air conditioning and heating of the interior spaces. The double envelope system consists of components defined by two main sections:

- the internal enclosure realized by a double-glazed frame at floor height, with sections that can be opened outwards;
- the external enclosure realized by a single tempered glass panel, connected, at each inter-floor level, to the apparatus including the external ventilation devices. The double envelope system realizes the diagonal passive ventilation through the integrated and functional constitution of two contiguous components, laterally enclosed by the transverse device of tempered glass panels in order to realize air conduction in a diagonal manner, upwards (so as to prevent the internal air flow from being reintroduced into the ventilation circle inside the cavity). The functioning of passive ventilation takes place by means of the "chimney effect", activated by the heat radiated by the internal glass panels in the cavity, and involves the capture of external convective flows by means of a slot (located at the horizontal connection section between the components) and by means of the aerodynamic action of the deflectors that leads them towards the ventilation devices (Fig. 6.12).

The double envelope units composed in this way provide for the lateral approach between two components (and, therefore, ventilation devices) of which:

- the left component provides for the inflow of convective flows, by lowering the regulating element, and the flow, first vertical and then diagonal, towards the cavity; the lower and upper sections of the ventilation device are open;
- the right component provides for the outflow of air from the cavity to the outside, by lifting the regulation element; the lower section is open and has deflecting wings that guide the air in the cavity to the outside, and the upper section is closed (Fig. 6.13).

The ventilation devices of the *corridor façades* consist of:

