THOMAS HERZOG
ROLAND KRIPPNER
WERNER LANG

Facade Construction MANUAL

Edition DETAIL

SECOND EDITION

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Foreword

30 years after the publication of our first construction handbook, this is the first in the series to deal with facades.
Over the centuries, architects' design services have often concentrated on developing impressive section drawings of buildings, which frequently became objects of heated controversy over questions of style chosen as well as a medium for conveying new artistic positions.

There is now an increasing focus once more on facades due to the growing importance taken on by exterior walls in the context of energy consumption issues and options for making use of environmental energy. In addition to this focus, and usually contrasting with it, are efforts at self-promotion and "identification with the address" for those clients for whom the "packaging" of their buildings, which often have quite banal interiors, has long since become a substitute for quality architecture. The booming Asian megacities show this quite clearly.

The sequence of this book's chapters takes an expedient approach to designing and developing facade structures. Aspects that apply generally to the exterior walls of buildings, involving demands made on them, their principal functionality and structural design, have been separated from descriptions of the special features of individual cases. The book represents more than just a collection of different buildings in various locations and contexts, of different types and technologies. Rather, specific features have been classified and described based on the various materials used in their walls or cladding.
The first part deals with demands made on facades from the inside, which derive from the building's usage type. Buildings face very different local climatic conditions, depending on the region in which they are located. Out of this confrontation arise the functional demands on an exterior wall. These are formulated as a remit that is initially open to a range of possible solutions, so implementation details are not described in this section. The book's most important statements are made in the form of images, diagrams and schematic illustrations showing the morphology of surfaces and openings.
A building's envelope interacts directly with its other subsystems: its support structure, the partitioning of rooms and technical building equipment. Various interdependencies exist or must be defined so that each structural system can be geometrically coordinated in the space. Dimensional and modular conditions and proportions must be defined for the building as a whole to be developed. Combining these aspects results in the parameters for material implementation based on the materials and construction methods to be chosen. If the materials and technologies used to manufacture them are important in defining further specific features, then certain physical, material, installation-related and aesthetic details must also be coordinated.

The second part of this book's structure is based on this context. Here the chapters have been kept separate from examples and precede them. Each begins with a brief summary of the history of civilisation's use of the material and its specific features. Here we do not limit the area of materials applications to building construction, simply because as civilisation has developed, technology has often emerged in different ways and interactions with materials and initial applications have often emerged from very different areas. Stone, ceramics and metal, for example, are so significant that whole cultural eras have been named after them. Today too, much technical innovation comes from the construction industry, especially in modern facade construction, through a transfer of technologies from different sectors, such as forming technologies, surface treatments and robotics. These chapters are followed by a section showing a selection of built examples focusing on materials, which provides insights into the range of possibilities available and is designed to inspire readers to further develop their own ideas. This is done by way of drawings of main facade details with explanations provided in keys because this is the medium usually used for conveying information to architects.

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We selected new projects with facades that interestingly embody the building as a whole, as well as “classics” that still set standards because of their architectural quality as well as a range of details that may be of practical value for architects and engineers working on older buildings.
Projects are shown here not as whole buildings, rather our descriptions focus on their facades, which is why contributors other than architects, such as specialist engineers, are rarely mentioned in project descriptions, unless they played a major role in creating the facade.

Readers will also notice that in describing construction details we have at times diverged from solutions or technical rules customary in Germany, as is justifiable in a book full of international examples. Those who would like more details on a project described are referred to the more detailed bibliographical references, which are indicated with a “🕮”.

It may be regarded as valuable to depict a building as a large technical object, not as a complicated system, possibly unmanageable and consisting of many kinds of components, but succinctly, simply, equally powerfully and sensitively designed. Developments in recent decades and enormously increased demands on building envelopes however, have led to the emergence of multilayer structures, each layer of which has specific functions. This is now a frequent feature of modern structures made of almost all materials, so structures made of specific materials and special facade construction topics are dealt with in separate chapters.

A centuries-old principle of modifying and individually influencing the permeability of facade openings, whether for reasons of the building’s energy balance, interior climate, lighting conditions or safety, is dealt with under the chapter heading of “Manipulators”, which takes on a new topicality and covers a wide range of different types.
We also take the view that the prevalence of multilayer and double facades in recent decades requires special mention and discussion because there is still great uncertainty regarding their design and planning. Planners often simply follow fashionable trends instead of making good use of the main advantages of such structures. Basic errors are often made because there is not enough awareness of structural and energy technology interconnections or of individual variants available for possible use in construction.
The integration of directly and indirectly operating solar systems in building envelopes is still uncharted territory for many and successful combinations of practical value, technical-physical function, design and construction solutions are still the exception rather than the rule, even though the first pioneering applications were implemented decades ago.

Munich, spring 2004
Thomas Herzog

For this second edition, Part B on “Structures built with specific materials” and the “Special topics” chapter have been revised and expanded to include examples from the past decade.

New to this edition are three sections that do not deal mainly with specific materials but cover issues that have become increasingly important and need to be examined separately. The main reason for this are bioclimatic factors requiring special architectural solutions for the structural subsystem “facade” involving design in accordance with functional, technical and aesthetic criteria: refurbishment, the integration of annexed technical structural systems and the greening of exterior walls.

It was therefore natural to develop a separate third section of the book covering these six areas. After a general description of remit and operating principles, it depicts a range of different solutions and renderings and various examples of built structures that represent the current state-of-the-art.

Further developments are bound to follow, if only for reasons of efficiency, profitability and a commitment to sophisticated design. It is to be hoped that architects enthusiastic about the design of structural systems and components, people whose profession relies on an ability to comprehend the “technical organism” of a building as a whole, right down to the smallest detail, will continue to make cogent contributions to a broad “culture of construction” as a social imperative.

The authors would like to thank all the people, institutions, architects, photographers and companies that have supported our work with their skilful contributions and everyone who worked on the new edition.

Munich, summer 2016
Thomas Herzog, Roland Krippner, Werner Lang

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Shell, wall, facade – an essay

This book on facades focuses on their functional and technical aspects. Some observations will, however, first be made that go beyond these aspects and embed this very complex and culturally specific topic, which also directly affects perceptions of architecture, in a broader context.

A protective shell

Building envelopes offer protection from the weather and enemies and a place to store provisions, and were the first and most important reason for building. Unlike structures such as bridges, towers, dams or cranes, buildings contain rooms, whose creation and use are an essential element of human civilisation and one closely related to the exigencies of climate.

This is demonstrated by the fact that the effort involved in construction is much less in regions where the outdoor climate conditions are generally those that people find comfortable. The more divergent the outdoor climate and indoor climatic requirements are, the greater the technical effort required to meet the requirements of people living inside structures.

Over the course of human development, people have spent long periods searching for convenient pre-existing spaces for themselves and their animals, sites such as caves, grottoes in cliffs and rocks or very dense masses of vegetation, protected places that would offer suitable conditions for survival (Fig. 2).

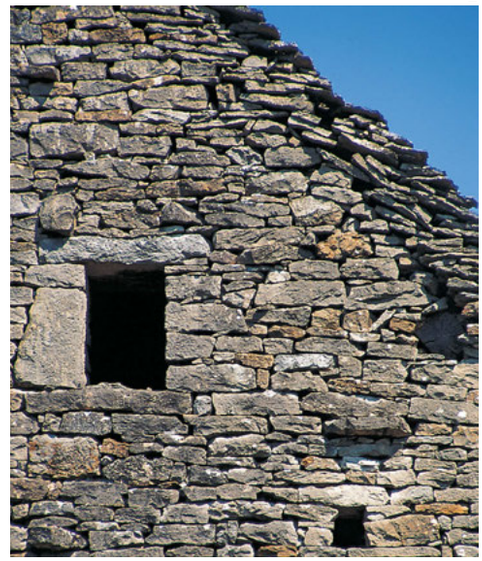
When people settled, they began to create such spaces artificially, using materials they found and various construction processes. They built roofs and exterior walls, and the exteriors of built spaces became important in providing protection from the weather and fulfilling various other functions (Fig. 3).

The hollow spaces existing in nature, surrounded by masses of stone or earth, were now reduced to relatively thin-walled structures built by people. Buildings, with an inside and an outside.

The term “exterior wall” designates in its constituents its position, namely “exterior”, and the character of this structural “subsystem”, that of a wall. During the history of construction – at least until and into the 20th century – walls have not only enclosed space, but also been an important part of the support structure that transfers its net load, own weight and the weight of roofs and wind forces imposed on them through the stiffening effect of the solid structure into the foundations. The word “wall”, especially the term “exterior wall”, is associated with a stable, robust, usually heavy, perhaps even forbidding element, which separates the private from the public and determines a building’s exterior character.



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1 Sucevita Monastery (RO) 16th century
2 Cave dwelling
3 Exterior wall made of local natural stone, Auvergne (FR)

A building’s exterior surface was now also a counterpart to its inner surface, long used as an important communication medium (e.g. for cave paintings). From now on it would also be a medium for images reflecting profane and sacred social structures and conveying hierarchies of values and claims to power.

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4 Farmhouse museum, Amerang (DE)
5 Majolica frieze on the “Ospedale del Ceppo”, Pistoia (IT)
6 Alhambra, Granada (ES)
7 Cathedral of San Martino, Lucca (IT) 12th–15th century
8 Casa Batlló, Barcelona (ES) 1906, Antoni Gaudí

Materials and construction

The space created between exterior walls now had to meet all the demands and functions of use and comfort. To do this, local conditions and users’ requirements had to be precisely recorded, influenceable and achievable through appropriate construction methods.

Technical solutions emerge in the context of materials, construction, joining, manufacturing processes, as well as result from demands that arise from gravity and other exterior and interior physical influences and factors. Building shells reflect the development of technologies in a region and with them a significant aspect of the local culture.

A decision to use a specific material may be based not only on demands coming from inside or outside, but also on rules governing the process of constructing a building envelope that must be observed. It is not only individual user requirements that determine a facade’s formation; they must also be considered in the context of issues of joining, construction and of technical implementation within the overall structural system, material principles and geometric order (Fig. 4). Here the professional skill of architects in their role as “master builders” is essential because only they know all the connections and various interdependencies within and between an architectural composition and the logic of construction.

Form

Exterior walls are often called “facades” in common speech, so apart from their basic functions of protection from the weather and shaping of the indoor climate, another aspect comes to the fore: our perception of a building based on its “face”, which is derived in a roundabout way from the French word “facade” and the Latin “facies”. What we mean here is something built, something that “looks out” into its environment, the first and most important semantic message we perceive [1].

Surfaces created by people have always also been information media, showing images of things governing our social life, transcendent and religious projections, objectives and reports: the veneration of deities, the hunt or ritual, combat, nuptials, prey and death, long before writing became available as an abstract form of communication (Fig. 5). The pictorial qualities of exterior surfaces are like those of interior surfaces in terms of their graphic features, structures, colours, engravings and reliefs, mixtures of information from writing, image and material effect. The entire spectrum became visible in pictorial form over the course of history – “the frisson of creation and the horror of death” [2].

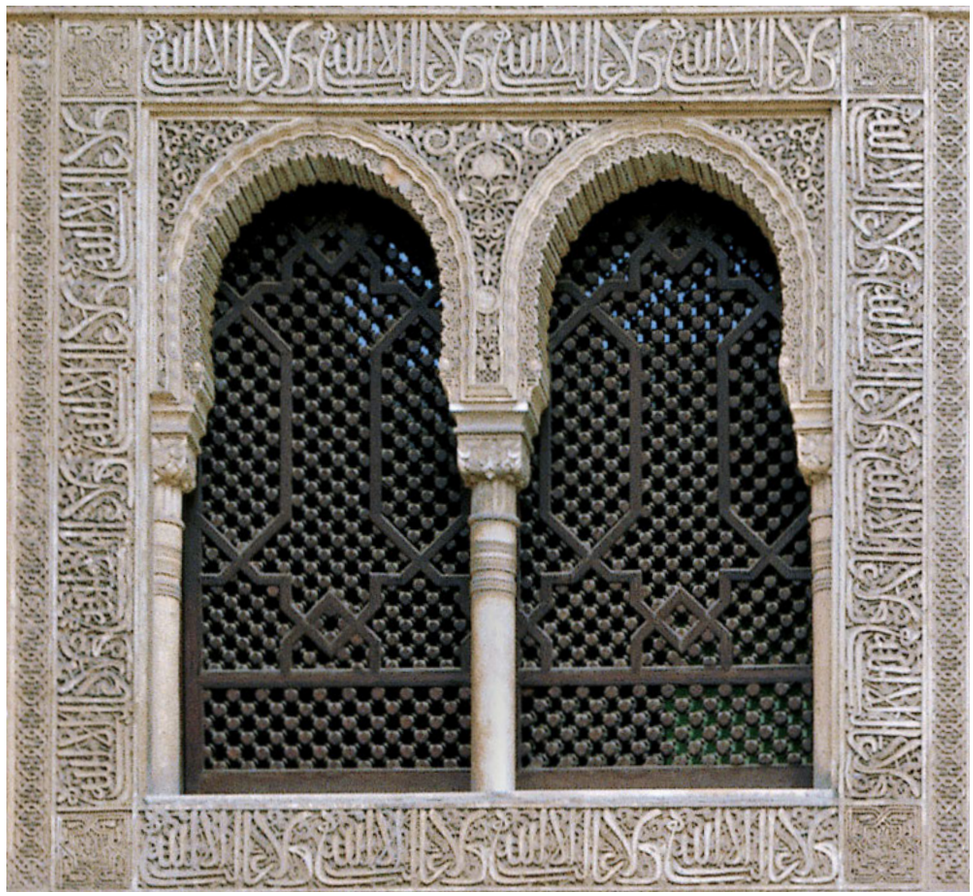
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It was humankind that first created buildings with their own differentiated form, three-dimensional objects that can be perceived from outside as a whole or as a composite of various individual items. Compared with simple wall surfaces, these had other features such as spatial proportions and volume in relation to their surroundings.

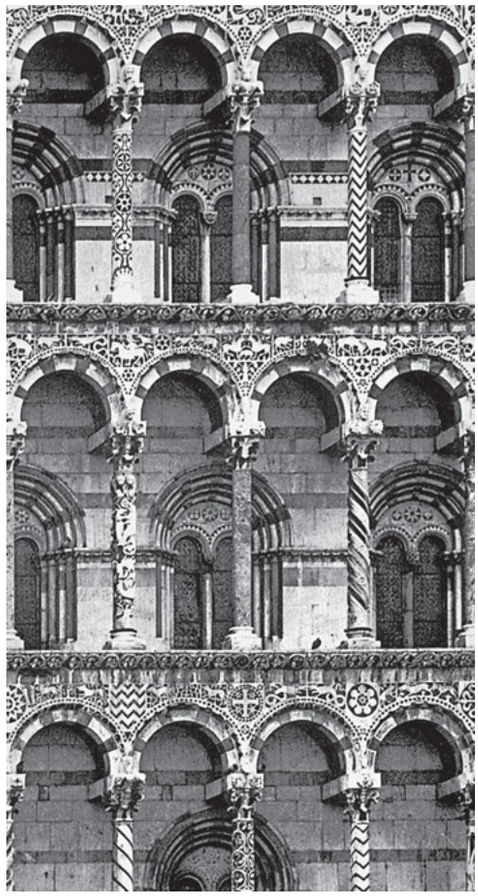
Built walls began to be differentiated as their construction became increasingly refined, with openings in them undergoing a similar process. Here too, the function and technical solution of framing them in a wall with a lintel and arch of the same or other material initially predominated. Requirements such as letting the maximum amount of light in through the smallest possible aperture by angling reveals at the sides inside and out, light refraction, screening those inside from view, regulating ventilation through external or set-in elements by varying their types and shapes, as well as artistic sophistication all became essential elements of architecture's overall impact (Fig. 6).

As for walls, local materials were also often used to equip openings with fixed or moveable elements. In some cases, veritable treasures with very elaborately designed faces and surfaces were created. The composition of multilayered front facades, such as those created for the cathedrals in Lucca and Ferrara, gives rise to a magnificent interplay of wall and opening by alternating spatial depth and a plastic moulding of all details (Fig. 7).

Additional effects were created on and around the facade by overlapping or penetration and alternating displays of objects, resulting in varying or alternating brightness and light and shade effects across the structure's overall volume and all its parts. Stereometric orders were abandoned in favour of a free development of forms, and there was a change from rounded surfaces curved in the same direction as or conversely to planar areas, which can be horizontal, vertical or tilted, folded or formed with other subdivisions (Fig. 8).



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The sociocultural environment

Local conditions, the type of society living in a specific region, its history, ethnography and view of the world, the local climate, which can differ across short distances, and the availability of local resources have all had a central influence on the design of building exteriors.

These issues influence regional or local cultures at the heart of what characterises societies, stabilises them, orients them and forms a basis for civic conventions. Coexistence requires cultural covenants. Buildings' appearances position them as contemporary documents for the long term [3]. In this sense, it is clear that buildings' exteriors have a special meaning that extends well beyond an individual building's effect, when we think of the dimensions of street frontages, squares or quarters, where exterior walls taken together define the public space.

The characteristics of facades' material effects, colours, proportions, volumes and pictographic information signal both the function that these things have and the importance attributed to them. There is, however, a risk that through arbitrary applications or disassociation buildings can take on a new semantic significance, one that can alienate them from their essence and cause them to lose their "integrity" – whether due to excessive tolerance of arrogant self-promotion or as a result of setting the wrong goals.

This does not rule out purely fashionable fittings in temporary situations, like those in art forms that rely on the passing of time or time limits, such as plays, opera, ballet or film. But if such features are allowed to define architecture, they can destabilise its aesthetic identity and any orientation towards wider cultural credentials can be lost.

Nor can a building's appearance be evaluated within the confines of a closed canon because that would mean that culture only prevails when it is frozen and no longer further developing. It is a feature of cultural processes that designers work creatively with existing traditions (Fig. 12).

An awareness of the importance of a building's exterior and its effect in public space should be seen as an essential aspect, relying on communication in a community. Having a building built involves communicating your views to those outside, signalling your own identity and how it defines a degree of intentional affiliation or classification in an existing spatial and structural context. An architect is usually involved in further developing this context [4].

Many examples show how much during the Renaissance, with humanism flourishing and an appreciation of the independently minded individual growing, the effect [illegible]

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as “display walls” was emphasised (e.g. Fig. 10). This emphasis was further heightened in the baroque era, which created facades oriented towards streets or squares that, in contrast to buildings’ other exteriors, became huge sophisticated backdrops with elaborate designs, using costly materials and important artistic media, almost detached from the building as a whole. More than technical or utilitarian aspects, a facade played a central role in showcasing architectural effect. An exterior wall became an image medium incorporating reliefs, sculpture, painting, mosaic and text. Walls’ primarily functional parts became objects of the highest decorative moulding (Fig. 9).

The integration of new design media and communications technologies have made “media facades” possible worldwide. Despite displaying new kinds of graphic and colour effects in transparent and translucent glass and membrane surfaces, these facades follow in the footsteps of earlier building envelopes as image media. An example in London (Fig. 11), where two originally similar structures face each other across the street, shows how this change can lead to contrasts, even denaturation. Once daylight’s competing brightness dims sufficiently and artificial light can dominate, electronically controlled LEDs and videos are the defining aesthetic factors of the information conveyed on these buildings’ exteriors and their architectural effects (Fig. 13).
The materials used in these buildings’ historic forerunners and their graphic or sculptural design entirely determined a facade’s effect, intensifying our perception of the building itself. Its own, original elements were the reason for this. The situation is different when a non-representational semantic message is conveyed by a neutral medium like a computer programme or projection technology that is not of the designer’s own making. Variable software allows for complete independence in terms of the content shown and largely also in terms of the form of presentation.

Facades with a very intensive effect created by constant change are the main attraction of this kind of urban space. The kind of continuous change due to the constant integration of new forms of technology is apparent on Times Square in New York – just one of countless examples. It creates a completely new, intensive cultural reference that other media make more effective, causing the aesthetic significance of the building’s facade to fade into the background (Fig. 13).



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9 Painted facade, Trento (IT)
10 San Giorgio Maggiore, Venice (IT) 1610, Andrea Palladio
11 Piccadilly Circus, London (GB)
12 Old – new, transition in detail
13 Times Square, New York (US)

Ageing

If we assume that a building enters into architectural history once it is completed, the issue of its ageing immediately arises, especially as it affects its external appearance, the building envelope, the part most exposed to the weather. It is exposed for a long time to a range of encroachments which eventually cause not only technically and functionally relevant changes but also changes in its appearance.

Some facades decay, deteriorate and become “shabby”, ageing badly because of their construction and materials. Others do not seem to age at all, which is due to the same technical criteria. Panes of glass, for example, some of which have been installed in buildings for centuries, may develop a slightly damaged surface, but their material and aesthetic characteristics may change little. Some materials age acceptably within a short time, even though they can change greatly, and may even become more beautiful, which is referred to as patination (Fig. 19). They do not lose their serviceability or technical fitness (because parts decay or sections become too thin due to corrosion, for example).

The creative and technical design and planning of facades therefore also involves ensuring that they will maintain their quality as they age and not lose value. Society’s willingness to accept such aesthetic changes and rate them highly for use in architectural monuments and valuable items is made clear when materials are known outside their natural context, as is the case for stone, copper and bronze. The most typical example may, however, be wood, which people know countless types of from



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childhood wherever it grows, and are aware that its appearance is never in a permanent state, as the example of an extension by Peter Zumthor in Versam shows convincingly (Fig. 20).

Outlook

If we ask ourselves now in the second decade of the new century what further developments can be expected in the facades of existing and new buildings that define public space and attract attention to their relation to existing buildings in various ways, we will find plenty of examples indicating answers.

Surprising effects created by unusual dimensions and/or a high-contrast, intensive long-distance effect, for example, often testify to planners' and builders' ambitions for a building with an outstanding, dominant effect, compared with the moderate "volume" of the architecture of other buildings in the urban environment (Fig. 15).

An expansion in design possibilities by breaking up building envelopes into polygonal instead of orthogonal elements of the usual kind has emerged where the choice of small structural elements, such as bricks, had hitherto allowed a high degree of freedom for ornamental design or where basic technical conditions made it inadvisable to divide surfaces using straight edges, in membrane structures, for example. It has become possible, however, to use CAD/CAM to divide surfaces in diverse, playfully individual ways, whose arrangement, interconnections and measurements are then precisely geometrically defined for manufacture and positioning. The buildings on Constitution Plaza in Melbourne were early precursors of this technique. Examples of buildings built after them, such as the Bergeron Center for Engineering Excellence at the York University campus in Toronto, illustrate use of these new options (Fig. 17).

Self-regulating, polyvalent systems that can be specifically used with new daylight technologies to reflect, refract and direct light to give roofs and facades a varied shared "skin", expand design options while dispensing with kinematics for regulation, for example, managing high levels of direct solar radiation in summer. At the same time, they allow diffuse light to penetrate and light rooms and enable users to see in and out (Fig. 16). Providing ventilation that is not flow-dependent in a building envelope can also expand the range of design possibilities.

Hopefully, the ever increasing need for thermal insulation will someday cease to be responsible for technical and aesthetic impairment. The purpose of a dormer window was traditionally to let in light and air, yet adding insulation to this kind of small window with a 0.2 m^2 glass surface, which for decades precisely fitted into a roof surface as a minor single element, has now turned it into an aesthetically absurd, disproportionate lump (Fig. 14).

Photovoltaic systems products, which are becoming increasingly efficient, cost-effective, colourful and varied in structure, will spread worldwide on a large scale. What is uncertain is what other innovations will emerge out of the science and technology of opaque, semi-transparent and fully transparent materials, whether in the area of generating and storing energy, providing shade by adapting a building's geometry to the sun's course, or in systems with modifiable properties or different conditions impacting the separating "building skin" in the form of outdoor or indoor climates.

Highly efficient insulating materials built into light, slender, moving parts that are easy to handle, in the opening sections of facades, for example, and insulating vacuum glazing, long extensively produced in Asia, will reveal their structural and physical potential and range of applications in various structures.

What is certain is that any construction or conversion of buildings that has to meet required comfort standards must do so simply and efficiently, based as far as possible on local climatic conditions. A building envelope can provide not only protective functions against unpleasant weather, but can also activate potential to create desirable bioclimatic effects inside the building in a way that allows for large-scale application in urban space. Only then can we expect a positive impact on the causes of climate change and new opportunities. If such basic elements do not remain the exception only for special customised buildings, but are instead applied worldwide in regional architecture and appropriate design and planning, they could become part of a solution for confronting potentially ominous, negative global developments.

Notes:

[1] That this is not always seen as a positive effect is shown by expressions like "it's all a facade", meaning that a person or thing's real quality is not what it seems on the outside.

[2] Jochen Wagner, Evangelische Akademie Tutzing, TV broadcast 02/2004

[3] This psychologically stabilises both the individual and society. The built environment is an important "prospect" for feelings of belonging, a sense of home and of individual identity.

[4] In his essay "Zukunft bauen" Manfred Sack wrote, "... every facade, and more, every structure, is a public issue and the Devil take the architect who takes it lightly. A facade belongs to everybody; only what's behind it is the business of those who have to live with it. So it is clear that a facade cannot be allowed to be a cosmetic feature. A city that is regarded as beautiful is, contrary to the assumptions of some, a social, general and political remit". From Sack, Manfred, "Verlockungen der Architektur". Lucerne 2003

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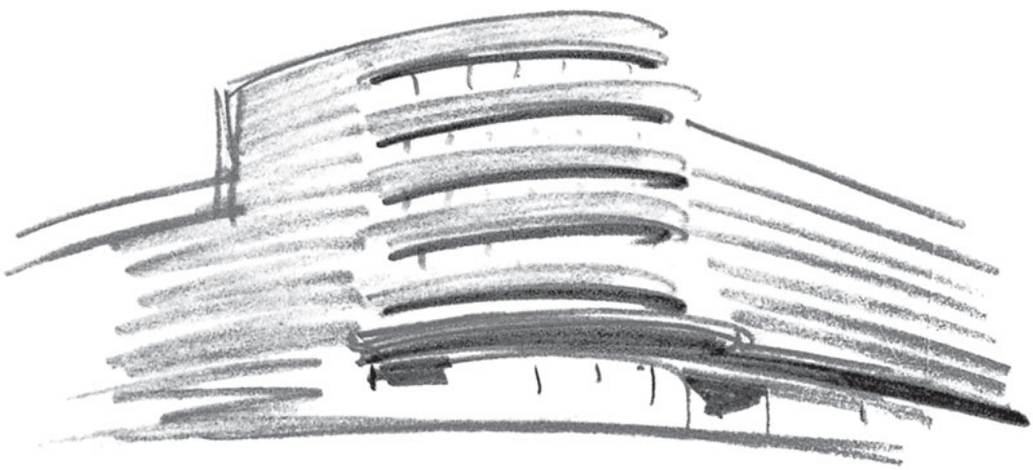


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14 Insulated dormer
15 Königsallee (Kö-Bogen) Düsseldorf (DE) 2013, Daniel Libeskind
16 Cité du design, Saint-Étienne (FR) 2009, LIN Finn Geipel and Giulia Andi
17 Bergeron Center for Engineering Excellence, Toronto (CA) 2015, ZAS Architects
18 Facade covered in climbing plants
19 Patinated bronze bay window, Boston (US)
20 Weathered wooden facade, Versam (CH) 1994, Peter Zumthor

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Part A The fundamentals

Whatever specific and very different facade designs may result from particular technologies and materials, there are also general rules and interdependencies that arise out of a building's basic functions, the type of loads and stresses imposed on it, the logic of its structure and the way it fits together, its geometric order, options for using prefabricated elements and physical effects.
These rules and interdependencies are overarching principles of general and fundamental significance, so we present them here before describing some completed buildings in detail.

Sketch for the Schocken department store, Stuttgart (DE) 1929, Erich Mendelsohn

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Outside

Site-specific conditions

Solar radiation levels
Air temperature
Humidity
Precipitation
Wind

Large fluctuations in external climate conditions

Local sources of noise
Pollution from fumes and dust
Mechanical loads
Electromagnetic radiation

Urban planning / design environment
Local resources
Sociocultural context

Facade

Functions offering protection from constant and changeable conditions (enhancing or reducing their impact)

Insulating / dampening
Sealing / blocking
Filtering
Storing (energy)
Controlling
Mechanical protection

Control functions

Controlling / regulating
Reacting / changing

Supplementary, direct-acting measures

Thermal insulation
Sun shading
(e.g. shutters, awnings, brise-soleils, louvres etc.)

Measures influencing the microclimate such as vegetation, bodies of water

Supplementary building technologies

Projecting collectors
Photovoltaic systems
Underground air ducts, geothermal probes etc.

Integrated facades

Integrated air and water collectors
Solar walls
Media cable routing / distribution
Heat recovery

Inside

Requirements

Minimal fluctuations in internal climate conditions

Comfortable temperature / humidity levels
Quantity and quality of light (lighting environment)
Exchange of air / inflow of fresh air and tolerable air speeds
Comfortable acoustic environment

Provision of views of the outside
Separating the private from the public
Mechanical protection
Protection against fire
Limiting the impact of toxic pollutants

Supplementary, direct-acting measures

Protection from glare
Screening from view (e.g. curtains)
Refraction and reflection of daylight etc.

Activation of interior structural elements (floors, walls, ceilings) for storing energy, heating, cooling and time-delayed release of stored energy

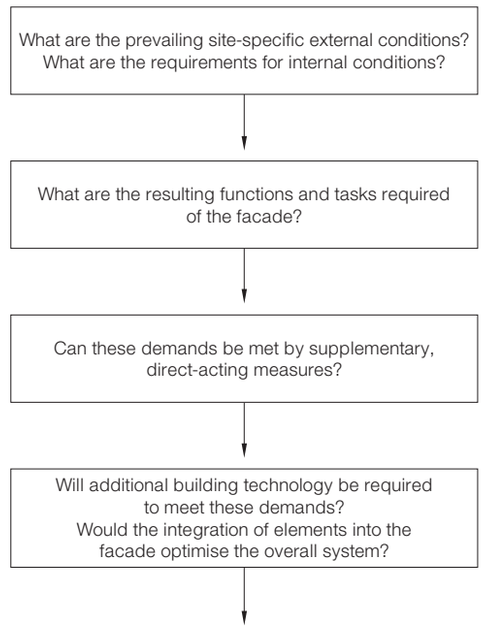
Supplementary building technologies

Convection heaters / radiators
Artificial lighting
Air-conditioning technologies (central/decentral) etc.

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A 1 External and internal conditions

The facade forms a separating and filtering layer between inside and out, between nature and people's dwelling spaces. Seen in a historical context, a desire for protection from an inimical outside world and the rigours of the weather was humanity's primary reason for enclosing interior spaces against the outside. Various other demands were subsequently added to these protective functions: interior light, an adequate exchange of air and the ability to see out while demarcating the private sphere from public space etc. Special technologies make it possible to regulate openings, allowing control and regulating functions to be added to the list of protective functions. Based on the direction from which a facade is viewed, all these demands can be classified into two groups and can be subdivided into countless individual aspects: site-specific external conditions and demands on internal conditions. A comprehensive understanding of these fundamentals and of their interdependencies and interactions form a basis for decisions in planning and building a facade.



A 1.2

Demands on facades from inside and out

Planners cannot usually influence external conditions, so they are essential criteria in finding and selecting land to build on. Every site offers specific, unique external conditions that require careful analysis because they vary in type and intensity depending on their district, region, country and continent. The immediate surroundings and microclimate can also have a significant influence. As well as the specific local climate with its specific statistically identified quantities and distributions of precipitation (rain, snow and hail), a nearby noisy industrial area that emits a strong smell, for example, may necessitate special measures for the planning and building of a facade.

In contrast, demands on internal conditions are not predetermined, but are decided on in the planning phase, based on a catalogue of requirements, which is drawn up in the context of planned usage. Precise knowledge of these key criteria is critically important in successful planning as they have an immediate influence on structural solutions and determine the amounts of energy and materials required for construction and operation in the long term. As well as demands on the interior climate, which are largely defined under the heading of "comfort" (see Fig. 1.12, p. 22), extensive measures arising out of various other qualitative requirements, such as a desire for a high-quality design or greater protection against break-ins, may have to be met.
These conditions and demands, shown in graphic form in Fig. A 1.1, determine a facade's protective and control functions. The former offer protection from the intensity of external influences, especially from the weather. The latter measure out their required and acceptable

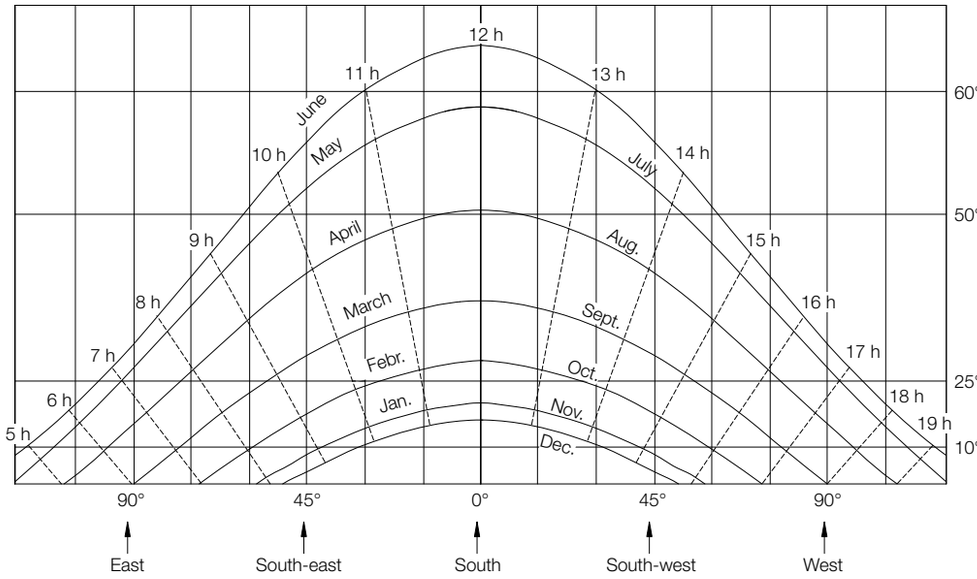
A 1.1 Requirements on facades from inside and out; protective, control and communication functions; supplementary passive measures and building technologies
A 1.2 Key questions/procedures for identifying marginal conditions and requirements

levels for the interior climate with the goal of achieving "thermal comfort".
If a facade is considered as a person's "third skin" (after their bodily skin and clothing), the analogy of planning goals becomes clear. Each of these functional layers must reduce the range of fluctuations of external climate conditions impacting the inner body to ensure a constant body temperature of about 37 °C.

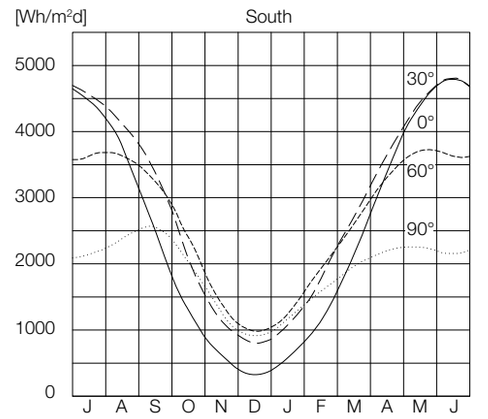
Climatic conditions may also dictate requirements that cannot be assigned to one side or the other but result from differences between inside and out, such as those caused by differences in temperature, moisture and pressure, which impose mechanical stresses on facade materials and structural details. Such stresses must be able to be absorbed by suitable measures (e.g. expansion joints, flexible connections etc.).

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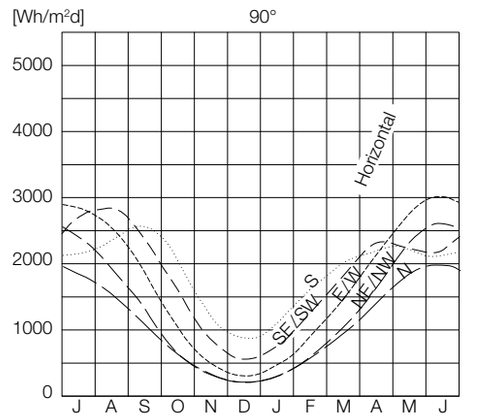
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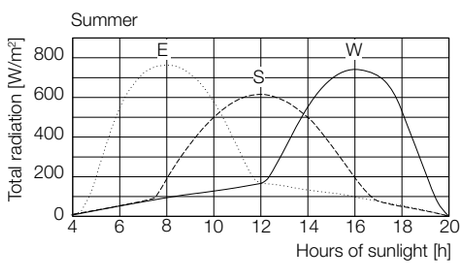
A 1.3

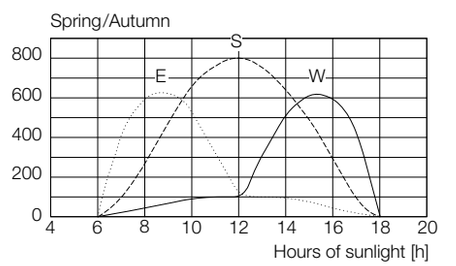


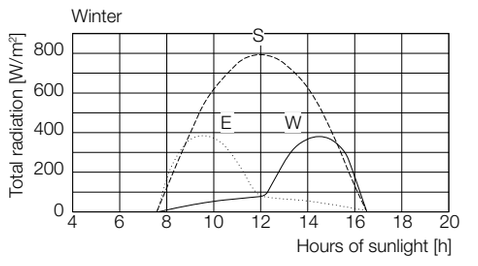
A 1.4



A 1.5







A 1.6

A 1.3 Diagram of the sun's course (50° N)
A 1.4 Solar radiation hitting south-facing surfaces pitched at various angles
A 1.5 Solar radiation hitting vertical surfaces facing various directions
A 1.6 Total solar radiation hitting wall surfaces pitched at various angles on sunny days at different seasons

Facades' performance potential

A facade should be able to meet the requirements resulting from the climate as much as possible. Adopting this approach can minimise or avoid the need for additional measures, such as further technical equipment, to control the interior climate. Knowledge of the relevant basic physical principles involved is indispensable in achieving this planning goal.

Supplementary direct-acting measures can support such functions on both sides of the facade. Other structural elements inside the building can also be "activated" to do this, by storing energy in walls and ceilings, for example.
Open areas of water outside or in interstices can be used for cooling (by evaporation) or dehumidification (if there is a sufficient difference between the temperature of the water and of the air in the room), and appropriate measures can make use of energy generated during peak periods. Solar radiation, from which buildings need protection, can be turned into electricity by means of photovoltaic modules or absorbed by collectors and used to heat water. High outdoor temperatures, wind and rain can also be made use of (see "Solar energy", p. 294ff.).
Remaining requirements that cannot be adequately met through structural measures must be met by technical systems providing temperature control, lighting, air purification, a sufficient exchange of air or humidification or dehumidification. Such supplementary technical measures always require additional energy as well as costly and complex transport of media and maintenance. If technical equipment of this kind is directly integrated into a facade, it is referred to as an "integrated facade" (see p. 322ff.). Equipment housed not in the building's technical centre but in the facade, at the point where it is required, is referred to as "facade-integrated decentralised building technology" [1].

Apart from external factors, other conditions imposed by the overall structural context must be taken into account, including the coordination of dimensions (see "Modular coordination", p. 46ff.), structural interdependencies, necessary tolerances and installation sequences – topics that will be dealt with in subsequent chapters.

External conditions: solar radiation

The sun is one of the most central and essential of all site-specific external conditions. It is our greatest direct and indirect energy source and makes all life possible.
The amount of energy that it sends to the Earth is about 10,000 times what humanity's global energy requirements were in 2000 (1 terawatt

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1,353 W of energy hits every square metre of the Earth's outer atmosphere). For human purposes, this is an infinite, cost-free and environmentally friendly source of energy.
To make use of solar energy in a building, it is essential to consider the intensity and duration of the radiation on its surface, depending on its facade's orientation and inclination. In planning facades, the following related factors and interdependencies must also be taken into account if solar radiation is to be made use of:

- The course of the sun, depending on the location and time of day and year
- Solar radiation levels, depending on the surface's orientation and inclination, location, time of day and year and weather
- Various kinds of solar radiation (diffuse, direct and different wavelengths) and their quantitative ratio depending on the weather, direction, location and time of day and year
- Interactions with surfaces and materials
- Relation to heating requirements based on planned usage

Figures A 1.3–A 1.11 show a selection of the main factors involved

The following solar radiation figures can be used as a basis for Germany [2]:

1,300–1,900	hours of sunlight / year
750–1,250	hours of sunlight / heating limit 15 °C
500–950	hours of sunlight / heating limit 12 °C
400–775	hours of sunlight / heating limit 10 °C

The proportion of diffuse radiation of all radiation accruing over a year is approximately:

South-facing facade	30 %
East and west-facing facade	60 %
North-facing facade	90 %

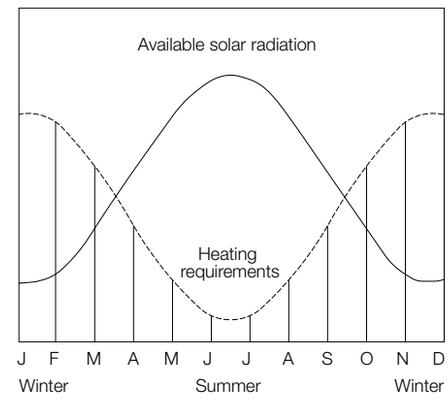
(Difference from 100 %: direct solar radiation)

Solar radiation can also be hazardous for people (overheating, premature skin ageing, skin cancer), who may need suitable protection from it.