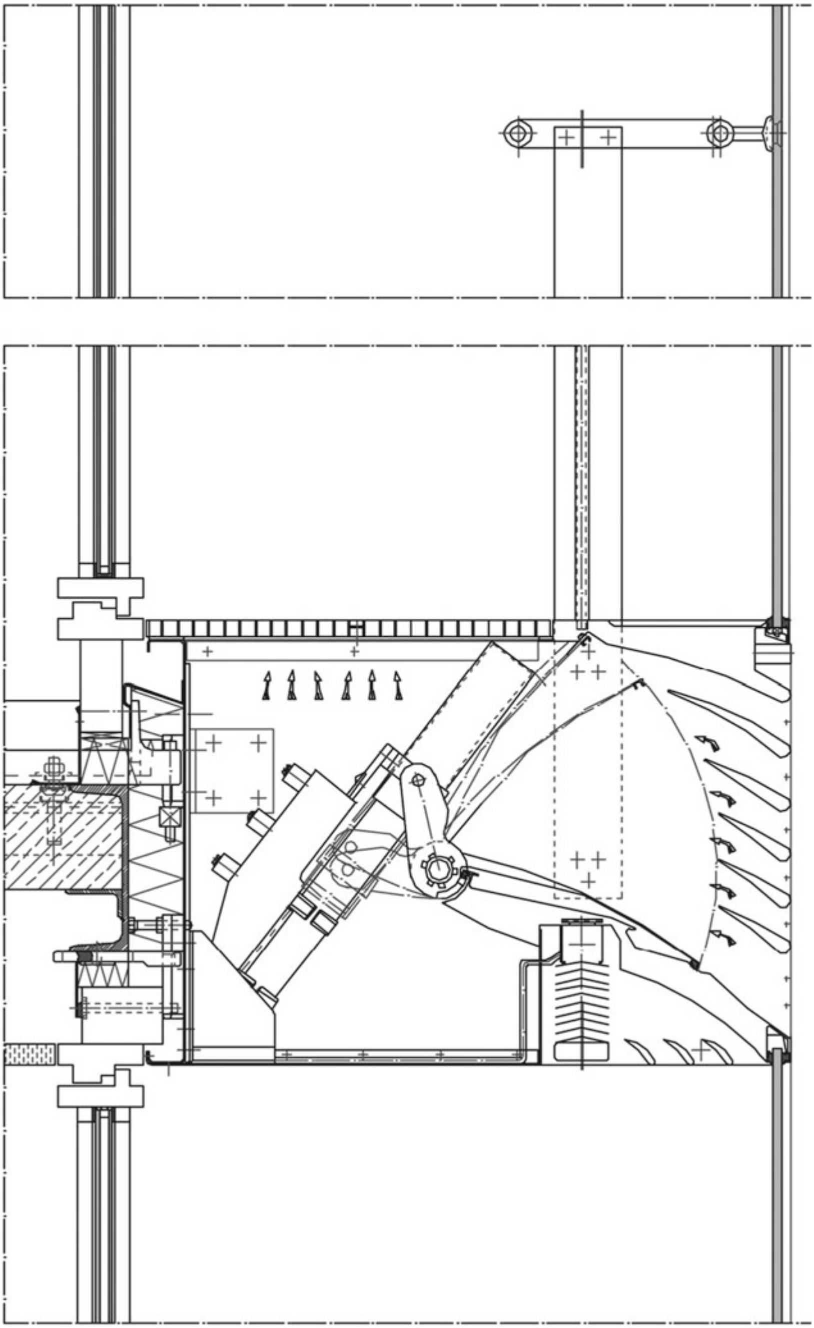

Fig. 6.12 Karl-Heinz Petzinka and Partners, *Düsseldorfer Stadttor*, Düsseldorf. Double envelope system that provides for passive ventilation by the “chimney effect” in the cavity and the capture of external convective flows through a series of aerodynamic elements aimed at the input of air flows close to the façade plane. © Courtesy of Karl-Heinz Petzinka and Partners

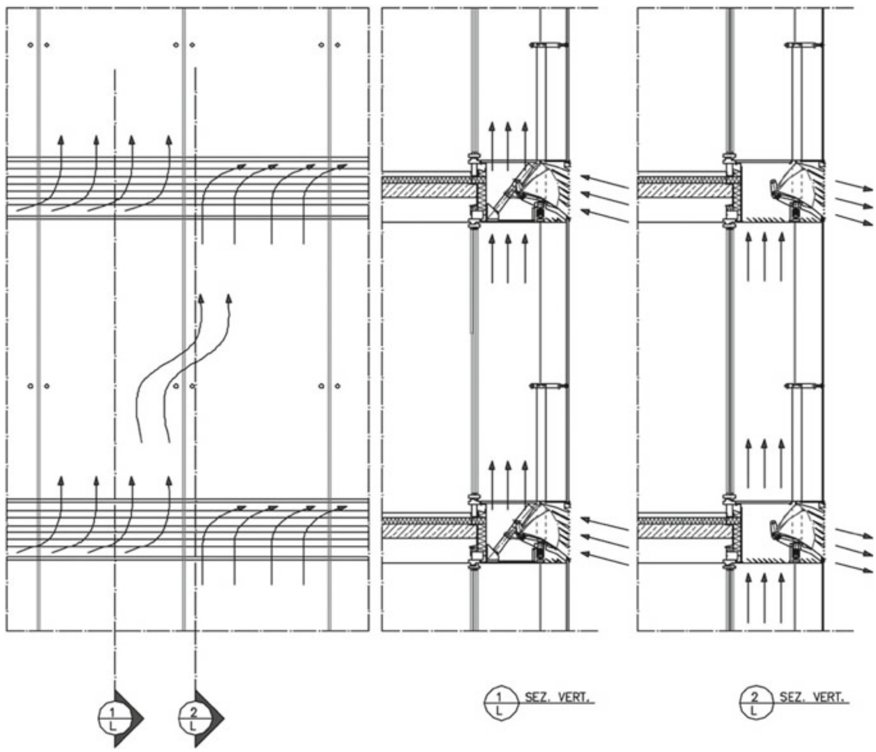

Fig. 6.13 Karl-Heinz Petzinka and Partners, *Düsseldorfer Stadttor*, Düsseldorf. Functioning of passive ventilation that takes place by means of the "chimney effect", activated by the heat radiated by the internal glass panels in the cavity, and involves the capture of external convective flows by means of a slot and by means of the aerodynamic action of the deflectors that leads them towards the ventilation devices: the left component provides for the inflow of convective flows, by lowering the regulating element, and the flow, first vertical and then diagonal, towards the cavity; the right component provides for the outflow of air from the cavity to the outside. © Courtesy of Karl-Heinz Petzinka and Partners

- a series of deflecting wings, facing outside the façade, which guide the external convective flows towards the regulating equipment;
- the regulation apparatus, electrically operated with centralized control;
- a series of deflecting wings inside the device, located in the lower section, necessary to direct the flow, in a vertical direction, inside the cavity (Fig. 6.14).