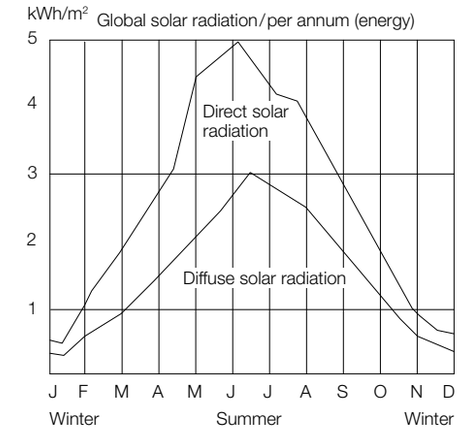
Thermal comfort

The various demands on internal climatic conditions can be summed up by the term "thermal comfort".
Among the main factors influencing these demands that are connected with the facade, are (Fig. A 1.12):

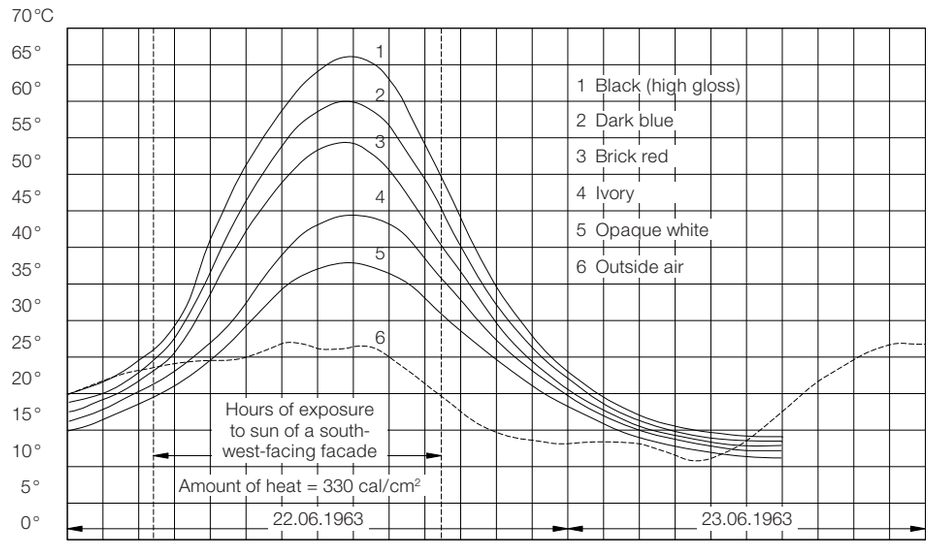
- Temperature of the air in the space (a)
- Relative humidity in the space (b)
- Surface temperature of structural components adjoining the space (c)
- Air flows reaching the body (d)



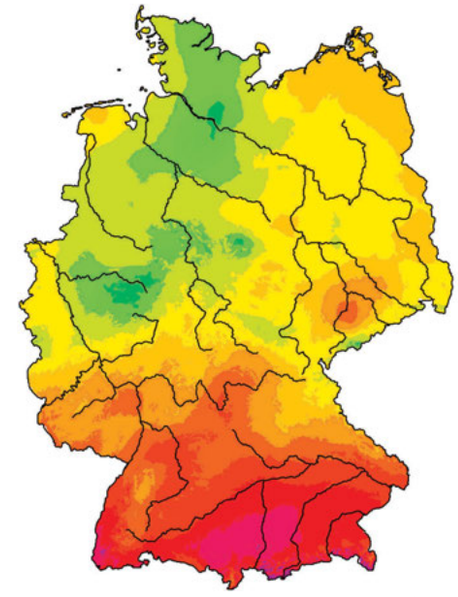
A 1.7



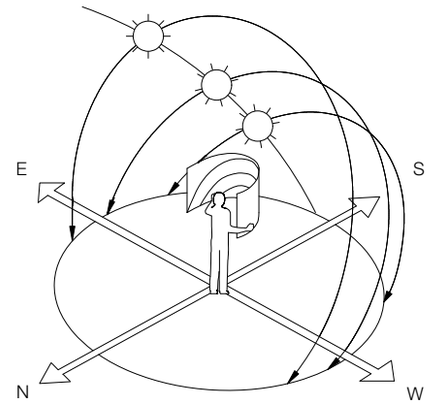
A 1.8



A 1.9



A 1.10

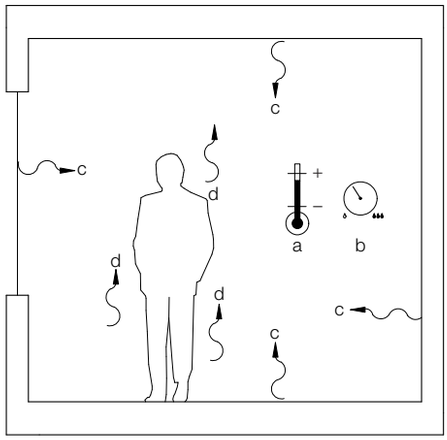


A 1.11

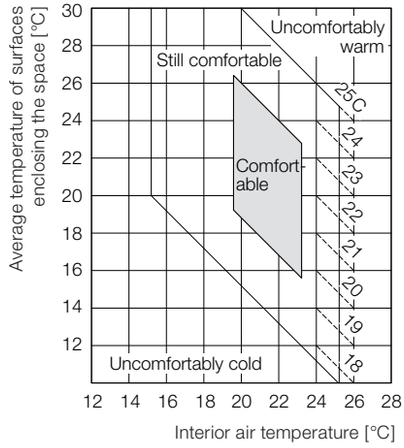
A 1.7 Heating demands / duration of sunshine (schematic diagram)
A 1.8 Daily average intensity of solar radiation in central Germany (50° N)
A 1.9 Temperatures measured on a sunny day on the surfaces of south-facing facades of different colours
A 1.10 Local distribution of annual global radiation [kWh/m²] in Germany
A 1.11 Projection diagram principle of the sun's course

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A 1.12

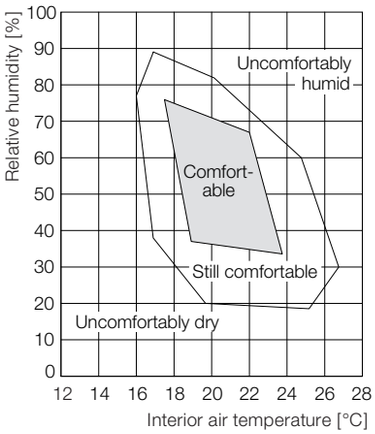


A 1.13

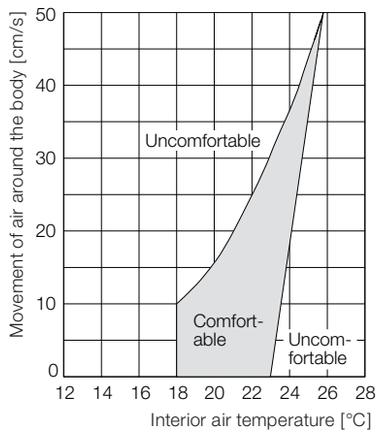
A 1.12 Factors influencing thermal comfort
a Interior air temperature
b Interior relative humidity
c Surface temperature
d Flows of air around the body

A 1.13 Interior/surface temperature
Comfort zone, depending on interior air temperature and average (fairly constant) temperature of surfaces enclosing a space (based on Frank, 1975)

A 1.14 Interior temperature/relative humidity
Comfort zone, depending on interior temperature and relative humidity (based on Leusden/Freymark, 1951)



A 1.14

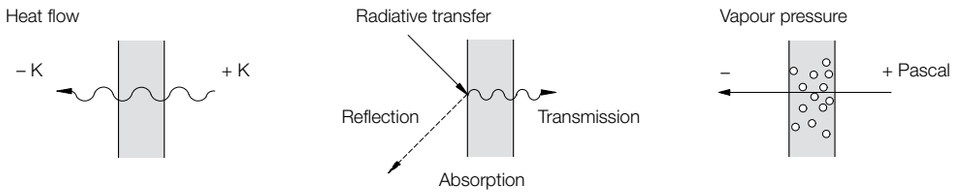


A 1.15

These measurable parameters, which can vary depending on region, habits, clothing, activity and individual perception, define thermal comfort. The ranges in which figures for individual influencing factors should be are called "comfort zones" (Fig. A 1.13–15). There are no binding target figures for any of these factors, and they are all mutually interdependent. Perceived room temperature consists of approximately equal parts of the temperature of air in the room and the average radiation temperature of the surfaces enclosing the room.

The idea of comfort is now increasingly being interpreted as involving more than just climatic requirements and has come to include
- Lighting environment and visual comfort: quantity and quality of light and brightness contrasts (protection from glare),
- Hygienic comfort (low levels of pollutants and smells),
- Acoustic comfort (noise), and
- Electromagnetic tolerability.

Psychological factors (e.g. materials, colours) and cultural aspects are also connected with these factors and should be taken into account.



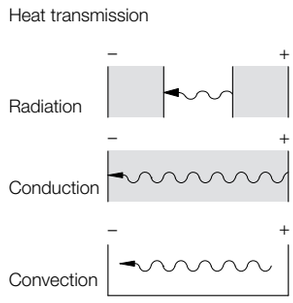
A 1.16

Fundamental physical principles

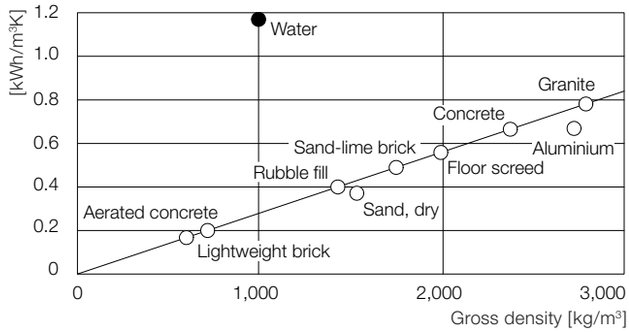
Knowledge of basic structural and physical principles, such as heat flow, water vapour pressure and radiation transport, is essential to an understanding of the functions of facades. (Fig. A 1.16).

Heat transfer
Thermal energy flows basically from a warmer (more energy-rich) side to a colder side. There are three basic principles of heat transfer (Fig. A 1.17):
- Thermal conduction
- Thermal radiation
- Thermal convection

A thermal transmittance coefficient (U-value) [W/m²K] can be calculated for planar structural components.



A 1.17



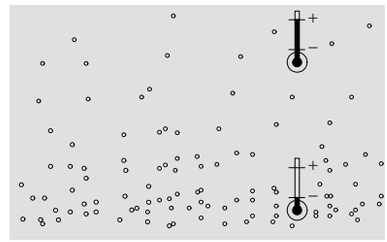
A 1.18

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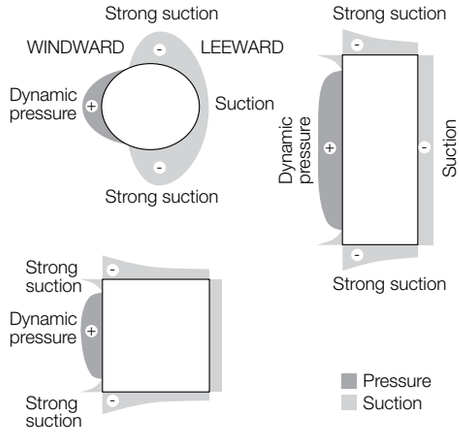
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A 1.15 Interior temperature / movement of air
Comfort zone, depending on interior temperature and movement of air (based on Rietschel-Raiss)
Scope of application for Figs. A 1.13–15:
- Relative humidity from 30 to 70 %
- Movement of air from 0 to 20 cm/s
- Largely constant temperature of all surfaces enclosing a space of 19.5 to 23 °C

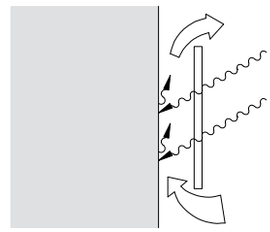
A 1.16 Fundamental structural and physical principles (selection)
A 1.17 Basic principles of heat transmission
A 1.18 Heat storage capacity of selected construction materials by volume
A 1.19 Warm air is lighter and rises.
A 1.20 Wind pressure and suction in flows around a building
A 1.21 If a facade is permeable to radiation, the layer of air in its interstices can heat up, causing the air to rise ("chimney or stack effect").
A 1.22 Geometric solutions for modifying air flows
A 1.23 Wind: annual average regional frequencies and directions in and around Munich
Wind speed:
a Up to 3 m/s
b More than 3 m/s



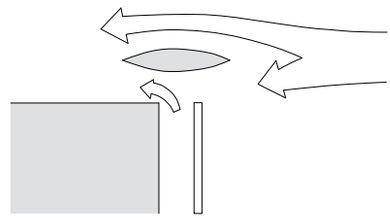
A 1.19



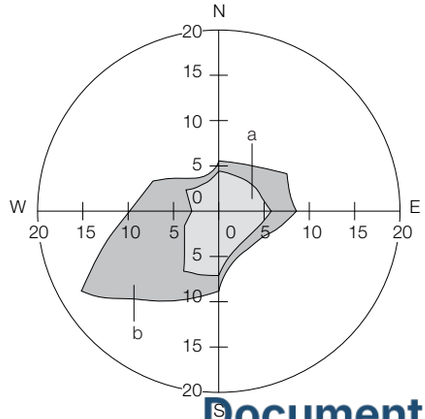
A 1.20



A 1.21



A 1.22



A 1.23

Thermal conductivity and heat storage capacity
Thermal conductivity and heat storage capacity are properties of specific materials and generally increase with bulk density, although the heat storage capacity of water compared with other construction materials is a clear exception (Fig. A 1.18).

Relative humidity
Air can absorb water vapour until it reaches its saturation point. This depends on the temperature, which is why it is called "relative" humidity. Humid air is slightly lighter than dry air at the same temperature.

Water vapour pressure
Water vapour moves from a side with higher vapour pressure (partial pressure) to a side with lower pressure. If the temperature falls below the dew point, condensation can occur (with a risk of condensate accumulating and mould forming).

Radiation transfer
Radiation hitting a structural element is reflected, absorbed or transmitted (Fig. A 1.16, middle).
A material's thermal radiation properties depend mainly on its surface properties, especially its colour (Fig. A 1.9, p. 21).

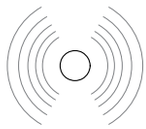
Wind, thermals and natural ventilation: basic principles

Streams of air in the atmosphere (wind), interacting openings outside and inside, and thermal effects in adjoining layers of air are phenomena at work in every building and are another external condition that must be taken into account. Wind situations can vary greatly in strength and direction depending on the weather and location (Fig. A 1.23), so only statistical values can be used as a basis in planning.
Streams of air that occur due to geometric properties of bodies in special wind situations can be investigated in wind tunnel trials and dynamic, highly complex flow simulations. Fundamental thermal principles play an essential role in facade planning (Fig. A 1.19–22).
In planning and building a facade, the goal should be to ventilate the building naturally as far as possible, thereby minimising the risk of "sick building syndrome" developing [3]. In doing so, the following problems that natural ventilation can cause must be avoided:
- Increased heating requirements
- Interior temperatures too high in summer
- Draughts inside
- Interior air too dry in winter
- Inadequate ventilation in very calm weather

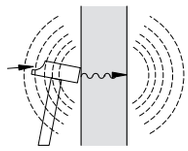
The more air heats up (absorbs energy), the more its gas molecules move (Fig. A 1.19); air pressure increases, air becomes less dense and lighter by volume and it rises. In a closed space this causes different air temperatures, with a layer of warmer air above and cooler air below.
Bodies obstruct airflows, causing the airflow to divide and move around them (Fig. A 1.20). This causes vortices and increases atmospheric pressure in front of buildings and a relatively lower pressure behind them (suction). It should be noted that wind direction can fluctuate greatly (Fig. A 1.23) and that such effects can change very quickly.
Close to the ground, interactions with (rough) surfaces and physical obstacles mean that wind speeds are generally lower, but they increase as buildings grow in height so wind pressure and suction are stronger at higher elevations.
When radiation energy penetrates a transparent or translucent surface and hits a structural component that is separated from the surface by a layer of air, it absorbs the energy and heats up. Some of this thermal energy is released into the air in the cavity, causing the air to heat up, rise (Fig. A 1.21) and circulate. This effect is intensified if the air can escape above and flow in from below.
Planners can use air flowing around a building to produce additional negative pressure (Fig. A 1.22) by creating and positioning bodies with appropriate geometries to intensify a chimney or stack effect or more quickly discharge warm air from spaces at lower levels.

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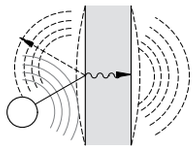
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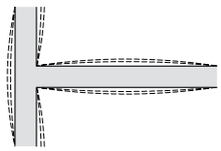
A 1.24



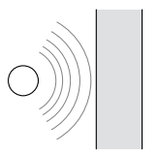
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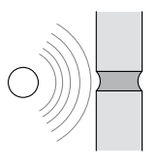
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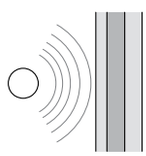
A 1.27



A 1.28



A 1.29



A 1.30

Sound transmission: basic principles

Sound is another external condition impacting facades and a requirement for interiors (soundproofing) because noise can come from either side of a facade.
Soundproofing requires particularly careful planning and construction as sound can be transmitted through the smallest acoustical bridge.
Sound waves spread out roughly spherically from sources of sound through the medium of air (airborne sound, Fig. A 1.24) and are more or less reflected by all the space-enclosing surfaces and objects in the space. The smoother and harder a surface is, the less dampened and more complete the reflection of the sound will be.

When a structural component made of solid material is made to vibrate, by mechanical influences (steps on a floor), for example, sound waves spread through its mass, which is referred to as structure-borne noise (Fig. A 1.25). If airborne sound causes a solid object to vibrate, structure-borne noise spreads through the object (Fig. A 1.26). This can also cause the layer of air on the other side to vibrate and transmit the sound waves in the form of airborne sound.
Sound waves can travel very long distances by means of structure-borne noise transmission (Fig. A 1.27). Wherever a building's "solid" structural components are connected, sound can be transmitted through them and right through the building by means of a phenomenon called "flanking transmission" or "flanking sound transfer".
One possible strategy for minimising airborne noise transmission is to increase an object's mass (Fig. A 1.28), making it as heavy and inert as possible by using a very dense material that airborne sound waves can vibrate only slightly, for example.
Another measure that can reduce airborne noise transmission is extremely efficient sealing (Fig. A 1.29), which can prevent airborne noise from spreading directly through gaps, joints, chinks and cracks.
Airborne noise transmission can also be muffled by a double-layered structure with an insulated space between the layers (Fig. A 1.30). This is particularly efficient if the two layers are of different thickness and weight and so have different natural resonant frequencies. The effectiveness of such measures should not be compromised by using rigid connections between the two layers (mass – spring – mass principle). Further structural-physical aspects of soundproofing are dealt with in the chapter on "Aspects of building physics and planning advice" (p. 52ff.).

Constructional implementation

Interactions between structural components, which arise during constructional implementation from resulting functional requirements and basic underlying structural-physical principles, are directly connected with the external and internal conditions outlined above.
Energy can get into buildings through a structural component that is permeable to radiation by means of transmission (Fig. A 1.31). When energy hits the surfaces inside a space, some of it is transferred to the material through absorption and from there transported further by means of thermal conduction (Fig. A 1.32). Some of this energy is also "stored", depending on the material's heat storage capacity. This potential is called thermal storage mass.
The energy is then more or less slowly returned into the space (depending on the material's specific thermal conductivity and other factors) by means of thermal radiation (Fig. A 1.33).
By choosing structural components with appropriate materials and dimensions, planners can make use of this effect to offset peaks in temperatures without requiring more energy input (for heating or cooling).
Regulated or controlled ventilation can use convection to transport energy between inside and out (Fig. A 1.34), and it can work in both directions. The skilful use of thermal effects (Figs. A 1.19, 21 and 22, p. 23) may even mean that mechanical ventilation can be dispensed with entirely.

The greenhouse effect
When high-energy, short-wave solar radiation hits surfaces inside a space, a substantial share of its energy is released into the interior in the form of diffuse long-wave radiation in the infrared range (Fig. A 1.35, left), thereby heating the air and surfaces in the space. The very low permeability to long-wave radiation of transparent and translucent facade surfaces (e.g. glass, translucent insulating layers or insulating multi-pane glazing, perhaps with an inert gas filling and additional coatings that enhance their effectiveness) prevents the radiation from escaping and keeps it "enclosed" in the space. This is referred to as the "greenhouse effect". If this effect is desired, its intensity can be greatly influenced by modifying the orientation of surfaces permeable to radiation to the source of radiation (usually by orienting surfaces towards the sun) and thus also the radiation's angle of entrance (Fig. A 1.36). The flatter the angle at which radiation strikes a surface is, the more the radiation is reflected and the more of it is kept outside (Fig. A 1.35). If radiation hits a surface at a 90° angle, the surface reflects only a minimal proportion of it. Like the proportion of absorption, the precise extent of reflection depends on the specific material and can be modified by additional measures, e.g. coatings (see "Glass", p. 188ff.).

Openings and angle of incidence
The amount of radiation entering through an opening of the same size and with the same orientation can vary greatly depending on the radiation's angle of entrance (Fig. A 1.37, p. 25).

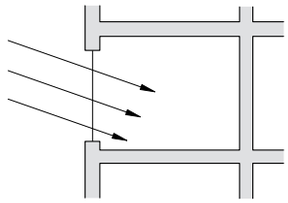
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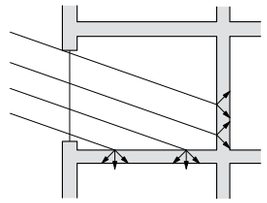
effect can play a crucial role in the planning of openings and sun protection systems, depending on changes in the sun's position through the different seasons (see "Edges, openings", p. 38ff.).

Consequences for floor plans / zoning
Demands on a facade can be influenced by arranging spaces in the floor plan based on the principle of a "thermal onion", which involves surrounding spaces that need higher temperatures with areas where lower temperatures are desirable (Fig. A 1.37). Such "buffer zones" can usually effectively reduce heating and cooling requirements.

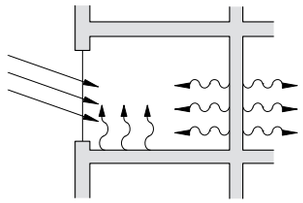
If the course of the sun is used to generate solar heat by means of the greenhouse effect, it can be useful to "capture" solar radiation in a projecting zone (Fig. A 1.38) and store the heat by designing interior surfaces accordingly. Very little solar energy will be gained from the northern side of a building in Central Europe, so this side must be insulated accordingly. Structures configured in this way can easily overheat in summer, so they will also require adequate shading and ventilation.



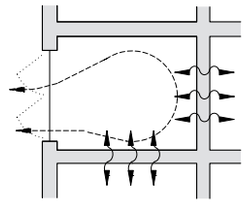
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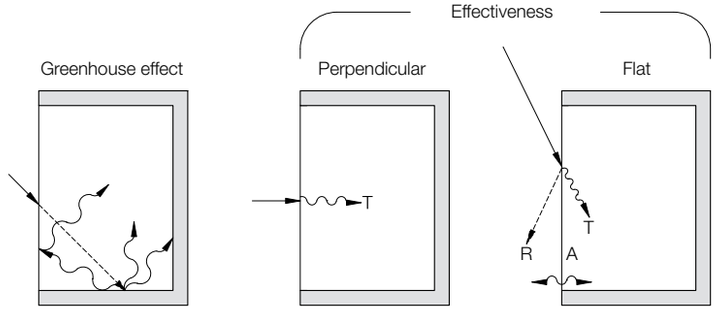
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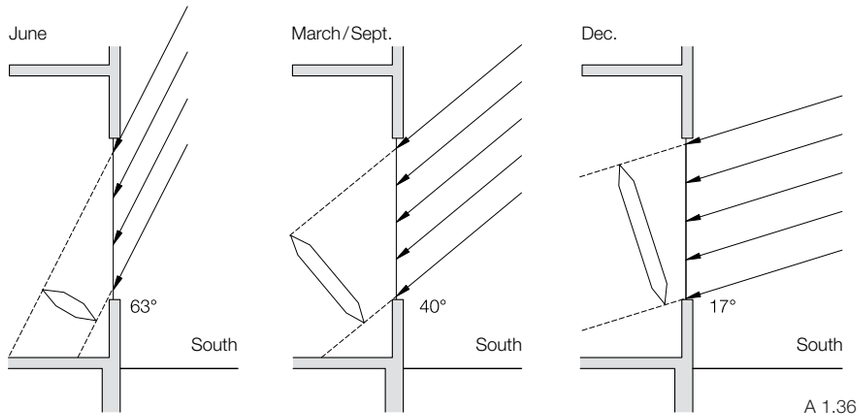
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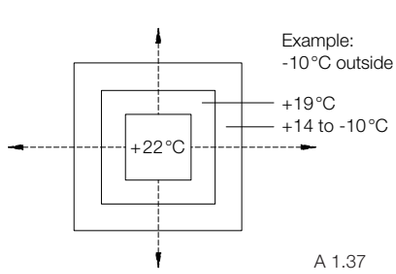
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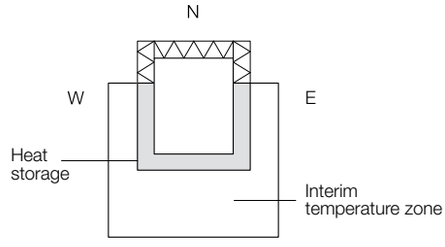
A 1.35



A 1.36



A 1.37



A 1.38

Notes:

[1] Hartwig, Helge: Zentral – Dezentral. Fassadenintegrierte dezentrale Gebäudetechnik. In: gi – Gesundheits-Ingenieur, 125. Jg. 05/2004, p. 227–234
[2] The number of hours of sunlight per year is for the reference period of 1981–2010. From the German Meteorological Service's (Deutscher Wetterdienst) Climate Data Center (CDC).
Hours of sunlight / heating limit were calculated here using data records from the WESTE weather data portal of the German Meteorological Service (Deutscher Wetterdienst).
[3] For more on the term "sick building syndrome" see also Dompke, Mario et al. (ed.): Sick Building Syndrome II. Documentation on a workshop in Holzkirchen, 1996, by the Fraunhofer Institute for Building Physics and Bundesindustrieverband Heizungs-, Klima-, Sanitärtechnik e. V. (German Industrial Association for Heating, Air conditioning and Sanitary Engineering) Bonn 1996

A 1.24 Source of sound
A 1.25 Excitation of mass by mechanical influences
A 1.26 Excitation of mass by airborne sound, transmission through materials (structure-borne sound)
A 1.27 Transmission of sound through structural components over long distances (also called "sound transfer")
A 1.28 Strategy 1 against airborne sound transmission: mass
A 1.29 Strategy 2: efficient joint sealing
A 1.30 Strategy 3: mass – spring – mass principle
A 1.31 Transmission
A 1.32 Heating – heat transfer
A 1.33 Thermal storage mass – thermal radiation
A 1.34 Convection – distribution – regulation
A 1.35 Greenhouse effect – utilisation
A 1.36 Angle of incidence of solar radiation / openings
A 1.37 "Thermal onion" – division of a floor plan into zones according to temperature
A 1.38 Building orientation – heat storage – thermal insulation

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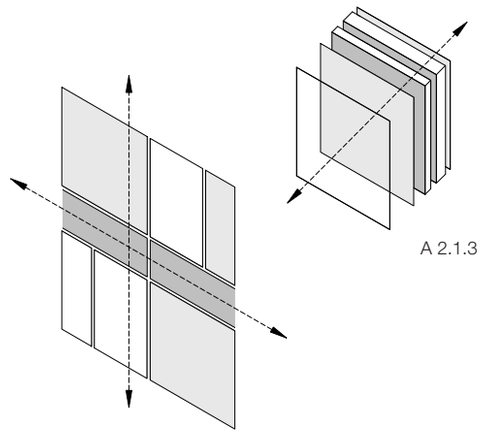
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A 2.1 Surfaces – structural principles

Facades are usually vertical, planar structures positioned between interior and exterior environments. Regardless of the materials they are made of, facade surfaces share diverse general features and common technical solutions, which will be described below. A knowledge of these features and principles will be helpful during the design process. A design principle can imply fundamental solutions for carrying out a specific construction task for predefined functions [1], using physical, chemical and geometric effects and combining their interactions to create an effective structure [2].

The facade's structure will be examined
- In the plane of the facade (Fig. A 2.1.2) and
- Perpendicular to the plane of the facade (Fig. A 2.1.3).

Depending on the required functions and demands, specific performance profiles that can vary across the surface must be assigned to facades. The technical and material implementation of such profiles may require several functional and construction levels perpendicular to the plane of the facade. Additional structures that are not part of the space-enclosing envelope (such as horizontal sun protection devices, light refraction systems, maintenance walkways etc.) may also be necessary. The overall goal should be a structure whose individual components work together efficiently.



A 2.1.3

A 2.1.2

A 2.1.1 Studio building, Munich (DE) 1993, Thomas Herzog with Peter Bonfig
A 2.1.2 Structure within the plane of the facade
A 2.1.3 Structure perpendicular to the plane of the facade
A 2.1.4 Functional criteria for facades
A 2.1.5 Structural criteria for facades

Classification of design solutions [3]

Functional criteria

Performance profiles as targets for facade surfaces are defined beyond general protective functions such as insulation and sealing; permeability to air, light and radiation (Fig. A 2.1.4) are also of particular importance. Their degree of permeability determines the character of the enveloping surface, its practical value and the quality of interiors. It also greatly influences a building's energy balance. Among the important criteria to consider in making decisions are the extent to which facade surfaces can react to changing conditions and whether they are modifiable and can even be self-regulating.

Permeability – air	Closed Partly permeable Open
Permeability – light	Opaque Translucent Semi-transparent Transparent Open
Energy gains	None Heat Power
Modifiability	Not modifiable Mechanical Phys. structural Chem. substantial
Regulation	Manual direct / indirect Self-regulating With control circuit

A 2.1.4

Permeability to air

Natural ventilation strategies require modifiable and adjustable permeability to air. The need to discharge surplus heat, water vapour and hot, toxic gases in the event of fire can also make a certain level of permeability necessary.

Permeability to light

The quality and quantity of its permeability to light and radiation determine a space's natural lighting and atmospheric character, allow people inside to see out and those outside to see in and thermal energy to enter or be emitted. It can be useful to take advantage of phenom

Part of the support structure	Non-load-bearing Load-bearing
Layered structure	Single-layer Multilayer
Shell structure	Single-shell Multi-shell
Rear ventilation	Not rear-ventilated Rear-ventilated
Prefabrication	Low High

A 2.1.5

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ena specific to human perception when planning perforated, semi-transparent surfaces, such as sun and glare protection devices. Surfaces with a very low proportion of small perforations set close together enable an observer looking towards a brighter lighting environment to see through them because our brain "adds" what is missing to form an overall picture. To an observer looking towards a darker lighting environment, however, such surfaces appear opaque because the eye cannot adapt to the reduced luminance of the small holes.

Energy generation
Surfaces permeable to solar radiation make it possible to directly generate energy by heating structural components, such as floors and walls, inside buildings. Using special technical equipment (e.g. a transparent thermal insulation absorbing wall, solar thermal or photovoltaic systems) heat or electricity for operating a building can also be produced in the facade structure (see "Solar energy", p. 294ff.).

Modifiability
Modifying the position or properties of structural components can enable a facade surface to react to changing external conditions, e.g.:
- By mechanically moving facade elements (positioning slats and louvres, opening shutters etc.)
- By triggering electrical, thermosensitive or photosensitive processes or reversible modifications in materials' properties that change their permeability to rays of light. These are either changes of a physical, structural nature – changes in aggregate state or a different orientation of crystal structures – or changes in chemical substances – changing chemical compounds [4].

Regulation
Modifiability requires regulation. Changing conditions can be tracked:
- By manual or mechanical activation, direct or indirect, e.g. the touch of a button
- By self-regulating, e.g. thermosensitive processes that modify thermotropic glass's permeability to light
- Based on the principle of feedback control system technologies using sensors and microprocessor-controlled servomotors

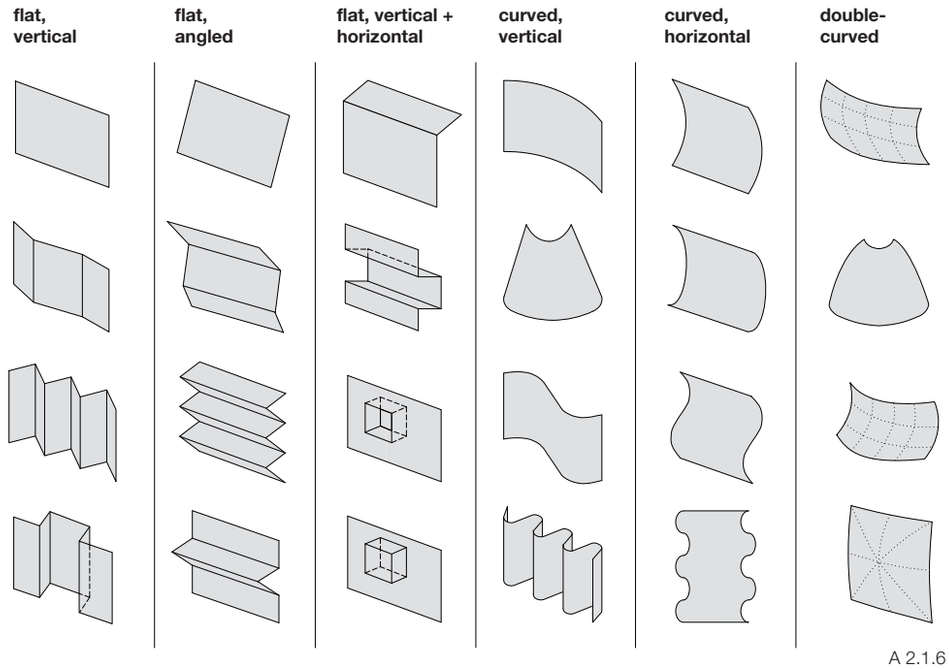
Fundamental design criteria
Resolving important fundamental design decisions is the best way to prepare for structural and material implementation (Fig. A 2.1.5, p. 27).

Connection with the support structure
Non-load-bearing facades do not bear loads or fulfil other functions of the support structure in ensuring the building's structural stability.

Layer and shell structures
Layers made up of different materials, thicknesses and structures can be optimised to fulfil specific sub-tasks and, based on structural-physical and constructive principles, put together to form a functional unit – the facade. Countless possible combinations with appropriate performance profiles are available. Individual functional layers can vary in thickness from tiny fractions of millimetres (Low-E coatings on thermal insulating glazing) up to a few metres (layers of air behind multilayer glass facades). The right sequence of layers is crucial for efficient functioning and preventing structural damage. Less significant or subordinate functional layers can be classified as layers or strata for the purposes of load-bearing. Shells, in contrast, can take on static loads and are freestanding (cf. p. 36) [5].

Rear ventilation
Rear-ventilated facades have one or more layers of air that use thermal lift forces to effectively discharge condensation and/or heat. Such structural systems are by definition always multilayered.

Prefabrication
The planned degree of prefabrication significantly impacts construction principles, type of element management, the absolute size of individual structural components and conditions in which the facade can be assembled and perhaps dismantled.



A 2.1.6

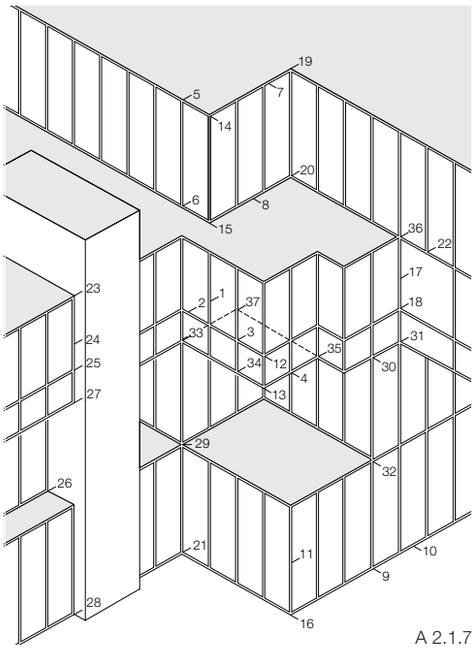
Structure in the plane of the facade

Types of surfaces
When establishing the exterior geometry of a building, the inherent principles of the envelope enclosing it must be taken into consideration.
Every facade consists of several flat or curved surface elements that intersect or touch each other or roof surfaces along specific lines (edges). How these surfaces are formed and arranged in space, whether vertical, inclined or almost horizontal, has a decisive influence on a facade's design and construction details (Fig. A 2.1.6). Cut edges and especially corners at which the three surfaces meet require special treatment and care.
The spatial planning of surfaces is determined by various factors that rarely arise alone, but are usually combined and have different weighting, such as:
- The geometry of floor plans and elevations in the building
- Usage aspects (e.g. the creation of niches for open spaces screened from view)
- Planning of the shell support structure itself (e.g. folded structure)
- Thermal insulation aspects (e.g. minimising the ratio of enveloping surface to volume)
- Structural aspects (e.g. channelling of water)
- Specific material aspects
- Design intentions

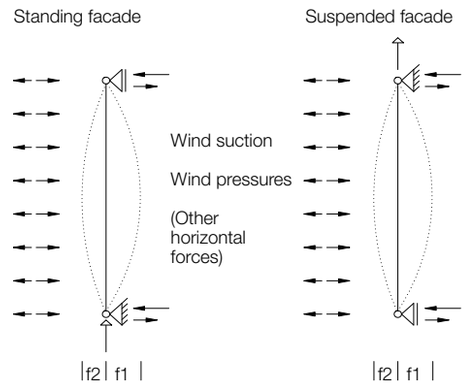
Evaluating different types of surfaces
Vertical surfaces
Channelling water over vertical surfaces is unproblematic, while folds and projections increase the external surface and inside edges must be dealt with by means of construction methods and geometry. Surfaces that meet at sharp angles can cause problems in manufacture and usage. In constructing vertical edges, it can be advantageous if they follow the direction in which facade water flows. Folded surfaces can be built as folded structures that form part of the load-bearing structure.
Figure A 2.1.7 shows 37 different geometric configurations in which facade surfaces

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A 2.1.7



A 2.1.8

A 2.1.6 Typical types of surfaces that can be combined to form countless forms
A 2.1.7 Examples of various joining details for perpendicular, orthogonal facade systems
A 2.1.8 Schematic diagrams of standing/suspended facades

meet or intersect with floors or roofs at edges and in corners. Each of these marked points requires its own detailing in construction and implementation. Points at which more than three different surfaces meet (such as no. 29), are almost impossible to manage effectively in construction and design. If different slopes or curves also play a role, the number of geometric and construction examples increases significantly [6].

Inclined surfaces
Every surface that tilts away from a vertical position, especially projections and recesses in steeply sloping surfaces, involves additional loads, stresses and aspects. They make it harder to channel water, while snow and ice formation causes further loads and stresses. Extensive horizontal surfaces must be treated like roofs and drained in a controlled manner, their surface is increased and sealing and insulating layers can project, resulting in structural weak points where they bend.
Every window reveal, bay window and loggia involves vertical and horizontal projections and inside and outside edges and corners.

Curved surfaces
Water runs easily off curved surfaces that are not perpendicular. Curves cannot usually be built continuously but typically consist of a series of polygons due to the basic geometry of materials and semi-finished products.

Double-curved surfaces
Double-curved surfaces are not necessarily connected to shell support structures or membrane structures. Such geometric forms are often created as translation surfaces, which can be built with even, individual polygonal areas.

Principles of load bearing
Loads impacting facades
A facade must safely withstand loads and transfer them to the support structure (primary support structure) (Fig. A 2.1.8). All facade structures, including non-load-bearing ones, must be planned and built to a scale that enables them to function as secondary support structures that can manage the following loads:
- Vertical loads: the structure's own weight, special loads (e.g. sun protection devices, plants, temporary scaffolding), traffic loads (e.g. live loads), snow and ice loads (these must be calculated for every planting or greening of a facade)
- Horizontal loads: Wind loads (there is generally an 8:5 ratio of pressure to suction, suction loads may be higher around edge areas), traffic loads (e.g. impact loads)
- Loads resulting from constraining forces caused by changes in volume due to variations in temperature or humidity

Facade surface loads are usually transferred into the support structure's floors, walls and supports. Vertical and horizontal loads can be borne and transferred separately into different structural components within the support structure.

Standing and suspended facades
A fundamental difference in load-bearing behaviour arises out of the question of whether a facade "hangs" or "stands", whether planar or linear structural components have to be designed to cope with tensile forces and bending or with compressive forces and bending as well as buckling (stability problems).
Suspended facades, where the dead weight imposed on the facade's structural components is transferred into the support structure (e.g. into floor slabs), has become the established method of building facades all over the world because of its basic advantages.
- The structural component is in a stable position immediately after it is hung (in contrast to the less stable position of a standing structural component), which is of considerable importance for safety on the building site, especially in the construction of tall buildings.
- A structural component's own weight functions as a tensile force along its long axis and the prestressing that this produces has a "stabilising" effect (reduces buckling loads), avoiding an adverse superimposition of buckling forces resulting from compressive forces and bending.

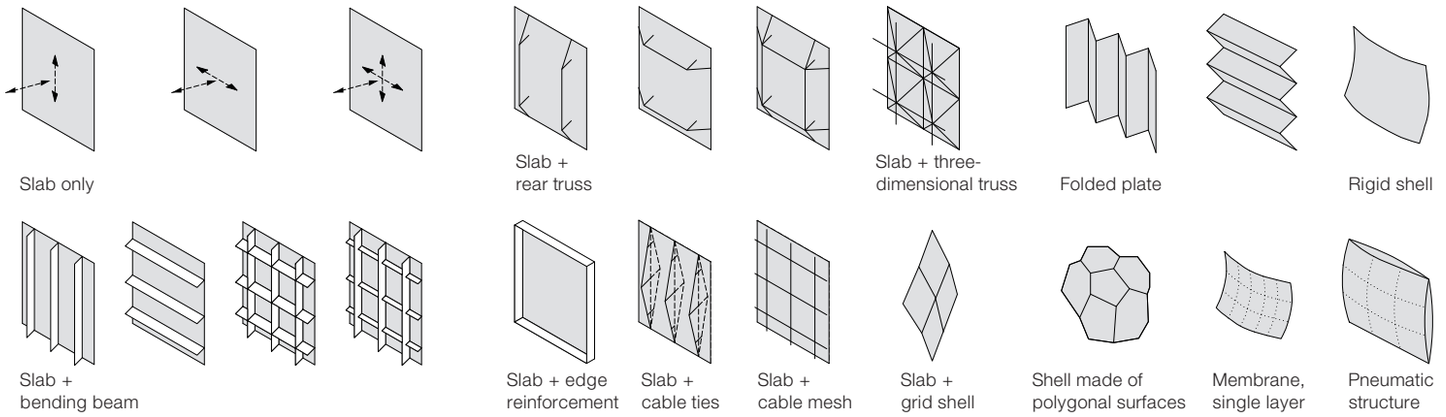
Suspended facades are more appropriate for surfaces with long spans, although they do not reduce deformations perpendicular to the plane of the facade to any significant extent.

Anchor and sliding points
If the facade and support structure are separate systems, they are subject to different temperature fluctuations and loads as well as the resulting changes in form, which makes it necessary to join them using unrestrained coupling with anchor and sliding points. Relative movements must be able to be absorbed in both directions (positive and negative tolerances). The interfaces between the two subsystems are sites where various trades, construction methods and structural tolerances usually meet, which is why fastenings must be adequately adjustable in all directions.
Connections between structural components in facades that expand longitudinally to different extents (for loading, thermal and hygric reasons) must also be designed to be unconstrained so as to prevent buckling.

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Principles
Bending + normal forces



A 2.1.9

Support structures

It is an inherent feature of space-enclosing shells that planar structural components are the central elements of all facades. Depending on their support structure (Figs. A 2.1.9 and 2.1.10) facades are exposed to only normal forces (tensile and/or compressive forces) in their plane or to bending perpendicular to their plane. Planar elements can have linear load-bearing components such as truss systems, bending beams etc. attached to them, or these components can be integrated higher up in the structural hierarchy than the planar elements. Elements can be also combined to form hierarchically structured systems with primary and secondary load-bearing components.
Planar and linear elements function either as structural units (e.g. T-beams, trussed slabs) or are separate, which can make planar structural components easier to remove and replace.

The logic of such structures is based not only on an efficient use of materials for bearing loads in the completed structure; prefabrication and installation issues are also involved. Transport and installation processes can cause other loads and stresses, which must also be managed.
It is often not permissible bending stresses, but restraining deflection and bending under loads – especially in glass structures – that is crucial in design.

Gravity walls

In walls whose structure cannot transfer tensile forces, the resulting vertical and horizontal forces must lie at the core of the wall's base area to ensure that the structure remains stable and to prevent the formation of gaping joints. Horizontal forces neutralise the pressure from vertical loads. Here it can be advantageous for the structural component to bear not just its own weight but also vertical loads from roof and floor slabs, i.e. be part of the primary support structure (= load-bearing facade). Masonry exterior walls usually comply with this principle.

Slabs

A "slab" is a planar load-bearing element that transfers horizontal loads through bending loads (in one or two directions) perpendicular to its plane. Bending resistance and stability (with superimposed compressive forces) are determined mainly by the structural component's depth (i.e. the component's effective thickness perpendicular to plane of the facade). A component's cross section, with materials concentrated at its edges, must be appropriately adapted to bear the loads imposed on it. Continuous spans can have the effect of reducing the bending moment. A simultaneous imposition of horizontal and vertical loads always causes a superimposition of bending moment and normal forces. Vertical forces can also be transferred through bending in the plane of a structural component, transferring forces horizontally to the sides.

Slabs + trussing

Architects can use trussing to form a force-fit structural unit with slabs to increase components' structural depth and also save materials. Trussing can be fixed to one or two sides. The slabs are additionally subjected to compressive forces in their planes. Connecting compression and tension members produces point loads, so potential problems caused by piercing have to be taken into account. Trussing does not cause any additional support forces that the primary support structure would have to absorb.

Slabs + bending beams

Linear support structures subjected to bending, and possibly compressive forces as well, limit the spans of planar structural components. The beams accumulate the point and/or line loads of planar structural components (slabs) and transfer them as single loads by means of bending to structural components higher in the load-bearing hierarchy.
If only wind loads are imposed, bending loads are uniaxial, but in both directions (wind suction and pressure). Superimposition of compressive forces and bending intensifies stability problems and there is a danger of buckling, especially in the direction of a section's weaker axis. Individual bending beams can be put together using links free of constraining forces to form extensive, curved or polygonal traverse support structures (e.g. post and beam facades). Manufacture, transport and installation considerations may limit the size of frame structures, although they can be combined with other structures or with each other to form prefabricated modular facades.

Slabs + linear structures, exposed only to normal forces

Linear support structures include:

- Planar and three-dimensional trusses: structures made up of compression and tension members, suitable for broad spans
- Cable trusses and nets: These prestressed structures can only absorb tensile forces and are only advisable if the building's support structure can absorb the powerful tensile forces required for pretensioning without costly and complex additional measures. These delicate-looking structures are especially ideal for surfaces designed to look very transparent.
- Grid shells

Folded plate structures, shells, membranes

Planar load-bearing structures that are only able to absorb tensile and/or compressive loads and stresses in their plane are especially suitable for absorbing evenly distributed planar loads. These systems are also designed to absorb bending loads when subjected to alternating planar loads and/or point loads. Appropriate prestressing ensures that membranes that can only absorb tensile loads and stresses will deform only slightly, even when they are subjected to alternating loads.