The type of envelope with horizontal-vertical division determines the construction of the *shaft-box façade*, in which the cavity is divided by vertical separating elements, which alternate the internal sections in closed wall modules and in wall modules equipped with ventilation openings: this type combines the functioning of the continuous cavity façade, in the area of vertical separations, and the *shaft-box façade*, in the area of ventilation openings. The temperature difference generated in the areas of the vertical partitions and the resulting convective flows are used to

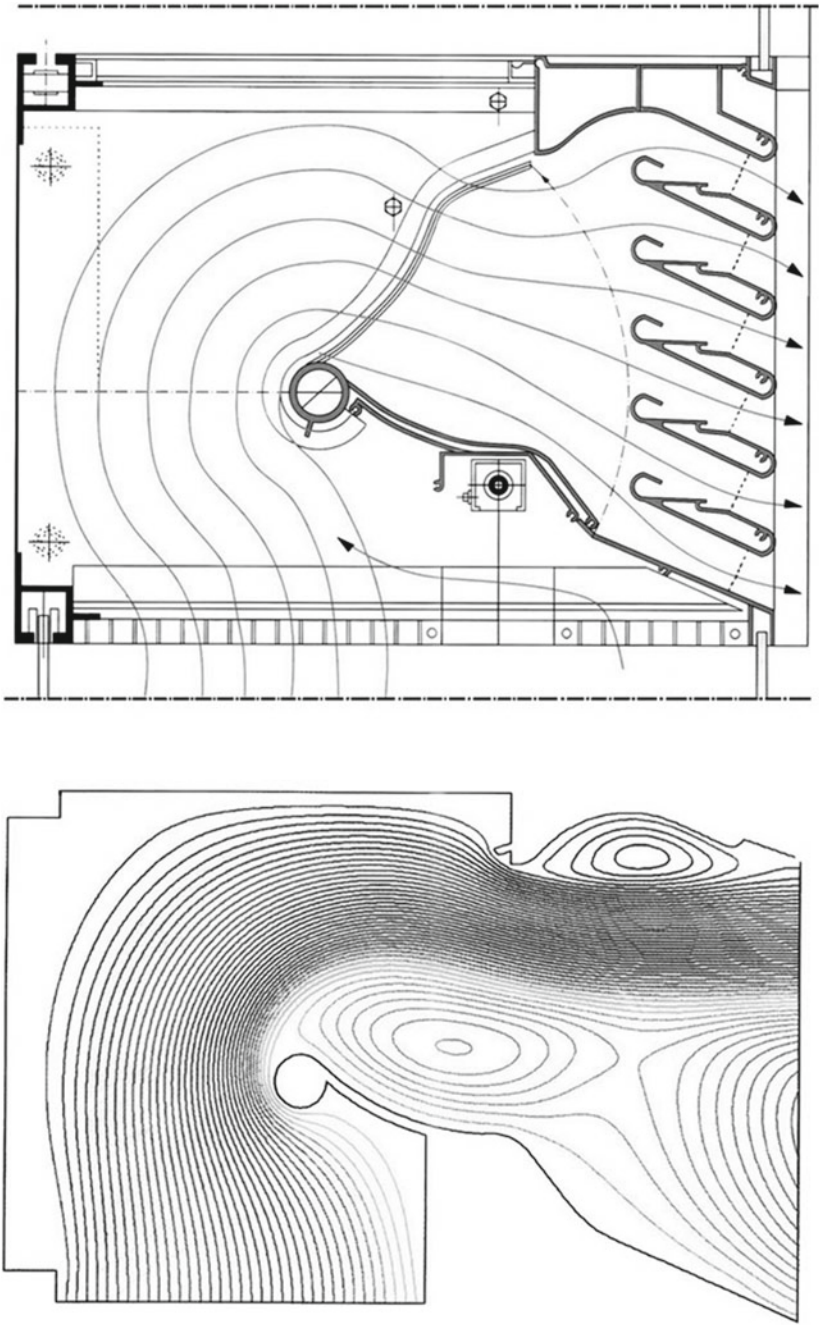

Fig. 6.14 Karl-Heinz Petzinka and Partners, *Düsseldorfer Stadttor*, Düsseldorf. Ventilation devices of the *corridor façades* characterized by a series of deflecting wings, facing outside the façade, necessary to direct the flow, in a vertical direction, inside the cavity of the double envelope. © Courtesy of Karl-Heinz Petzinka and Partners

increase the air exchange between the cavity and the interior spaces. The supply of outside air takes place at the curtain modules equipped with ventilation openings: the expulsion devices are located at the top of the side modules dividing the cavity. In this way, a depression is created that draws the exhaust air and allows the entry of outside air. The device that encloses the modules behaves in the form of an *environmentally responsive wall*, capable of "responding" actively and "organically" to climatic loads: it operates differently during the winter period, distributing the heat accumulated by the mass of air in the cavity, and during the summer period, with the aim of preventing overheating in the rooms by removing the heat and transferring it outside (Fig. 6.15).

The passive ventilation is of the vertical-diagonal type, through the integrated and functional constitution of three contiguous components, laterally enclosed by the transverse tempered glass partitions in order to conduct the air upwards and to prevent the internal flow from being reintroduced into the interspace. The double envelope units composed in this manner provide for side-to-side joining between the components and, therefore, between the ventilation devices:

- the first and third box-window components (integrated, laterally, by the vertical separation panel) provide for the ventilation devices to be in the open condition towards the outside, by means of the downward rotation of the concave wing element;
- the intermediate component is open to the reception of air flows extracted from the interior spaces (by means of the opening of the windows related to the two lateral components), by diagonal conduction and through the bypass openings arranged at the top of the vertical separation panels. It provides for the ventilation devices to be in the closed condition, by means of the upward rotation of the concave wing element, so that the inflow of external air is prevented and the outflow of internal air into the cavity (coming from the diagonal conduction from the two side components) is prevented. The functioning of the double envelope system is realized through the regulation of the ventilation devices, which realize the passive ventilation for cooling or heating of the internal spaces (combined with the reduction of heat loss by transmission): the opening and closing of these devices regulates the ventilation flow with respect to the temperatures of the air outside and inside the built environments, to the micro-climatic conditions (especially in relation to solar radiation) and to wind stress, affecting the energy use for air conditioning and heating of the internal spaces (Figs. 6.16 and 6.17).

The double envelope system is defined by two main sections:

- the internal enclosure, realized by an opening frame at floor height, with an aluminium frame and double-glazing. The frames relating to the central band (equipped with the components in which the air flow intake takes place) can only be opened for maintenance operations;
- the external screen, assembled to mullions and transom framing of the unit, made of a single sheet of laminated glass at floor height (Fig. 6.18).

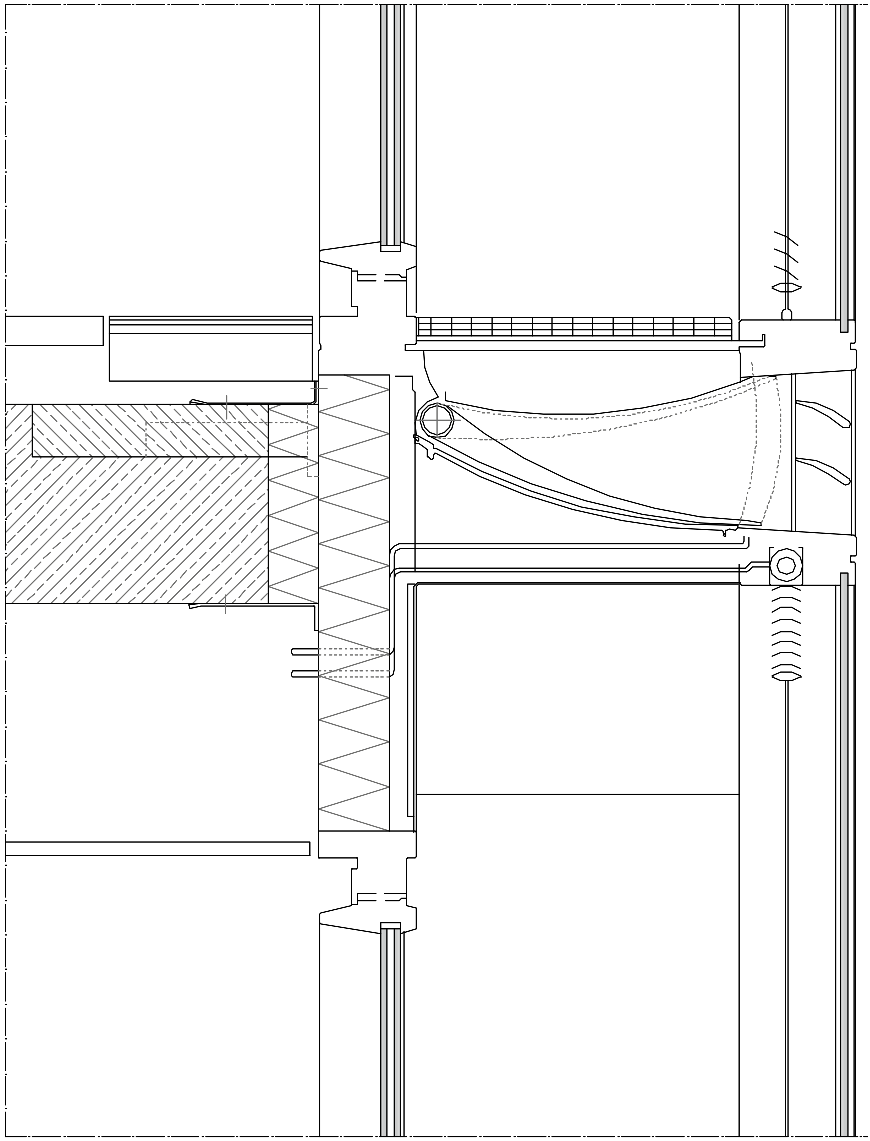

Fig. 6.15 Norman Foster and Partners with RKW (Rhode, Kellermann, Wawrowsky), *Arag* Tower, Düsseldorf. Louvers at the base of the two side components (as box-windows) introduce the outside air, which is drawn in convectively (for natural ventilation) through the motion generated by the central ventilated module: the opening and closing of these louvers regulates the ventilation flow with respect to the differences in air temperature (outside and inside) and solar radiation. © Courtesy of RKW