Structures of planar facade components

Planar structural components can be classified into structures that can be built using different materials and are often combined. The variants shown in Figure A 2.1.11 do not represent an entire facade structure, but only the construction methods used to make layers or shells. A solid material slab designed to absorb bending

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Loads in the structural component	Load-bearing structure principles
Mainly only normal forces	
Compression only	Gravity (weight) principle
Compression + tension	Folded plate
Compression + perhaps tension	Shell
Tension only	Pneumatic structure Membrane structure
Bending and normal forces	
Bending + compressive forces	Standing slab
Bending + tensile forces	Suspended slab

A 2.1.10

forces might be either the entire system of a storey-high, single-shell or single-layer structure or a small-scale element in exterior wall cladding. Among the criteria to be taken into account in selecting a suitable principle are:

- Load-bearing capacity, depending on structural requirements (Fig. A 2.1.10)
- The overall structural context: the component's size, workability, connection options, joints, deformations, changes in length, degree of prefabrication, resistance to moisture and frost etc.
- Structural physical properties: specific weight, thermal conductivity, thermal storage capacity, resistance to moisture vapour diffusion, translucence etc.
- Visual effect

Continuous structures

In this context, a continuous structure is a solid section with an anisotropic or isotropic form. These planar structural components are prefabricated in factories or on site in formwork with joints between individual production steps. The structural components' size and form depend on their materials and manufacture. They can be built to have specific load-bearing properties as reinforced (with metal rods, glass fibres, natural fibres, synthetic fibres etc.) composite materials designed to absorb tensile and/or compressive forces. This principle is also at work in solid material slabs designed to absorb bending forces and membranes made of composite material that can absorb only tensile forces.

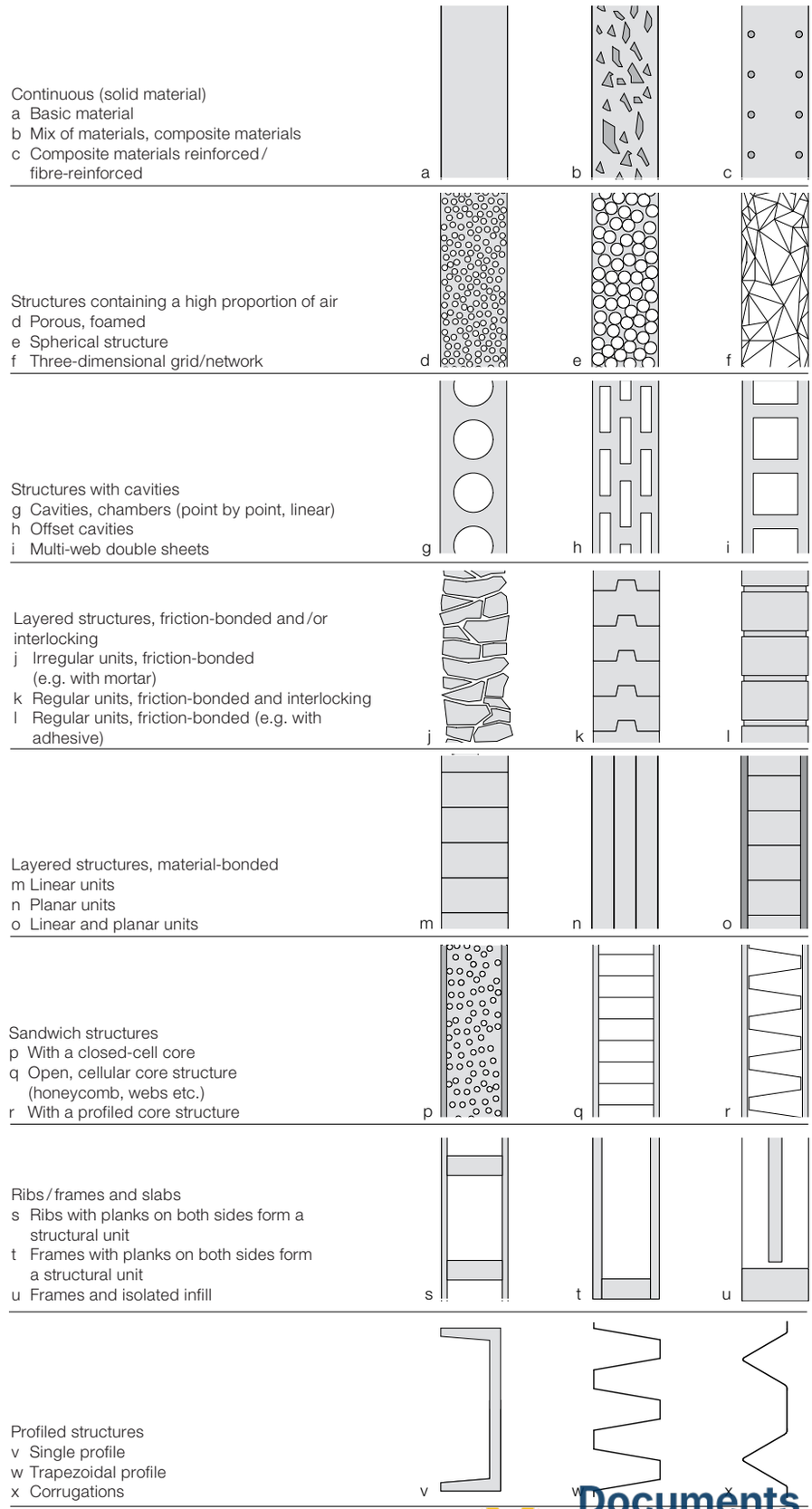
Structures containing large proportions of air or cavities

Various manufacturing technologies can increase the amount of air in structural components with the following goals:

- Reduction of weight and material
- Decrease in thermal conductivity (= improving thermal insulation)
- Creation of cavities for installations

If the material can be concentrated at the components' edges, their ability to absorb bending loads will probably only be slightly less than

A 2.1.9 Load-bearing structures for facades
A 2.1.10 Loads in planar facade structural components subject to vertical and horizontal loads
A 2.1.11 Overview of planar facade structural components



A 2.1.11

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that of solid sections. Substantially thinning out material in these areas will subject edge zones to tensile and compressive loads and expose webs to shear forces.

Layered structures with frictional and/or positive form-fit bonding
Layering small-format, irregular units without a binding agent is a traditional construction method which is still used in building facings. Enclosing units in metal mesh (gabions) section by section greatly increases their stability.
Coordinated modular units of regular shape and size can be joined with frictional and/or positive form-fit bonds to form larger structural components. Building structures in small modular steps can make them easier to modify.

Layered structures with fused bonding
Rod-shaped, planar or three-dimensional structures (e.g. honeycombs, lattices) can be fused together (using mortar or adhesive, for example) to form larger planar components. One special form of this technique is sandwich construction.

"Sandwich structures"
Bonding thin-walled surface layers resistant to tensile and compressive forces together with a shear-resistant core (usually in a very open or porous structure) produces a structural unit that is highly resistant to bending and makes economical use of materials. Structures with well-insulated intermediate layers are generally suitable for producing light, opaque facade panels.

Panels with ribs or frames
Ribs/frames combined with planar panels and infill can mutually stabilise each other to produce planar structural components with very good load-bearing capacity that also make economical use of materials. Cavities can be filled with insulating materials.

Profiled components
This principle can be used to produce very rigid units with a minimal use of materials. A U-shaped or Z-shaped element is a profiled component, and they can be put together to form larger planar units. Profiled components can be made of various materials resistant to tensile and compressive forces by means of sheet metal and solid forming, extrusion or casting techniques (such as extrusion moulding).

Joining facade components
Almost every facade is an assembly of individual structural components, and thereby creates a range of different joints that break through layers and shells (e.g. weatherproof envelope) and often form potential weak points, which have to be sealed as best as possible. In other cases, joints remain open so that

- Vapour pressure can be released
- Air can flow in or escape (for rear ventilation)
- Any accumulated facade water or condensation can run off
- Relative movements are tolerated
- Light can penetrate

The very diverse "seams" between structural components require particular care and attention because many aspects relevant to construction can concentrate here (Fig. A 2.1.12). As well as functional and technical factors, joints can help to structure individual components and entire facades (inside and out) and emphasise geometric and structural orders.

Joints in exterior facade surfaces are completely exposed to weather. The higher a building is, the greater the wind forces acting on it. At building edges, flows are concentrated and wind speeds higher. Rainfall can add to facade run-off water and accumulate as it flows down the building. The positioning of joints in the direction in which precipitation and facade water runs off, which is determined by gravity and wind, is an important factor in their loading. Joints parallel to the flow direction of facade water (vertical joints) are usually subject to lower loads than those that do not follow run-off direction. Changes in the volumes and lengths of adjoining structural components due to loads, temperature fluctuations and moisture absorption or release also impose loads on all kinds of joints. This is most evident in prefabricated modular facades, but wet-on-wet construction methods also do not form rigid structures.

Principles of joint sealing
Joint sealing is designed to curb or prevent a mix of air and water (fluid) entering into a joint. Sealing elements at the edges of facade components are never completely seamless, so the sealing effect is always only relative. Only bonded materials create a complete seal. If a joint cannot be sufficiently closed with a sealing element in its plane, other strategies will be required. Seals that use several layers and various sealing elements (multilayer sealing systems) have proven their worth in this context.
Joint sealing relies on a few basic principles that can be implemented in a wide range of ways (Fig. A 2.1.13). In choosing a sealing system, the extent to which and direction in which structural components will move or are expected to move is crucial [7].

Contactless sealing systems
Structural components are deliberately kept at a specific distance from each other and their edges formed to impede flows due to turbulence in the joint. This principle allows for large relative movements and is appropriate for the first layer in a multilayer sealing system. The joint in a labyrinth seal is bent and folded in keeping with the overlapping principle.

Damp	Rain/facade water Capillary water Water vapour/condensation Ice formation, snow
Air/wind pressure	Airtightness/windtightness Reduction of wind pressure/suction Ventilation openings
Sound	Airborne sound Structure-borne sound
Light	Lighting UV-resistant joining material
Transfer of forces	Element – Element Substructure – Element
Compensation for tolerances	Manufacturing tolerances Installation tolerances Movement tolerances
Assembly	Adjustability, fixing Sequences Independence from weather
Maintenance	Necessity Options/access
Disassembly	Removability Recycling Reusability
Joint pattern	Overlapping Shadow gap Undercut Profiled Change of materials Colour

A 2.1.12

Butt joints
A butt joint between two structural components without any sealing element is the oldest form of contact seal (in Fig. A 2.1.13 not shown). The uneven surfaces mean that the gap can be reduced but not entirely closed, not even with elastic or plastic materials and the application of force.

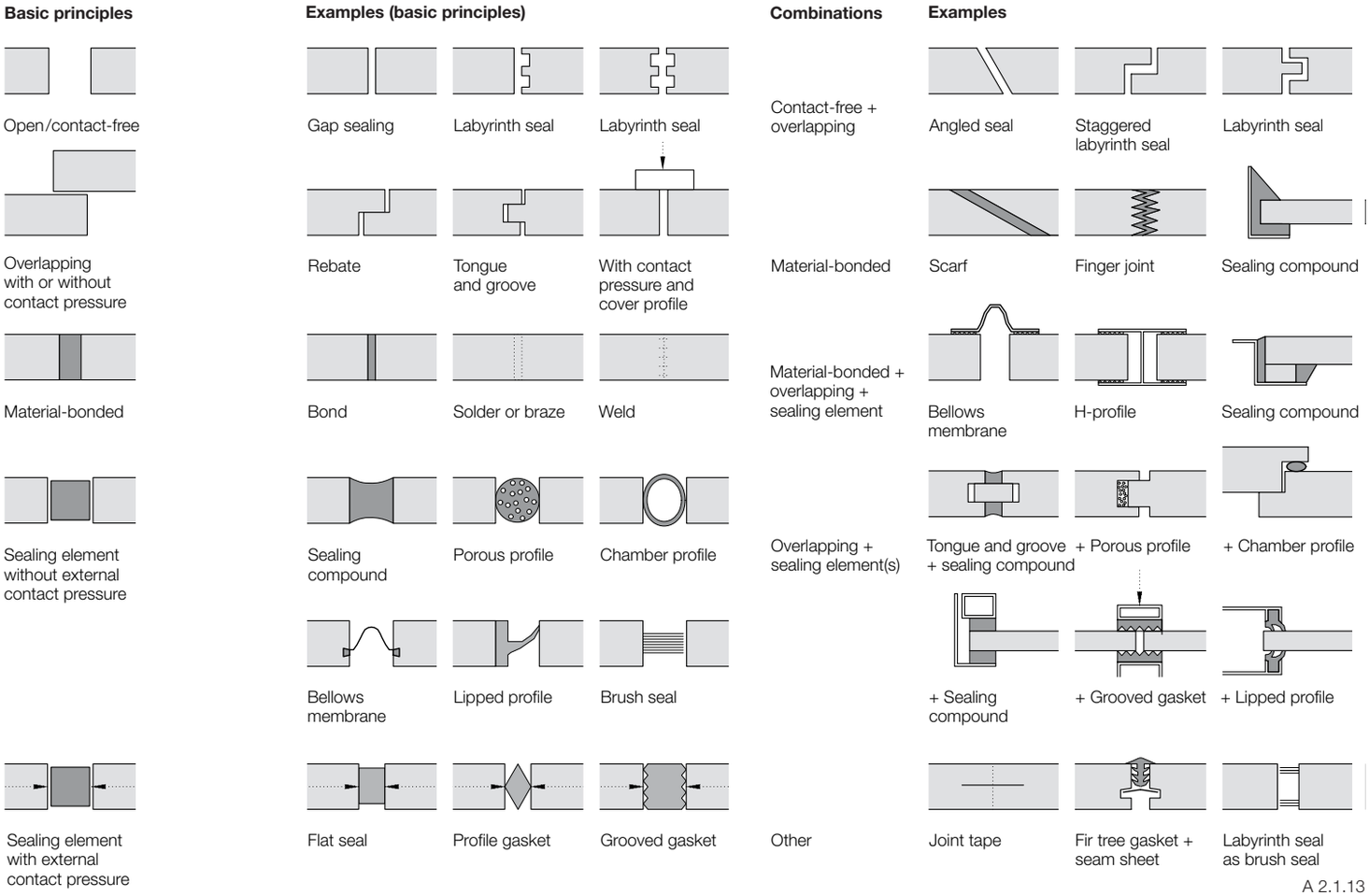
Overlapping
Overlapping is the simplest, oldest and most effective sealing principle and is still used in many sealing systems. Overlapped elements must follow the flow direction of facade water.

Figure A 2.1.14 shows examples of reliable facade water run-off over a horizontal joint without sealing elements based on overlapping principles. Some versions allow for horizontal movement between structural components (e.g. for opening sashes).

Bonded material seals
Bonded material seals are connections made with grouting or adhesive bonding or by welding, soldering, brazing or milling and can provide a complete seal in some cases. They can generally not withstand relative movements or can do so only to a limited extent.

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A 2.1.13

Sealing compounds
Sealing compounds are suitable for uneven surfaces. Their sealing effect is based on an adhesive bond between the sealing element and sides of the joint. Rigid sealing compounds can produce load-bearing, friction-locking connections. Sealing compounds with plastic or elastic deformation properties can absorb slight relative movements. Mistakes made in using these compounds often only become apparent some time after completion.

Porous and hollow-chamber profiles
Porous and hollow-chamber profiles are larger than the joint's maximum volume before they are installed and in a prestressed state when compressed. They can absorb slight relative movements across the joint axis, yet measures must be taken to prevent shifting if they are to withstand movements along the joint axis. The greater internal prestressing of hollow-chamber profiles makes them more suitable for frequently alternating loads and larger movements in joint areas than porous profiles.

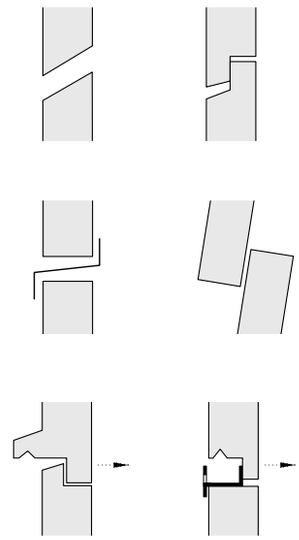
Bellows membranes
Bellows membranes can absorb large relative movements both across and along the joint axis. They can be inserted between adjoining structural components in various ways, such as a press-fit or adhesion.

Lipped profile
A lipped profile is an elastically deformable element with one or more sealing lips that internal spring forces press onto a structural component's edges. They can absorb large translational movements parallel to a joint axis. Profiles with specific forms may also be able to absorb movement across a joint axis to a limited extent.

Sealing elements that use contact pressure
The application of external force can be used to tightly fit a sealing element's surfaces to the edges of structural components. The contact pressure of profiled seals operates on small areas of the elements' surfaces. Water is stopped from penetrating into cavities through capillary action, and wind pressure due to turbulence is reduced. Such joints can only barely withstand relative movements, and it is important that the sealing element stays in place.

Combinations
The basic principles outlined above can be combined to form more complex, very effective, usually multilayer sealing systems. A seal's impermeability is always relative, so supplementary measures (e.g. glass rebate ventilation/drainage) should be taken to compensate for a possible complete or partial failure of sealing systems.

A 2.1.12 Aspects of joint formation
A 2.1.13 Principles of joint sealing
A 2.1.14 Examples of horizontal joints for draining off facade water, left: outside



A 2.1.14

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The principle of double sealing is that a first external seal prevents water on the surface from penetrating and a second seal, perhaps with a hollow-chamber profile, stops air from flowing through. Turbulence in the interstice (e.g. in labyrinth form) reduces wind pressure and any water that has penetrated can run off.

Installation sequences

Two general principles govern the installation and dismantling of joints based on overlapping principles:

- Individual elements can only be installed in a certain strict order and must be dismantled in precisely the opposite order. Individual elements in such a chain can only be exchanged with some restrictions and subsequent damage (e.g. of sealing elements or rebates). Special solutions may be required for joining and sealing reused or refitted structural components (e.g. in Fig. A 2.1.13, p. 33 “tongue and groove” and “grooved” components).
- There is no fixed sequence for installing and dismantling individual structural components. Elements in the same system can be replaced (e.g. in Fig. A 2.1.13, p. 33 “gap ring”, “cover profile” and “sealing compound” joints). This is especially recommended if there is a risk of damage (e.g. in the plinth zone) and an element has to be replaced.

From monolithic to multilayer/multi-shell

Homogeneous shell structures made primarily of just one material (often referred to as monolithic) are unlikely to meet the current increased thermal insulation demands made on building envelopes.

Planners can precisely adapt a facade’s performance profile to meet certain requirements by creating differentiated structures that assign individual functions to different layers with a specific material and structure. Making layers or shells modifiable allows the building envelope’s properties to adapt to periodically changing external conditions. Individual layers and shells can be subsequently added or replaced, making it possible to adapt the building envelope to differing requirements during its use. This means that an outer weatherproof shell designed to be a “wearing course layer” can be renewed after a period of use without the underlying structure having to be changed. This principle can also be useful in subsequent retrofitting for renovating and optimising existing exterior wall structures.

Assigning individual functions to layers and shells may, however, also have disadvantages depending on quality of the materials and construction methods chosen:

- Creation of lots of interfaces between different materials and structural components with the risk of material incompatibilities
- Increased number of joints and therefore of potential weak points
- Creation of uncontrolled cavities
- Attachment problems: penetration of water-bearing or insulating layers, creation of bending moment in the anchoring of facing shells
- Greater cost and effort involved in manufacture
- Greater maintenance cost and effort
- Building a wall may involve several trades and responsibilities, which can increase the cost and effort involved in coordinating them and result in overlapping liabilities
- Problems in separating and thus disposing of individual layers

The following tendencies are currently predominant:

- Increasing performance of functional layers
- Reducing the space required for layers (e.g. vacuum insulation) through to miniaturising of functional structures (e.g. prismatic light deflection systems less than 0.1 mm high)
- Surface coatings using nanotechnology
- Combination of several functions in a single polyvalent layer

The functions of layers and shells

The following functions (often also combined) can be allocated to individual layers or shells, e.g.:

- Visual effects, information media
- Mechanical protection
- Protection from driving rain
- Windproofing
- Blocking/restricting of vapour permeability
- Light refraction and diffusion
- Reflection of light radiation and thermal radiation
- Absorption of thermal radiation
- Reflection of electromagnetic radiation
- Absorption of sound
- Reflection of sound
- Heat storage
- Reduction of heat transition
- Transfer of loads
- Discharge of heat
- Absorption and release of water vapour
- Conversion of solar energy into thermal or electrical energy

Other layers may be formed based on structural requirements, e.g.:

- Release of water vapour
- Discharge of condensation or surface water
- Balancing out unevenness
- Layers for material-bonded joints (adhesive layers)
- Measures for stabilising layers (e.g. preventing thermal insulation layers from swelling)
- Substructures for connecting layers and shells
- Separating layers that are required because of materials incompatibilities
- Sliding layers allowing for unrestrained movement

Typical structures and how they work

Figure A 2.1.15 shows a selection of schematic representations of structures classified according to functional and structural criteria (see also “Classification of design solutions”, p. 27f.). The number and thickness of the layers and shells vary greatly. They can be divided into solid and lightweight structures and are suitable for temperate climate zones.

Protection from driving rain

Moisture-absorbing materials require protection from frost, and any moisture that may penetrate must be able to periodically completely evaporate. Facade water can be drained off through various layers. Some facade water will run off down the back of the cladding of ventilated weatherproof shells with open joints. This reduces the risk of soiling since less dirt is deposited on horizontal surfaces because it is regularly washed off.

Windproofing

Facades usually need to be windproof. The inner facade layer of a multilayer facade must be windproof, as must joints with other structural components.

Thermal insulation

Material layers that trap a large proportion of stationary air guarantee good insulating properties. Open-pored insulating materials that can absorb moisture and water through capillary action, which greatly impairs their functioning, must be effectively protected from moisture.

Water vapour diffusion

The water vapour diffusion resistance of layers must generally diminish from the inside to the outside to prevent condensation from forming in a structural component (and avoid steam traps). Condensation that collects in wall structures during the heating period must be able to evaporate completely in warmer seasons.

Rear ventilation

Effective rear ventilation of a facing shell requires a distance of at least 20 mm between cladding and shell and adequate ventilation openings of at least 50 cm^2 for every metre of wall length [8] to efficiently release moisture (infiltrated facade water and/or condensation) and heat (in summer). Layers of stationary air (no rear ventilation) have an additional insulation effect.

Heat storage

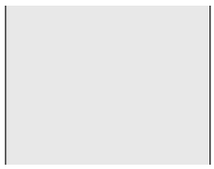
Inside layers with good heat storage capacity can be activated to help regulate the interior climate.