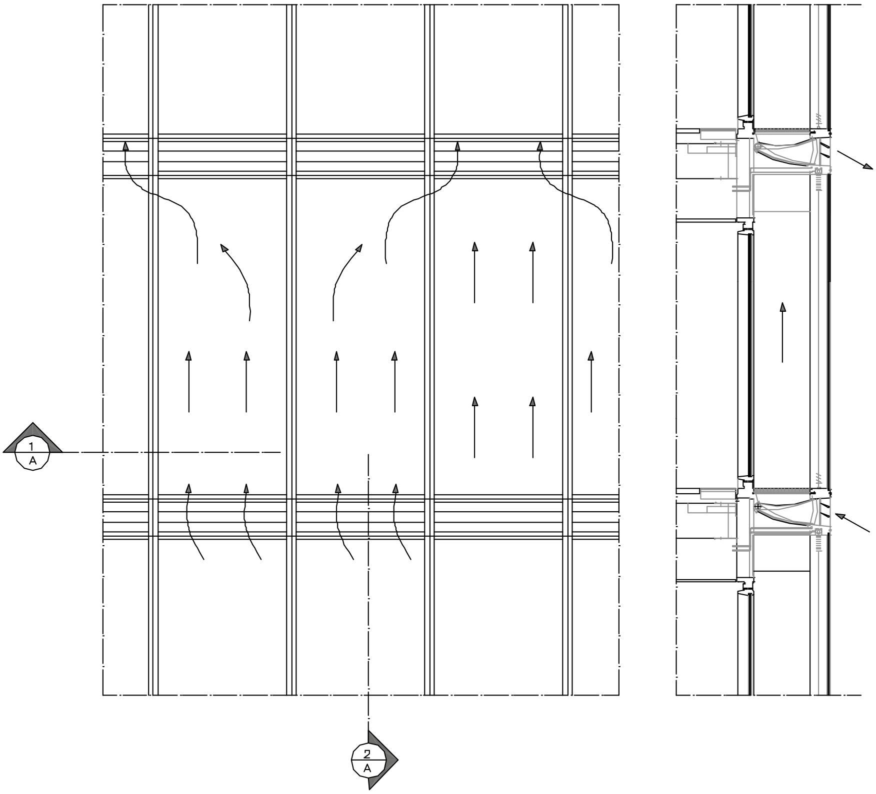

Fig. 6.16 Norman Foster and Partners with RKW (Rhode, Kellermann, Wawrowsky), *Arag* Tower, Düsseldorf. Double envelope units providing for side-to-side joining between the components and the ventilation devices, where the first and third box-windows provide for the ventilation devices to be in the open condition towards the outside and the intermediate component is open to the reception of air flows extracted from the interior spaces. © Courtesy of RKW

Fig. 6.17 Norman Foster and Partners with RKW (Rhode, Kellermann, Wawrowsky), *Arag* Tower, Düsseldorf. Functioning of the double envelope system which realizes the passive ventilation for cooling or heating of the internal spaces. © Courtesy of RKW

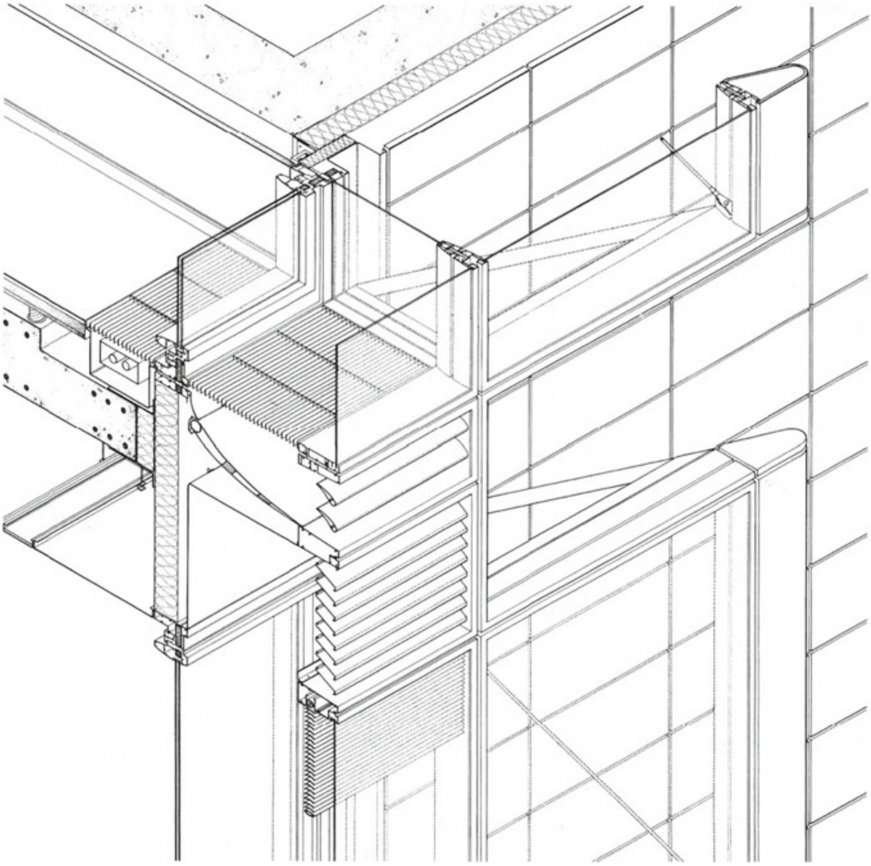

Fig. 6.18 Norman Foster and Partners with RKW (Rhode, Kellermann, Wawrowsky), *Arag* Tower, Düsseldorf. Composition of the double envelope system according to the application of the internal curtain (with opening frame at floor height) and of the external screen realized by a single sheet of laminated glass. © Courtesy of RKW