Sun shading

Sun shading devices that reduce the input of energy through layers that are permeable to solar radiation are most effective mounted outside. Their rear ventilation [illegible]

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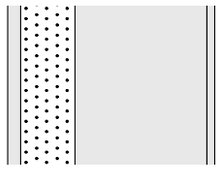
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Not permeable
Not modifiable

Load-bearing or non-load-bearing
Single-layer
Single-shell
Not rear-ventilated

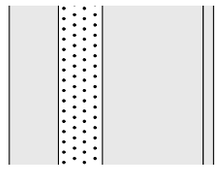
Material structure determines performance; can only be adjusted by changing the wall thickness; any moisture that has penetrated must be able to periodically completely evaporate



Not permeable
Not modifiable

Load-bearing or non-load-bearing
Multilayer
Single-shell
Not rear-ventilated

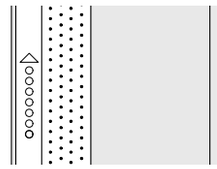
Improved insulation due to the insulation layer; inner and outer wear and protective layer; heat storage capacity can be used to heat the interior



Not permeable
Not modifiable

Load-bearing or non-load-bearing
Multilayer
Double-layer
Not rear-ventilated

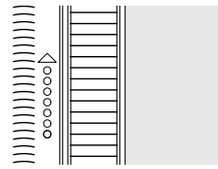
Robust external shell provides physical protection for the insulation layer and against driving rain; outer and inner shells may be partly connected, but do not form a structural unit



Not permeable
Not modifiable

Load-bearing or non-load-bearing
Multilayer
Double-shell
Rear-ventilated

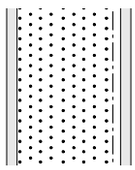
Facing shell can be exchanged; mounting may not be allowed to impede rising airflows; condensation and any penetrating moisture are safely extracted; ventilation openings required



Not permeable
Energy producing
Modifiable

Load-bearing or non-load-bearing
Multilayer
Triple-shell
Rear-ventilated (outermost shell)

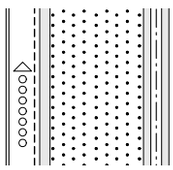
Rear-ventilated shell made of light-deflecting louvres; translucent shell with transparent insulation in front of a solid absorber; overall structure opaque; energy production modifiable and can be regulated with control circuit technology



Not permeable
Not modifiable

Load-bearing or non-load-bearing
Multilayer
Single-shell
Not rear-ventilated

Lightweight structure; inner and outer layer usually joined to form a structural unit; vapour trap prevented by a barrier on the inside; as stud wall also part of the load-bearing structure; sandwich structures are a special case



Not permeable
Not modifiable

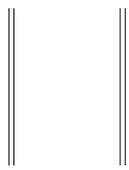
Load-bearing or non-load-bearing
Multilayer
Double-layer
Rear-ventilated

External, rear-ventilated wear and protective layer; diffusion resistance declines towards the outside; separate wind protection layer; inner lining is a separate layer

Permeable (light)
Not modifiable

Non-load-bearing
Single-layer
Single-shell

The structure itself is not energy-producing, even though it is permeable to solar energy, which is absorbed by structural components in the interior; no insulation



Permeable (light)
Not modifiable

Non-load-bearing
Single-layer
Double-shell
Rear-ventilated or not rear-ventilated

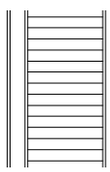
Low level of insulation because air circulates in the cavity (heat losses due to convection); shells do not form structural unit; risk of condensation forming in the cavity



Permeable (light)
Modifiable and regulated

Non-load-bearing
Multilayer
Single-shell

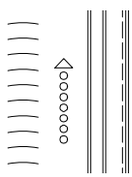
Functional unit made of several translucent or light-refracting layers, with reflecting layers if required; permeability to light can be modified



Permeable (to light)
Modifiable

Non-load-bearing
Multilayer
Single-shell

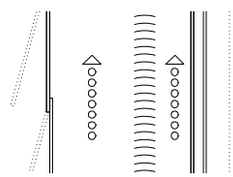
Functional unit made of several translucent layers; improved insulating due to thermal insulation; permeability to light can be modified and is self-regulating, with thermotropic glass, for example



Permeable (light)
Modifiable

Non-load-bearing
Multilayer
Double-shell
Rear-ventilated

Good thermal insulation due to two stationary layers of air / inert gas and possibly reflective coating (Low-E); adjustable or fixed louvres as rear-ventilated facing shell



Permeable (light and air)
Modifiable

Non-load-bearing
Multilayer
Four-shell
Rear-ventilated

Double facade, outer and inner glazing; openable, air cavity between shells has controlled ventilation, louvres and glare protection on the inside; separate shell for regulating permeability to light



Permeable (light)
Not modifiable

Non-load-bearing
Multilayer
Single-shell

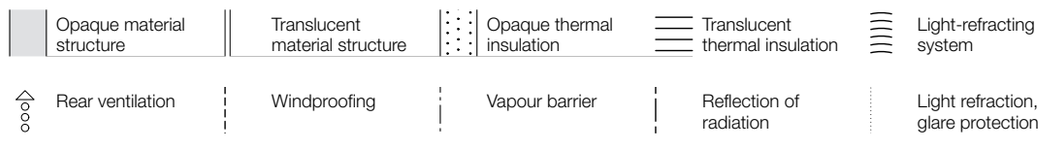
Pneumatic structure with translucent layers that form a single structural unit, depending on the system, i.e. a single-shell structure



Permeable (light)
Not modifiable

Non-load-bearing
Single or multilayer
Double-shell

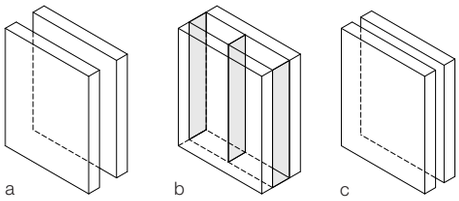
Membranes as two structurally separate shells; layer of air or controlled ventilation for extracting water vapour and heat; but there are heat losses due to convection



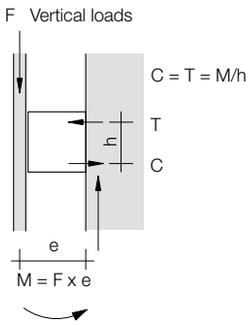
A 2.1.15 Structures / assemblies of layers and shells perpendicular to the plane of the facade, self-supporting

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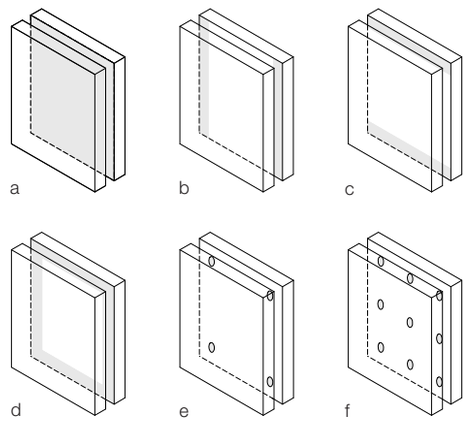
A 2.1.16



A 2.1.17

Geometry	Point-by-point Linear Planar
Detachability	Detachable Not detachable
Method	Interlocking bond Friction-locked, load-bearing bond Material bond
Loads and stresses	Compression Tension Bending Shear Torsion
Movability	Not sliding Sliding in one direction Sliding in two directions
Adjustability	Not adjustable In one direction In two directions In three directions

A 2.1.18



A 2.1.19

heating of surfaces that would otherwise radiate heat into the interior. Such functional layers have the characteristics of shells.

Connecting layers and shells

Layers and shells must be put together to form a structural unit, the facade. Functional and structural physical aspects are more important in determining the sequence of their installation than construction issues are. A functional layer will be exposed to various loads depending on its position in the structure. Some planar structural components, due to their material properties and/or thicknesses, are not or only somewhat able to absorb and transfer forces (e.g. thin foils, soft fibrous insulation, fills, layers of air etc.). Clear load-bearing hierarchies that establish which structural components bear which planar structural element are therefore required.

A facade's functional layers are identified as layers or shells depending on the degree of their structural autonomy. Layers are not or only somewhat load-bearing and/or parts of a superordinate structural unit, such as structurally-irrelevant foils and coatings, layers of air, insulation, layers of plaster, individual panes in multi-pane insulating glazing and individual membranes in a pneumatic structure. Shells are largely load-bearing structures ranging from partly up to entirely three-dimensional and/or structurally autonomous. A shell can consist of several layers, such as the inner and outer skin of a double facade, structural components separated by air layers (e.g. rear ventilation) or non-load-bearing layers of insulation.

A facade structure (e.g. post and beam) either joins several shells that are high up in the load-bearing structural hierarchy or joins them as the substructure (e.g. to brackets) of a structurally subordinate component (e.g. a facing shell) to a component higher up in the load-bearing structural hierarchy. In the latter case the vertical loads of the subordinate shell due to the distance e (= lever arm effect) cause a bending moment, which must be absorbed by the substructure or shell that is higher in the load-bearing structural hierarchy. Figure A 2.1.17 shows that increasing the distance h between attachment points can greatly reduce the compressive and tensile forces that have to be transferred. This does not affect shear loads, although wind suction also subjects attachments to tensile forces.

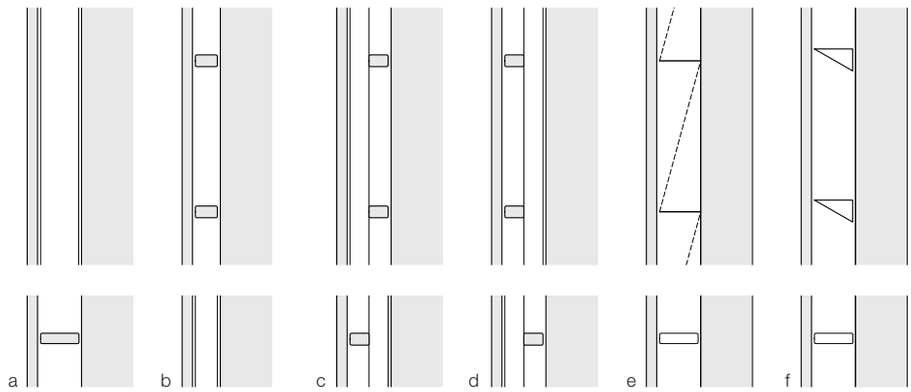
Anchorings or attachments for facing shells often penetrate thick layers of insulation, creating a powerful lever arm effect. Connecting elements made of materials like metals that conduct heat well can become "thermal bridges" on which condensation can accumulate, requiring the metals used to be rustproof. Not even galvanised zinc-coated steel connections are permissible here [9]. Insulating material must be tightly packed around connecting elements to ensure that such structural weak points are not further weakened. It is also advisable to minimise cross sections through which heat can escape. Another strategy is to use plastic spacers to create a thermal separation between the connecting element or connection. Drip edges over connecting elements perpendicular to the structure prevent facade water, melt water, dew or condensation from getting into insulating layers or other layers or shells by means of adhesion.

Connecting layers is less problematic than connecting shells because layers are generally closer together. Attachments should impair or penetrate functional layers (e.g. weatherproof shells, sealing layers, windproofing, moisture barriers, thermal insulation) as little as possible so as not to impair their effectiveness and to keep the risk of structural-physical problems and resulting damage to the building to a minimum.
Uncontrolled cavities and continuous penetrative joints should always be avoided (so joints should be staggered). Layers of air between shells should generally be ventilated and drained. Horizontal substructures must not be allowed to constrict necessary ventilation cavities. Air cavities must be permanently protected from small animals (insects, small rodents) by means of gratings, perforated sheets or nets.

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A 2.1.16 Spatial and structural aspects resulting from the addition of functional layers:
a At a distance, not joined
b At a distance, joined via a substructure
c No gap, directly joined, no substructure
A 2.1.17 Interplay of forces involved in attaching facing shells
A 2.1.18 Criteria for attaching layers and shells
A 2.1.19 Attachments of planar structural components
a Planar
b Linear, perpendicular
c Linear, horizontal
d Linear, circumferential
e Point by point
f Point by point
A 2.1.20 Examples of substructures for facing shells (top: vertical section, bottom: horizontal section)



A 2.1.20

Direct contact of functional layers with each other or between connecting elements must be prevented if there is a risk of material incompatibilities from corrosion (galvanic or contact corrosion). This type of corrosion can also occur in metals not in direct contact if there is a risk of water acting as a medium.

Attachment strategies
There are various ways of connecting layers to each other or shells to substructures (and vice versa). The following must be taken into account:
- Secure transfer of all loads
- Constraint-free supports for structural components with anchor and sliding points
- Stipulation of installation sequences and possible subsequent replaceability
- Identification of interfaces between different trades and firms
- The adjustability of connecting structural components made by different trades and those manufactured with differing tolerances

Attaching facing shells
Facing shells and rear-ventilated cladding are attached by means of substructures (leaving space for insulation and/or rear ventilation) to planar structural components higher in the load-bearing structural hierarchy. For taller buildings, suspended (top-supported) installation is preferable to standing (bottom-supported) installation. Several types of substructures are available (see Fig. A 2.1.20):
a Posts
b Beams
c and d Vertical and horizontal load-bearing elements, rear ventilation and draining must not be impaired by horizontal load-bearing elements; variant d is problematic in this respect
e Substructure made of tension/compression members and diagonal suspension to absorb vertical loads, or combinations with other linear load-bearing elements (vertical or horizontal)
f Brackets clamped into the load-bearing shell; combinations with other linear load-bearing elements (vertical or horizontal) are another possible solution

Which principle is appropriate in a particular case depends on the following factors:
- Size and weight of individual planar structural components in the cladding
- Options available for attaching facade cladding (e.g. transfer of forces that is linear or at points)
- Requirements due to rear ventilation
- Options for attachments to and loading of shells higher up in the structural hierarchy (Can large tensile forces be transferred and absorbed, for example?)
- Structural and physical aspects (significance and risk of thermal bridges)

Very heavy facing shells or other elements (balconies, trellises etc.) attached to the front of thermally separated envelopes should have their own structure and perhaps a foundation for transferring vertical forces. Shells only then have to be anchored to transfer horizontal forces and prevent buckling.

Adjusting connections
The following strategies can be used to make connections adjustable:
- Underlay or lining
- Spacer screws and bolts
- Fasteners that can slide in long slots or on rails (e.g. Halfen channels)
- Connections in oversized slots that are subsequently filled in
- Available and sufficient options for positioning fasteners on surfaces offering a material bond (an adhesive surface or “welding embedment”), very precise setting of screws, bolts and dowels etc. in installation

Notes
[1] VDI-Richtlinie 2221: Düsseldorf 1993. p. 39f.
VDI-Richtlinie 2222: Düsseldorf 1997, p. 5f.
[2] VDI-Richtlinie 2221: Düsseldorf 1993. p. 39f: “Effect: an invariable, predictable occurrence resulting from physical, chemical or biological natural laws.”
[3] The revised classification builds on typological investigations carried out during a research projects on building envelopes:
Herzog, Thomas; Krippner, Roland: Gebäudehülle. Synoptische Darstellung maßgeblicher baulicher Subsysteme der Gebäudehülle mit Schutz- und Steuerungsfunktionen als Voraussetzung für die experimentelle Arbeit an ihrer energetischen und baukonstruktiven Optimierung. Abschlussbericht (unpublished). TU Munich 2000.
Herzog, Thomas; Krippner, Roland: Synoptical Description of Decisive Subsystems of the Building Skin. In: Pontenagel, Irm: Building a New Century. 5th Conference Solar Energy in Architecture and Urban Planning. Proceedings. Published by Eurosolar. Bonn 1999, p. 306–310
[4] Nitz, Peter; Wagner, Andreas: Schaltbare und regelbare Verglasungen. Published by Fachinformationszentrum Karlsruhe. BINE Themeninfo, I/02. Karlsruhe 2002
[5] The definition of shells in the literature is inconsistent and partly contradictory. The definition made here seems to be the most plausible. Confusion is caused when the classification refers only to a specific type of structure (e.g. a single-layer concrete wall) and not to the whole envelope system (e.g. a double-shelled structure with a concrete wall and an aluminium profiled sheet metal weatherproof shell). See “Connecting layers and shells”, p. 36f.
[6] Herzog, Thomas; Nikolic, Vladimir: Petrocarbona Außenwandsystem. Bexbach 1972
[7] The description and to some extent classification of joint sealing systems is based on the following research report: Scharr, Roland; Sulzer, Peter: Beiträge zum methodischen Vorgehen in der Baukonstruktion. Außenwanddichtungen. Published by the VDI. Düsseldorf 1981. It used scientific methods to investigate and demonstrate “elements and structures of sealing systems in exterior walls with an analysis of built structures” in construction.
[8] See DIN 18516 Part 1: Berlin 1999. This does not apply to “small-format slabs” with a surface ≤ 0.4 m² and dead weight ≤ 5 kg
[9] See DIN EN ISO 8044: 2015-12 Corrosion of metals and alloys and DIN 18516 Cladding for external walls, ventilated at the rear

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Facade Construction Manual Herzog, Krippner, Lang (2014). Руководство по проектированию и конструированию фасадов

A 2.2 Edges, openings

Edges

So far, we have dealt with building envelopes as continuous surfaces and their structure in terms of thickness. Surfaces in and around a building envelope are, however, finite, so every surface is also defined by its edges. When the structural, functional and design properties of a building envelope change, they can be described as different definable areas. Any change in their properties is usually one of permeability.

Openings are the parts of a building envelope permeable to flows of energy and materials, which is generally the case when the parts can be opened entirely, e.g. the sashes of windows [1]. It therefore seems expedient to expand the word “opening” to include the link to the physical process. A skylight, for example, is an opening in a roof through which light can enter.

A change in properties (performance) also involves a change in structure. The word “edges” as used in this chapter refers not to the edges of an individual structural component that is put together with many similar parts to form a whole (e.g. bricks in masonry), but rather to transitions from a planar surface to an opening.

The reveal

A reveal’s depth depends primarily on the surrounding wall structure (Fig. A 2.2.5, p. 41). Reveals can be increased in size by adding additional elements, but cannot be made smaller. The reveal’s geometric form has a direct influence on daylight entering the building and on views and lines of sight. Figure A 2.2.4, p. 40 illustrates some basic features. The design of reveal surfaces is connected with the (structural) terminations of structural components used in and around openings (e.g. windows). A reveal can also help to reflect daylight into the interior. As well as geometry, the properties of specific surfaces must be taken into account here.
The depth of the reveal is always in proportion to the opening size, and it in turn in relation to the wall’s surface. A facade’s external three-dimensional effect is largely created by the offsetting of individual areas of the facade and the resulting shadows.
Structural aspects involved in building reveals include:

- Transferring wind loads
- Dissipating the structure’s own weight
- Sealing against wind, precipitation etc.

Openings

Openings in the building envelope are indispensable for using the interior and supplying it with light and air. Their protective and supply functions mean that the permeability of openings should be modifiable because fluctuations in exterior conditions are pitted against a desire for stable conditions inside. Openings in the building envelope mediate between inside and out and control the exchange between the interior and exterior climate. Individual parameters such as heat, light, air, sound, moisture etc. can be summed up by the term “regulation of permeability”, for which elements that close openings are used [2]. The most familiar of these is the window, which through appropriate material lets light in, even when they are closed, although air can only be exchanged if the window sashes are open, through slot ventilation between the sash and the frame, or through adjustable slits in the frame. The functions of lighting and ventilation can of course be provided separately. The simplest form is fixed glazing with a separate (opaque) sash for ventilation [3].

The advent of extensively glazed facades (e.g. in greenhouses) in the 18th century and construction of buildings like the Crystal Palace in London (1851) and the Glaspalast in Munich (1854) represented a transformation. A window, once a transparent element in an opaque wall surface, was now an opening element in an entirely transparent facade. Analogous to windows in a solid wall, the openable elements of a (transparent) glass facade were also called windows.

Position and geometry

An opening’s arrangement and geometric shape are always related to the space behind it. Its position and geometric form affect daylight levels inside, ventilation and users’ views of the outside. An opening’s position is always related to its use in horizontal and vertical positions. A change of floor plan usage can modify the horizontal relationship to openings. In contrast, it is not usually possible to modify the relative vertical arrangements of openings because of the difficulty of raising or lowering a room’s floor.

Vertical structuring of the facade surface
The facade of a storey can generally be divided into three areas (Fig. A 2.2.2, p. 40):

- Upper window area (a)
- Eye-level area, from the interior looking out (b)
- Floor to parapet area (c)

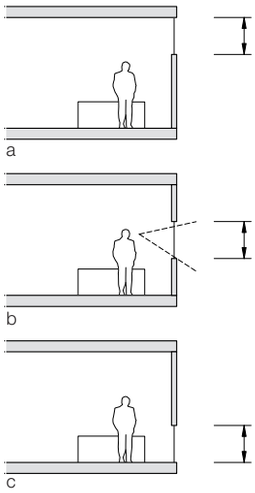
The following terms describe upper and lower areas around openings (areas around edges) in punctuated facades.

- “Lintel area” describes the area above a window/door up to the roof
- “Dado area” describes the area under a window/door down to the floor

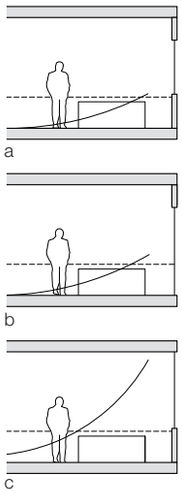
A 2.2.1 House, Paderborn (DE) 1995, Thomas Herzog and Andrea Heigl

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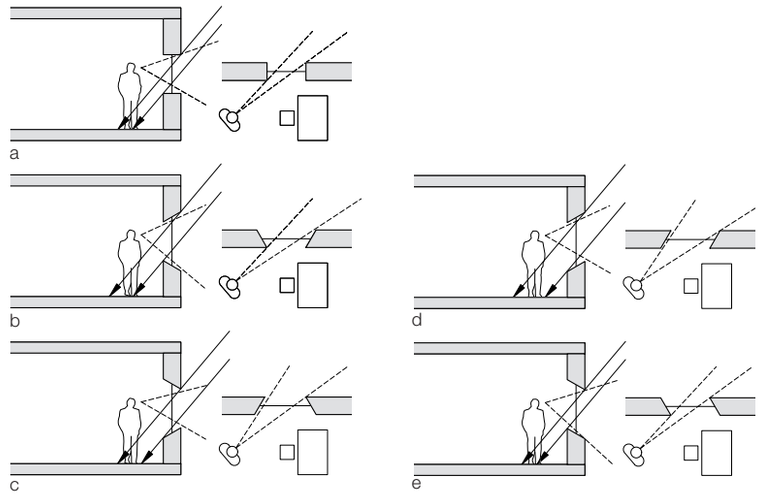
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A 2.2.2



A 2.2.3



A 2.2.4

Lines of sight
A desire for fresh air is often accompanied by a desire to stand directly at an opening (an open window), so manual operation of moveable closures and contact with the outside must be taken into account in planning openings. The opening should allow for this as well as closing the inside off from the exterior. Here a distinction is made between visual and physical links. The figures below indicate a user's average visual axis based on various positions in the room [4]:
- ca. 175 cm standing
- ca. 130 cm sitting down to work
- ca. 80 cm sitting on the floor
- ca. 70 cm lying down (at a height of 30 cm)

An opening's position and partitioning must be adapted to its type of use and position.