Moreover, the type of envelope with a horizontal-vertical division is articulated through the “cell” façade typology, defined by units that are independent of each other both on a functional level (as far as the ventilation of the cavity is concerned) and on a production and construction level. The units are equipped with air inflow and outlet openings, in which the ventilation louvers (also of the adjustable type) are displaced laterally, so as to prevent incoming and outgoing air currents from mixing. The application of the “cell” façade is defined according to the objective of regulating thermal, lighting and internal ventilation conditions, balancing environmental comfort in office spaces and controlling energy consumption: the functioning allows the regulation of ventilation, heat loss, solar radiation and natural lighting through the application of the sun shading in the cavity (Fig. 6.19).

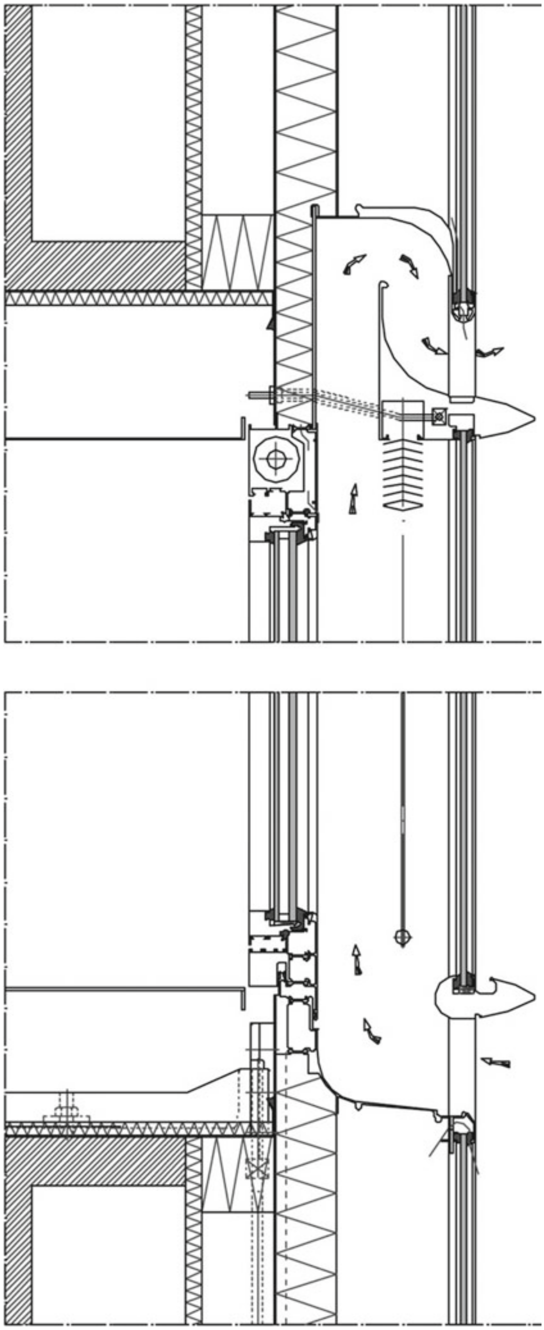

Fig. 6.19 Norman Foster and Partners, *Commerzbank* Tower, Frankfurt. Functioning of the system through the opening of the internal window frame with double-glazing, the regulation of air inflow and outflow, by the aerodynamic action performed by the two extruded aluminium wing profiles, for the capture of convective flows. © Courtesy of Norman Foster and Partners

Specifically, the system provides, through the opening of the internal window frame, for the regulation of air inflow and outflow, according to the aerodynamic action performed by the wing profiles (in extruded aluminium), for the capture of convective flow (in the lower position) from outside the façade towards the inside of the ventilated cavity and, subsequently, for outflow (in the upper position) towards the outside. The cavity between the internal window frame and the external cladding incorporates a sunscreen, which filters and reflects daylight, protecting the interior spaces from direct solar radiation and glare phenomena: during the winter season, this device can be closed, depending on the lowering of the temperature, so that the cavity can be configured as a thermal storage air cavity, sheltering the internal surface from the effects of low temperatures (and improving the thermal insulation of the window frames by 20%) (Fig. 6.20).