Light
The amount of light entering a space through a facade diminishes in the space's depths (Fig. A 2.2.3 [5]) and is measured in the form of the daylight factor (DF). It specifies ratios of illumination levels inside and out (only diffuse light) under standard conditions as a percentage [6].

The external factors influencing interior light are:
- The structure's orientation
- Time of day
- Local solar radiation conditions (climatic conditions, local shade from the surroundings, such as from vegetation and/or other buildings)

The positioning and geometry of openings in the facade is of fundamental importance in this context. High window openings let more light into the depths of rooms.
A room's actual luminance is largely determined by the reflectivity of interior surfaces, which in turn depends heavily on the predominant colours [7].

Ventilation
Put simply, ventilation is "the exchange of air in a space for outside air" [8]. Enough air should be exchanged in a space to meet hygienic demands, taking structural physical aspects into account (removal of pollutants in the air, discharge of moisture). Based on their drive forces, a distinction is made between mechanical ventilation (which moves air mechanically) and free ventilation, also called natural ventilation. Natural ventilation moves air by using differences in pressure between the inside and outside. These pressure differentials result from the following forces that are produced by natural conditions [9]:
- Wind forces: differences in pressure between inside and outside caused by wind impacting the facade result in the exchange of air
- Thermal lift: forces that arise due to differences in density because of temperature differences (thermal stratification). When wind pressure increases, thermal lift adds to its force.

Figure A 2.2.6 [10] shows the basic principle of air exchange through a facade opening due to thermal stratification without the influence of wind. There is no movement of air in the area of the imagined plane N (neutral zone). Changing the opening's vertical position and the influence of wind forces can shift this plane vertically. As well as the formation and positioning of ventilation openings in a facade, their variability is a crucial factor in the context of the physical properties of the building's envelope and mass [11].

Continuous ventilation requires small ventilation openings that are easy to regulate. Particular attention must be paid to interior airflows because this kind of ventilation continues for a long period.
- Ventilation from one side: To make efficient use of thermal lift, two openings should be positioned at the greatest possible vertical distance from each other. Systems that are easy to regulate prevent undesirable cooling and draughts.
- Cross ventilation: To make use of thermal lift in this case, the vertical distance between the air intake and air outlet should be as large as possible. This distance is not important in systems that employ wind-induced pressure differences.

Brief, intensive periods of ventilation require openings with the largest possible ventilation cross-sections:
- Ventilation from one side: The neutral zone in the middle of the opening means that the surface can be divided into two parts by a vertical distance.
- Cross ventilation: Air flows through in only one direction.

The exchange of air as well as the movement of air are relevant considerations in ensuring comfort [12], including:
- Air speeds at interior air intakes
- Maximum air speeds occurring in the room
- Average air speed in the room
- Average air speed at occupant levels (1 metre above the floor)

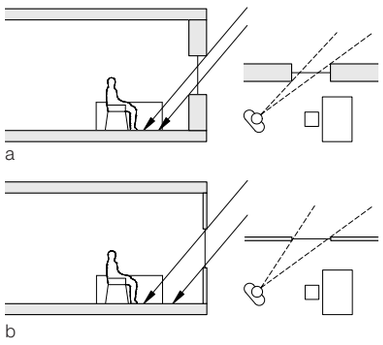
The upper limit value of air speed for comfort is regarded as 0.2 m/s. In office and administration buildings in particular, paper will be blown about at this air speed [13]. A draught is defined as the "undesirable local cooling of the human body" by a flow of air [14]. There are no absolute values governing draughts, which is why reference is often made to a "risk of draughts" [15]. To prevent draughts, it is preferable to distribute air entering the room through the space as much as possible.

Problems in the "comfortable incoming air supply" arise in summer with the ingress of warm outside air and in winter with draughts resulting from the ingress of cold outside air (which cold air downdraughts at the facade adds to). Distributed building technology for preheating or cooling incoming air in and around facade openings can counteract this problem.

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A 2.2.2 Areas of a facade, based on usage
a Upper window area
b Eye-level area
c Floor to parapet



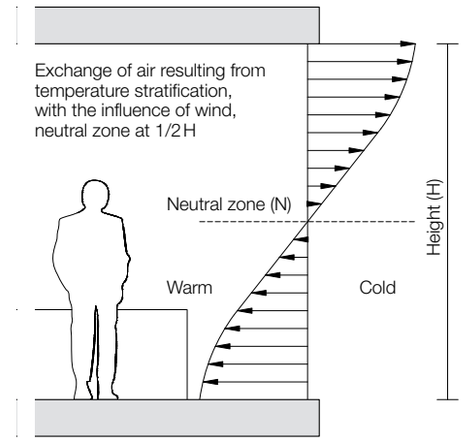
A 2.2.5

A 2.2.3 Influence of the position and size of openings on incoming daylight levels
a Middle
b Low
c High

A 2.2.4 Influence of the shape of the reveal (in a wall of even thickness with the same form on all sides)
a Parallel
b Sloping outwards
c Sloping inwards
d Parallel, trapezoid, sloping inwards
e Parallel, trapezoid, sloping outwards

A 2.2.5 Influence of wall thickness on lighting levels from daylight and views
a Thick wall
b Thin wall

A 2.2.6 Principle of the exchange of air through facade openings resulting from temperature stratification without the influence of wind forces, neutral zone N at 1/2 H



A 2.2.6

The effect of mechanical ventilation is more predictable than fluctuations in external conditions, so observations and investigations often only deal primarily with mechanical ventilation. Only in recent years have we seen an increase in approaches that take fluctuating conditions involving free ventilation into account in simulations and measurements. Increasing knowledge of natural ventilation and the growing importance of using environmental energy, especially solar energy, has resulted in more consideration being given to windows for ventilation. Aerodynamic factors affecting air intakes (gaps in partly opened windows, profile formation) must be defined for windows as they are for mechanical ventilation, for which precise figures are available on all components. Some effects familiar from air-conditioning technology can be applied to windows.

Displacement ventilation, which uses relatively low air speeds, spatially separates incoming air from exhaust air in a displacement flow moving upwards. Air enters at a low temperature in a stratum near the floor (laminar stratification of incoming air near the floor), and internal heat sources use thermal lift to draw air out of the incoming air layer and extract exhaust air at ceiling height. Displacement ventilation is usually used together with mechanical ventilation and can also be used with natural ventilation if ventilation openings in the facade allow incoming air to enter the room at floor level.

The Coandă effect can be used to make the ingress of incoming air as deep as possible into a space. When laminar jets of air are blown through slots not right under the ceiling but somewhat lower than it, the turbulence induced causes the jet to follow a surface, “sticking” to it in a sense. This effect, familiar from mechanical ventilation and sometimes called the turbulence boundary surface effect [16], can be applied to window ventilation under certain conditions. An exterior air flow is directed along smooth surfaces as tangential ventilation. The very low levels of turbulence ensure that this system is also effective in the depths of the room. The surfaces must be very close to the air intake. The position and geometry of incoming air openings (window aperture positions) must also be taken into account. The lower the temperature of supply air compared with interior air, the greater the risk of draughts. Exterior air entering a room can be pre-warmed by positioning incoming air openings adjacent to heat sources. The incoming air should be able to warm up from structural components by means of convection. Window ventilation is only possible at a certain outdoor temperature, if the guidelines established to maintain comfort are to be complied with. Depending on the type of window, an outdoor temperature of 0 to 6 °C has been specified as the lowest limit [17].
When outside temperatures are close to the range required for comfort, incoming air should be able to reach users in the room as directly as possible without being heated by warm structural components. When outside temperatures are high, incoming air can be cooled (slightly) by cooler structural components by means of convection. Effective thermal masses can release the thermal energy absorbed during night time ventilation or as structural components cool.
Window ventilation can only be of limited use on days when outside-air temperatures are high, if comfort is to be maintained.

The positioning of ventilation openings in the facade and type of ventilation (ventilation from one side or cross ventilation) determine the depths of the room at which free ventilation through openings in the facade is effective. The type of ventilation can also make a major contribution to comfort. Without referring to specific details on the arrangement of the opening sash, the general rule of thumb is that rooms that can only be ventilated from one side are regarded as being able to be “naturally ventilated” up to a maximum room depth of 2.5 times the clear height (H). For cross ventilation, the maximum possible room depth is up to 5 times the clear height [18]. If ventilation is on one side and an opening is set high up, ventilation is effective up to a room depth of up to 2 H. Adding a lower and an upper opening increases the effectiveness to up to 3 H [19]. These figures are not at all absolute and can only serve as rough guides. The type of opening has not been taken into account.

Small window openings must be precisely positioned and formed because an airtight building envelope magnifies the effect of streams of air in the room like a jet effect. If ventilation cannot be regulated by means of window openings, additional elements (e.g. flaps) can be set into the facade. The tables in DIN 5034 specifying a minimum window size for dwellings refer to adequately supplying rooms with daylight and the size of ventilation openings cannot be deduced from them.

Changing permeability

Structural devices can influence permeability. Rigid and modifiable, i.e. moveable elements can be used to do this.

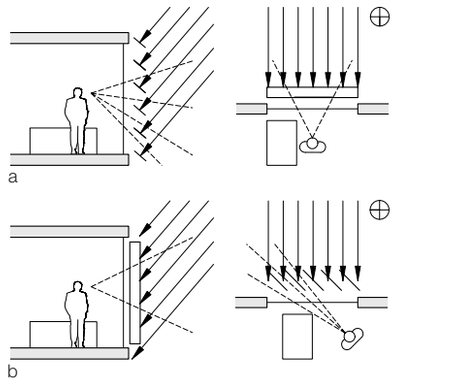
Rigid elements

Solar radiation and climatic conditions vary over the course of the day and year, so the effects of immoveable elements change with them (shading, reflection, light refraction) depending on the sun’s height.
Various principles can be used to provide shade (Fig. A 2.2.8, p. 42):
- Complete direct coverage of the facade surface
- A projecting element
- The addition of other, smaller elements (e.g. louvre or grid structures)

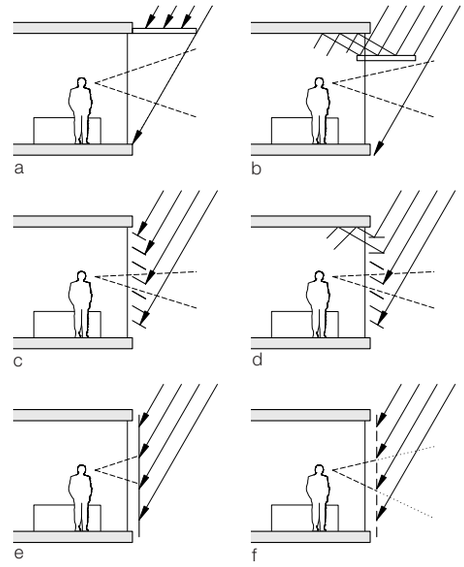
Louvre structures can be divided into two categories based on their positioning, orientation and the related height to depth

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A 2.2.7



A 2.2.8

- Horizontal louvres angled appropriately can prevent sunrays hitting a south-facing surface at a steep angle from penetrating inside a building.
- Vertical louvres can keep sunlight striking an east or west-facing facade at a shallow angle out of the building.

Both principles can provide shade while also allowing building occupants to see out (Fig. A 2.2.7).

Moveable elements

The chapter on “Manipulators” (p. 266ff.) deals in detail with moveable and modifiable elements in and around openings and shows examples. The observations below deal with moveable windows.

Windows are primarily characterised by the possibility of partially opening and closing the building envelope. Of all a window’s various possible features (material, type of movement, structure of the window frame, attachment to the wall) the type of opening (type of sashes), with its function of opening the facade, defines a window’s structural and design characteristics.

The various kinds of window openings can be further classified as types by defining four considerations (Fig. A 2.2.9) [20]:

- Movability
- Degree of movability
- Type of movement
- Other distinguishing characteristics

First consideration: movability of the facade surface

Facade surfaces can be divided into fixed and openable based on their movability. Window openings are classified based on static (load-bearing) and structural aspects (elements for fixed glazing and moveable sashes). The size of individual transparent fields depends on the availability of materials (e.g. panes of glass) and defines the window’s partitioning.

Second consideration: degree of movability

A window’s degree of movability is determined by its freedom of movement, which is in turn governed by the window’s frame and sash structure and type of fittings.

Third consideration: type of movement

Windows can be further differentiated based on the way they move. This movement is often also reflected in the term used for the window.

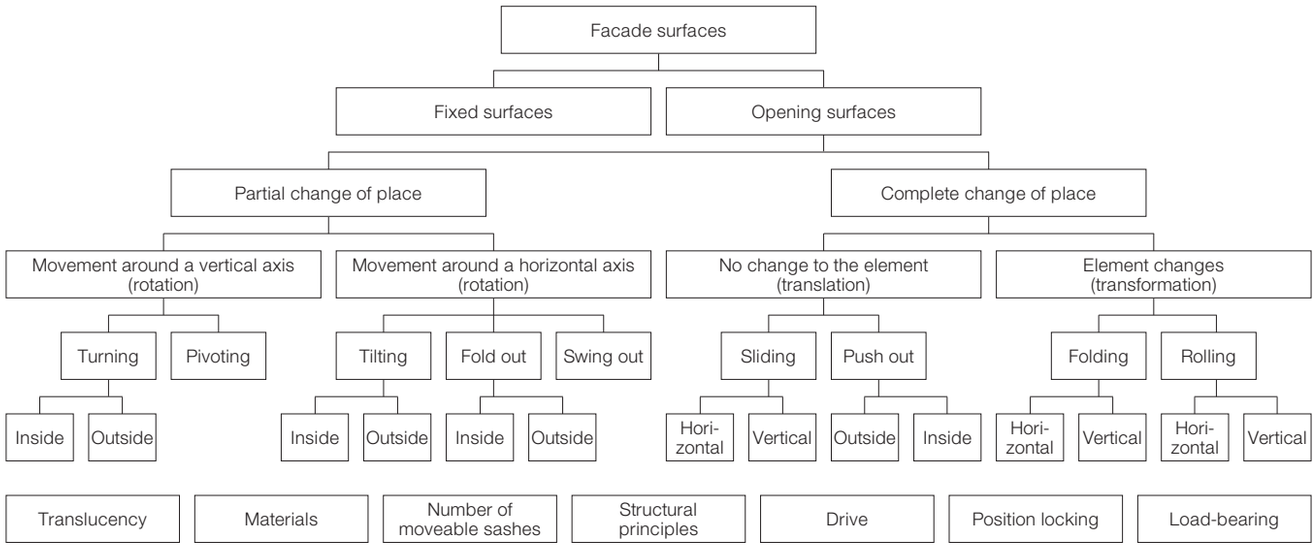
- Partial change of place, movement around a vertical axis (rotation):
  - Pivoting window
  - Side-hung window
- Partial change of place, movement around a horizontal axis (rotation):
  - Hopper window
  - Top-hung window
  - Pivoting window
- Movement involving a complete change of place without changing the element (translation):
  - Sliding window
  - Push-out window
- Movement involving a complete change of place and element (transformation):
  - Folding window
  - Roller shutter
- Combinations

The folding windows usually used are in fact often windows with pivoting panes whose entire surface is not folded but consists of several individual frames, in contrast, for example, to the folding walls used as partitions, where the entire wall surface folds.

A facade as part of the building envelope has the fundamental function of vertically separating two spaces. The types of window movements can therefore also be differentiated in a secondary consideration by their relationship to the facade plane – usually outside/inside and upper/lower, e.g.:

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A 2.2.9

- Turning: inwards/outwards
- Folding: inwards/outwards
- Sliding: horizontal (to the right/left)/vertical (upwards/downwards)

Further distinguishing features
Distinctions can also be made in this context based on construction principles and resulting features. As well as distinctions made for all moveable surfaces based on the number of sashes, specific features also define types of opening.
The number of sashes (moveable sashes, those that lock in place or can be moved only for cleaning or maintenance, fixed surfaces) can indicate varieties of possible openings.
One distinguishing feature that has gained in importance in the context of controlled natural ventilation is the way sashes are moved, which can be manual or mechanical.
Specific construction principles involve various types of openings, so they can only be differentiated by the principles of their movement. Some features are based primarily on construction and only secondarily on the opening mechanism, regardless of the opening's typological classification.

Performance range of the type of movement
Movement mechanisms have various features that are of fundamental importance because of their influence on function, construction and design [21]. The performance range of an openable element in the building envelope is made up of functional properties (Fig. A 2.2.10, p. 44):
Architects need a precise knowledge of types of movement and related performance profiles to make effective use of windows as components of the building envelope in terms of energy balance and user comfort. [22].

Possible combinations
The terms used highlight the diversity of the types of movements of windows resulting from possible combinations:
- Side-hung window with side-hung or sliding fittings
- Side-hung hopper (turn and tilt)
- Top-hung window: push-out, top-hung window
- Folding (combination of pivoting and sliding movement)
- Folding window: folding, sliding window
- Pivot-hung window; pivoting/sliding window
- Pivoting window
- Sliding windows: upwards sliding, lift and slide, hanging, drop-sliding, drop, horizontal lift and slide
- Parallel push out sash; tilt and parallel sash; turn and parallel sash

Types of movement have developed through individual steps into a multitude of variations. Some types from the middle of the last century that are now largely no longer produced are still frequently found in existing buildings. Such windows are no longer used because of joint sealing problems, among others, and higher modern structural physical requirements that involve heavier panes and make much higher demands on fittings and frames. In tackling joint sealing problems, an adequate exchange of air has become less important than reduced heat losses (partial optimisation), instead of solving the problem in its context.

Building with facade elements

A building envelope cannot usually be made in one piece, so it has to be worked on in individual pieces during construction. Some fundamental terms used in scientific systems have been expanded to stipulate five steps for architecture in this context, resulting in the following series of classifications (Fig. A 2.2.11, p. 45):
- System
- Subsystem
- Structural element/component
- Element
- Material

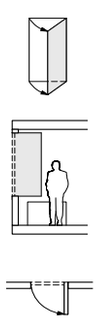
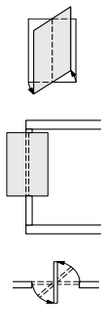
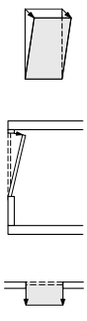
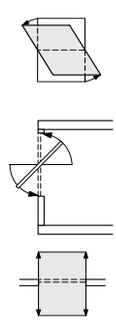
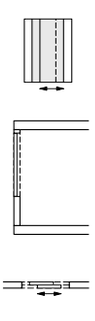
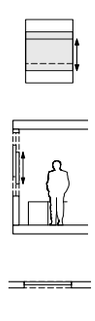
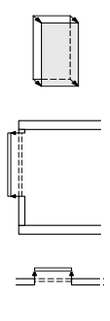
The choice of scale or section considered can result in a shift in this system (e.g. in urban development: city = system, building = element).

Assembly and installation sequences
Construction processes involve the chronological progress of assembly, and until construction is complete, there are various intermediate states. Depending on the situation, external conditions can influence construction. In inner cities, in particular, materials for large construction projects can only be transported to a certain extent. Climatic conditions also directly influence construction processes. Changing weather conditions can result in delays that affect the entire further construction process. Erecting a facade as protection from the weather makes it possible to continue erecting the building largely independent of changes in the weather.

A 2.2.7 Shading from louvres: influence of orientation
a South-facing facade: horizontal louvres
b East/west-facing facade: vertical louvres
A 2.2.8 Principles of sun shading: screening/filtering of direct sunlight
a Projection: screening
b Projection: shading due to the screen and reflection for use of daylight
c Louvre structure: screening
d Louvre structure: screening and reflection for use of daylight
e Covering: screening
f Filtering: perforation
A 2.2.9 Typological classification of types of movement of windows

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Comparison of window movement types to determine their performance profile	**Side-hung window opening inwards**	**Pivoting window**	**Hopper window**	**Top hung window**	**Horizontal pivot window**	**Horizontal sliding window**	**Vertical sliding window**	**Push-out window**
								
Obstruction of usable floor space related to the depth of the room	opening width	1/2 opening width	minimal	none (if outward opening)	1/2 opening width	none	none (if outward opening)	none
Options for installation in high-traffic areas	yes (if outward opening)	no	yes	yes (if outward opening)	only if opening is limited	yes	yes (if outward opening)	yes
Views through: maximum clear aperture and partitioning	100 %	100 % with vertical partitioning	no clear aperture	no clear aperture	100 % with horizontal partitioning	50 % with vertical partitioning	50 % with horizontal partitioning	no clear aperture
Geometric description of the minimum/smallest opening area possible	1× gap at the side, top and bottom angled	2× gaps at sides top and bottom 2× angled	2× gaps at sides angled, top slot aperture	2× gaps at sides angled, bottom, slot aperture	4× gaps at sides angled, top and bottom, slot aperture	2× gaps at sides slot aperture	top and bottom	circumferential gap
Geometric description of the maximum/largest opening area possible	complete opening area	complete opening area, perpendicular partitioning	2× gaps at sides angled, top slot aperture	2× gaps at sides angled, bottom, slot aperture	complete opening area, horizontal partitioning	50 % of opening area as perpendicular partitioning	50 % of opening area as horizontal partitioning	circumferential gap
Suitability for slot ventilation	limited	limited	limited	limited	limited	good	good	good
Suitability for complete opening for brief, intensive airing	good	good	no	no	good	good	good	no
Adjustability of openings	only with extra fitting	only with extra fitting	only for maximum tilt position	with the fitting used for opening	no	good	good	good (mechanical drive)
Protection from weather (from precipitation) for slot ventilation	no	no	yes	yes	yes	no	above: yes below: limited	limited (with element added to upper opening)
Movement type against slamming in wind	no	no	no	with extra fitting	no	yes	yes	yes
Potential for combination with interior manipulators	no	no	limited	yes	no	yes	yes	yes
Potential for combination with exterior manipulators	yes	no	yes	no	no	yes	yes	limited
Outside can be cleaned from the inside	yes	yes	with detachable fitting	no	yes	no	with extra (detachable) fitting	no
Notes on sealing	also outward opening (in wind and rain)	horizontal seals offset	bottom rebate not always possible	for use in windy areas	vertical seals offset	bottom rebate possible, contact pressure requires additional feature	bottom rebate possible, contact pressure requires additional feature	no protection from weather, not even when minimally open
Notes on fittings	projecting sash produces moment	loads borne centrally	sash must be secured against falling	sash must be locked in position when window is open	sash can sag when window is open	high, narrow formats can jam	compensation for sash's own weight required, can jam	scissor must transfer wind forces

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Term	Example
System	Building
Subsystem	Envelope (roof, facade), load-bearing structure, supply and disposal, inner partitioning, access
Structural element/component	Window sash in window frame
Elements	Profile, insulated glazing, fittings, seals
Material	Metal sheeting, glass

A 2.2.11

A 2.2.10 Comparison of types of movement of windows for identifying different performance profiles
A 2.2.11 Basic terms for an architectural systems analysis

Prefabricated components made of elements
To enable construction to proceed largely independently of weather conditions, individual parts can be prefabricated under controlled conditions in factories almost anywhere, which can greatly reduce construction time on site and the associated risks. Prefabrication can also offer much greater precision and lower tolerances.
Windows in punctuated facades are set into recesses in the facade structure. Methods based on two different principals are used to build non-load-bearing exterior walls for facades with large areas of glass construction, with the distinction in this case made based on their assembly.