The process by which natural ventilation occurs involves the air induced from outside being diverted and forced into a circular convective motion by the flow generated by the solar radiation transmitted inside. In this way:

- part of the radiation is reflected and diverted by the sunshade foils;
- the upward rotational flow, heated mainly by computer equipment and operators in the office, is sucked in and conveyed outside through the opening at the top of the window frame.

In addition, the application of the shading device inside the ventilated cavity allows the thermal load to be conveyed towards the outside, preventing it from affecting the cooling and air exchange processes of the internal spaces.

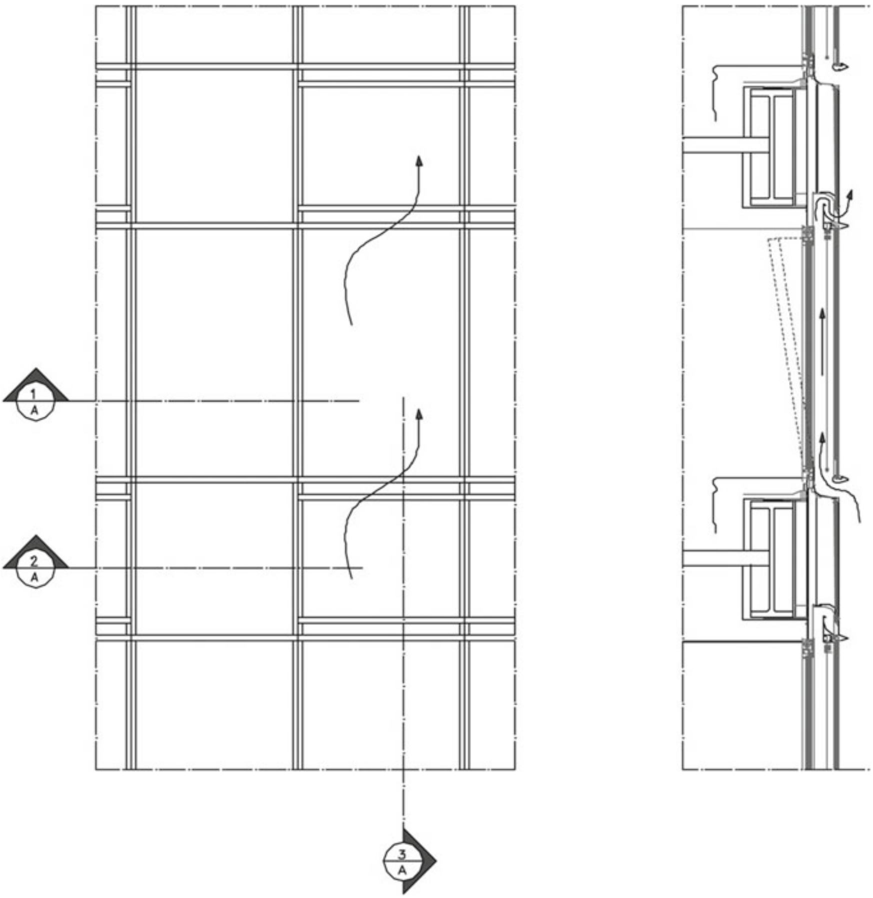

Fig. 6.20 Norman Foster and Partners, *Commerzbank* Tower, Frankfurt. Natural ventilation inside the cavity activated by the air induced from the outside which is deflected into a convective motion by the solar radiation transmitted inside. © Courtesy of Norman Foster and Partners