Element facades
These are facades made up of individual prefabricated units that are put together to form a whole facade on site. The term refers not to the sequence in the systemic context above (see p. 43), but to their prefabrication and the assembly process. Prefabricated elements in glass facades usually consist of panes of glass held in frames, so this type of construction is also referred to as frame construction. Element facades are suitable for tall administrative buildings. The elements are lifted into place by a crane and installed without scaffolding.

Post and beam facades
In contrast to element facades, a post and beam facade consists of individual elements: vertical facade posts and horizontal facade beams that are put together on site. The term describes their structural principle. Post and beam facades are now used mainly for low-rise buildings.

Notes:
[1] In this chapter the word “window” (as used in common speech) refers to a moveable, transparent closure of an opening in a wall.
[2] Dietze, Lothar: Freie Lüftung von Industriegebäuden. Berlin 1987, p. 18
[3] Le Corbusier made this distinction in his work for the La Tourette cloister (1960).
[4] Pracht, Klaus: Fenster – Planung, Gestaltung und Konstruktion. Stuttgart 1982, p. 102
[5] Graphic based on Müller, Helmut; Schuster, Heide: Tageslichtnutzung. In: Schittich, Christian (ed.): Solares Bauen. Munich/Basel 2003, p. 63
[6] VDI Guideline 6011. Dusseldorf 2016
[7] Miloni, Reto P.: Von Aperturfläche bis Zenitlicht. Kleines Tageslicht-ABC. In: Fassade/Façade 01/2001, p. 12
[8] Meyringer, Volker; Trepte, Lutz: Lüftung im Wohnungsbau. Published by the Federal Ministry for Research and Technology. Karlsruhe 1987, p. 11
[9] A distinction is made between drive forces depending on a building’s local situation because wind forces are created by climatic conditions due to solar radiation and differences in temperature.
[10] Graphic based on Zürcher, Christoph; Frank, Thomas: Bauphysik. Vol. 2: Bau und Energie – Leitfaden für Planung und Praxis. Zurich/Stuttgart 1998, p. 80
[11] As for Note 7, p. 33–36
[12] Givoni, Baruchi: Passive and Low Energy Cooling of Buildings. Van Nostrand Reinhold, New York/London/Bonn 1994, p. 42
[13] In specifying air speed figures, it should be noted that air speeds above 0.15 m/s can be subjectively (physically) perceived. Hanel, Bernd: Raumluftströmung. Heidelberg 1994, p. 6
[14] Fanger, Ole: Behagliche Innenwelt. In: Uhlig, Günther et al.: Fenster – Architektur und Technologie im Dialog. Braunschweig/Wiesbaden 1994, p. 217. For a design using very airtight windows, ventilation openings were installed above radiators to ensure a minimum supply of air.
[15] Draughts as well as noise are the main reasons for dissatisfaction with air conditioning and ventilation systems. Recknagel, Hermann; Schramek, Ernst-Rudolf (eds.): Taschenbuch für Heizung und Klimatechnik einschließlich Warmwasser- und Kältetechnik. Munich 2001, p. 59
[16] Recknagel, Hermann; Sprenger, Eberhard; Schramek, Rudolf (eds.): Taschenbuch für Heizung + Klimatechnik. Munich 1999, p. 1207
[17] Zeidler, Olaf: Freie Lüftung in Bürogebäuden. In: HLH, Vol. 51, 07/2000
[18] Daniels, Klaus: Gebäudetechnik – ein Leitfaden für Architekten und Ingenieure. Zurich/Munich 1996, p. 260
[19] Baker, Nick; Steemers, Koen: Energy and environment in architecture. London 2000, p. 58
[20] Westenberger, Daniel: Vertikale Schiebefenster – Zur Typologie der Bewegungsarten von Fenstern als Öffnungselemente in der Fassade. In: Fassade/Façade 03/2002, p. 23–28
[21] Westenberger, Daniel: Vertikal verschoben – Eigenschaften und Leistungsspektrum von vertikalen Schiebemechanismen bei Fensteröffnungen. In: db 09/2003, p. 86–91
[22] This chapter contains sections from the dissertation of Daniel Westenberger. Westenberger, Daniel: Untersuchungen zu Vertikalschiebefenstern als Komponenten im Bereich von Fassadenöffnungen. Diss. TUM, Munich 2005

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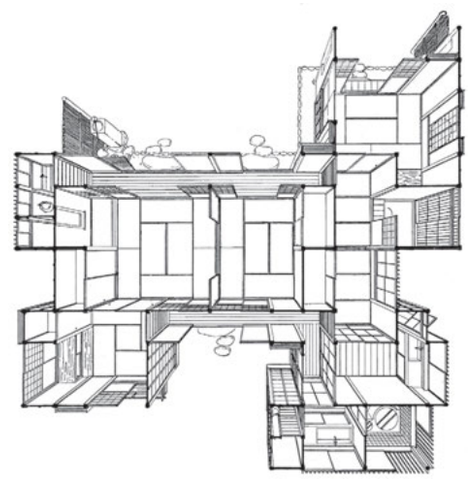
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Проектирование

A 2.3 Modular coordination

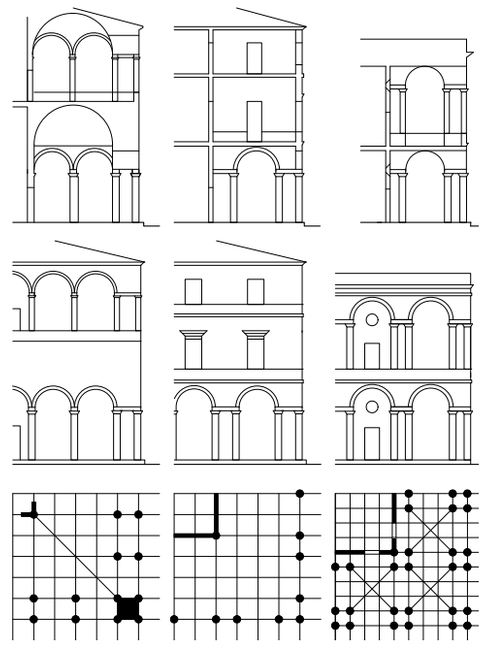
Buildings usually consist of a range of different individual parts (structural components or elements) that are generally produced by different manufacturers and built in and installed in varying chronological orders, so consistent geometric rules must be followed to produce a structure free of defects. This “grammar” applies to the overall structural and the technical context of (building-related) subsystems, such as the support structure, exterior walls, interior structure and supply and disposal (Fig. 2.3.4), and is generally referred to as modular order [1].

From column orders to modular coordination systems

The dimensional coordination of a building’s structure is not a new topic. Vitruvius described a “modulus” as calculated part, a basic measurement that was based on the lower (half of) a column’s radius, on which “symmetry … is based [as] an interrelation of individual separate parts for planning the building as a whole” [2].
In Antique and Renaissance architecture, fundamental dimensions (spacing and height of columns, entablature height and projection) were specified in “column moduli”. The structure and form of columns were based on the proportions of the human body, so there was a close relationship between the “module and the measure of man” [3].
These orders of columns and proportions and the related module (modulatio) theory are also connected to the square grids laid over building floor plans and facades, where the distance between individual lines is also referred to as the module. This invisible module is the abstract basic unit of a (theoretical) geometric system for organising spatial dimensions and structuring buildings.
Geometric and modular orders are not only found in European architecture. Japanese dwellings are often measured using a tatami mat as the basic unit, which is unique in architectural history. Tatami, hard-pressed, rectangular straw mats with an aspect ratio of about 1:2, are laid out in homes and can serve as the fundamental module of their structure and dimensions. The tatami is however just one element in the modular system of a wooden Japanese house. Developed in an attempt to bring about standardised measurements for structural components, there is not just one ideal size, but depending on two specific distances between columns, one module for the city (approx. 95 × 190 cm) and another for the country (approx. 90 × 180 cm). Discrepancies in the tatami modular system are the result of manual work by skilled craftsmen (Fig. A 2.3.2) [4].
Jean-Nicolas-Louis Durand’s work heralded a paradigm shift in the (modular) planning and design of buildings. Around 1800 he departed from anthropometric, hierarchically structured

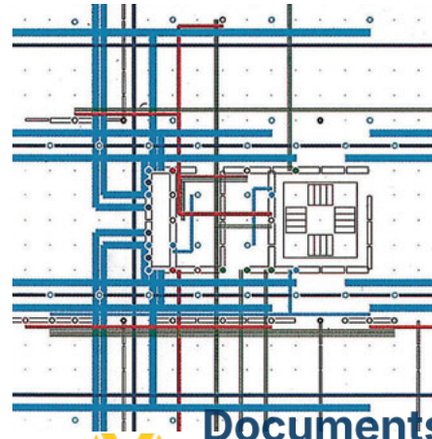


A 2.3.2



A 2.3.3

A 2.3.2 Perspective view of the floor plan of a typical single-storey Japanese house
A 2.3.3 Arcade system based on the work of Jean-Nicolas-Louis Durand
A 2.3.4 “ARMILLA”, tools for computer-assisted technical installation route planning in high-tech buildings, layout of secondary lines, Fritz Haller

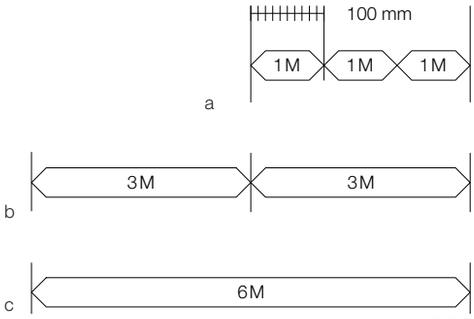


A 2.3.4

A 2.3.1 Eames House, Los Angeles (US) 1949, Charles and Ray Eames

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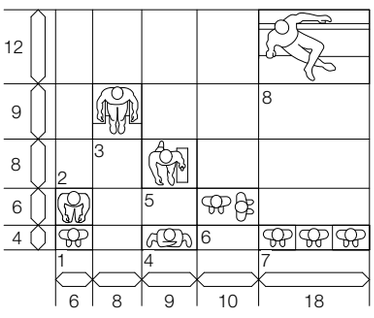
A 2.3.5

A 2.3.5 Modular order
- a Basic module
  The basic module is the unit size used in dimensional coordination. The basic module M agreed on EU-wide measures 100 mm.
- b Multiple module
  A multiple module is a standard multiple of a module with a whole-number multiplier. Multiple modules include 3M, 6M, 12M.
- c Construction module
  A construction module is a multiple of multiple modules and the figure that defines the coordinating dimensions for the load-bearing structure.

					1					
				2	5	3				
			4	10	6	15	9			
		8	20	12	30	18	45	27		
	16	40	24	60	36	90	54	135	81	
32	80	48	120	72	180	108	270	162	405	243

2.3.6

A 2.3.6 Preferred increments
Preferred increments are selected multiples of modules. Applied together with modules, preferred increment figures make up multi-modular or modular dimensions. For practical reasons they must be limited to specific multiples of modules. Coordinating dimensions should ideally be made up of preferred increments.
Preferred increments are:
1, 2, 3 to 30 times M
1, 2, 3 to 20 times 3M
1, 2, 3 to 20 times 6M
1, 2, 3 etc. times 12M



A 2.3.7

A 2.3.7 Numerical values for the length and width of frequently-used spatial dimensions, expressed in modules based on the scale of the human body:
1 Person standing
2 Person sitting
3 Person sitting in a chair
4 Person standing with legs apart
5 Person walking with baggage
6 Two people standing
7 Three people standing in a row
8 Person sitting on a sofa

architecture and based all construction and architectural elements on a standard grid with rational dimensions (Fig. A 2.3.3, p. 47). His system's starting point was the distance between columns, which as the "structural material-related size of a girder" also takes aspects of a design's economy and practicality into account [5]. Durand's work formed an important basis for developing the module system, which subsequently became the foundation of the development of industrial construction.
Konrad Wachsmann also dealt with the industrial production and the coordination of standardised elements in his book "The Turning Point of Building" (1959).

Modular coordination systems based on square grids or planar surfaces can influence floor plan and facade design as well as spatial organisation. Coordination systems of this kind are the result of precise theoretical and practical investigations of "measurements, measurement methods, the definition of dimensions and dimensioning, from the smallest component through to the complete building" [6].
The transition from manually crafted construction to (partly) industrialised construction processes made it necessary to define the possible leeway in the relative positions of individual parts in an increasingly precise way. Technical manufacturing processes can make parts with very precise dimensions, so defining and controlling tolerances are essential elements of geometric modular order.
The Modulor, developed by Le Corbusier between 1945 and 1955, was a clear departure from this technological approach and uniform modular grids. His Modulor proportion system is based on a series of numerical values, although they are not based on the same initial dimension, so it is a method based more on a "directional, dynamic structure" [7].

Dimensional coordination and modular order

Modular order is a system of coordinating dimensions made up of moduli and rules for coordinating the dimensions of technical parts whose position and function in a system must be compatible. It uses moduli to regulate "with the help of grids and coordination systems the position and size of and links between technical elements" [8]. Dimensional coordination establishes rules for the dimensions of structural components, forming the basis for planning, manufacture and installation, coordinating processes and those involved in them, and determining the degree of industrialisation of construction.
This system enables the position of every structural component, dimensions important for connections and the dimensions coordinated with other adjoining or associated structural components to be recorded. Modular order aims to ensure:
- Overall geometric and dimensional coordination of the structure
- Replaceability of products
- A limit to the wide range of potentially applicable products
- Prefabrication and controlled and consistent installation on site

Terminology and units

Modules

Modules are ratios in technical dimensions. In Europe, the basic modular unit is M, which is 10 cm (Fig. A 2.3.5 a).
To limit the wide range of possible dimensions of structural components and appropriately design modular dimensions and functions of structural components, preferred increments – multiples of modules –, i.e. a multiple of M (M = n × M), are specified. Multiples of modules or planning modules define a design's systematic construction (Fig. A 2.3.5 b). DIN 18000 on "Modular coordination in building" proposes various planning modules, namely 3M, 6M, 12M, which build on the basic module [9].
Multiples of planning modules are put together to form a construction module, which determines the structure and coordination of construction (Fig. A 2.3.5 c). Common construction modules such as 36M, 54M, 72M etc. are classified according to their type of use. Construction modules can be added or subtracted to form parts or multiples of them, which DIN 18000 refers to as preferred increments. Preferred increments should be limited to a certain number of multiples for practical reasons. Application-oriented preferred increments with multiple applications are characterised by several options for subdivision (Fig. A 2.3.6). Based on preferred increments or multiples of modules, functional modular dimensions can be defined to accommodate various human activities such as standing, sitting, lying or walking (Fig. A 2.3.7) [10].

Reference systems

Reference planes, lines and points are required to determine a modular structural component's position and general dimensions as well as its relationship to adjoining components.

Grids

A grid is a geometric spatial coordination system that has a regular sequence of constantly spaced reference lines, the grid dimension. They determine the spacing and position of lines in the system depending on the planning dimensions chosen. A grid's spacing is built on a module or multiples of a module. In most cases the grid's basic form is a rectangle or square. Grids can be used to plot every structural component in its position and coordinate

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it with other structural components. Reference is also sometimes made to axial dimensions, which determine the spacing of a structure's grid lines and form a coordinating system based on construction modules.

Types of references

Types of references are established rules for plotting modular and non-modular parts of coordination systems. There are two basic means of plotting structural components on a modular grid:

- Axial control lines (grid reference/axial dimensions, centre-to-centre measurements)
- Face control lines (planning grid/standard measurement)

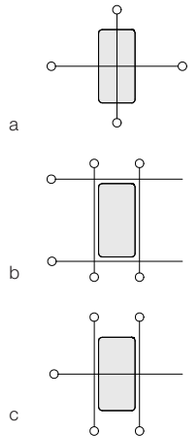
Axial control lines establish a relationship between a structural component and the reference system by making a structural component's axial line coincide with a reference line, i.e. the structural component is centred on the reference line. This shows the structural component's position and centre-to-centre spacing of structural components, but does not define their cross-sectional form or their dimensions, so the dimensions of adjoining structural components cannot be deduced in this case (Fig. A 2.3.8a).
Face control lines or standard measurements use at least two lines in the reference system to plot a structural component, showing its position and general size (in two dimensions) (Fig. A 2.3.8b). A combination of axial control lines and standard measurements defines a structural component's position in one dimension and its size in a second dimension (Fig. A 2.3.8c).
Structural components are three-dimensional, so they can be clearly plotted using types of references in a coordination system in all three dimensions. The choice of a type of reference and their combination will depend on the individual case at hand. DIN 30798/3 specifies the following "rules of thumb" for classifying technical parts:

- Face control lines in all three dimensions (cubic elements/cubicles)
- Face control lines in two dimensions, axial control lines in one dimension (planar parts/wall elements)
- Face control lines in one dimension, axial control lines in two dimensions (linear elements/columns)
- Axial control lines in all three dimensions (punctiform elements/nodes)

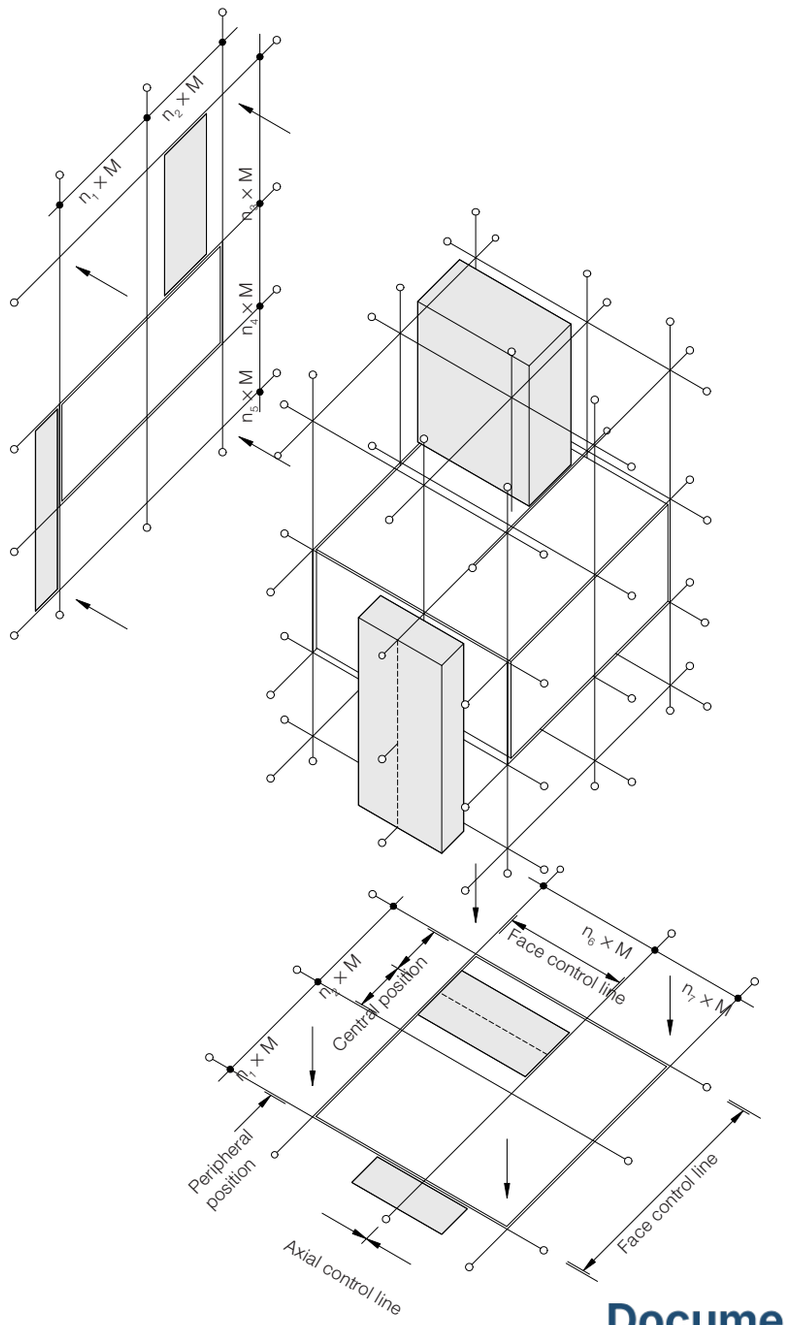
When arranging structural components that can have different sizes in one or two dimensions, a distinction is made between their central or inner position and peripheral or outer position. A centrally positioned structural component's central axis coincides with the central axis of the modular zone, while a structural component in a peripheral position has a primary reference surface aligned with one of the

A 2.3.8 Types of reference
a Axial control line
The structural component is positioned so that its central axis coincides with coordinating lines in at least one dimension, i.e. its position is shown.
b Face control line
The structural component is defined in at least one dimension between two parallel coordinating lines so that it is aligned with them, i.e. its dimensions, position and often its form are shown.
c Combination
A combination of axial control and face control lines show a structural component's position in one dimension and its dimensions in a second dimension.

A 2.3.9 Geometric definitions



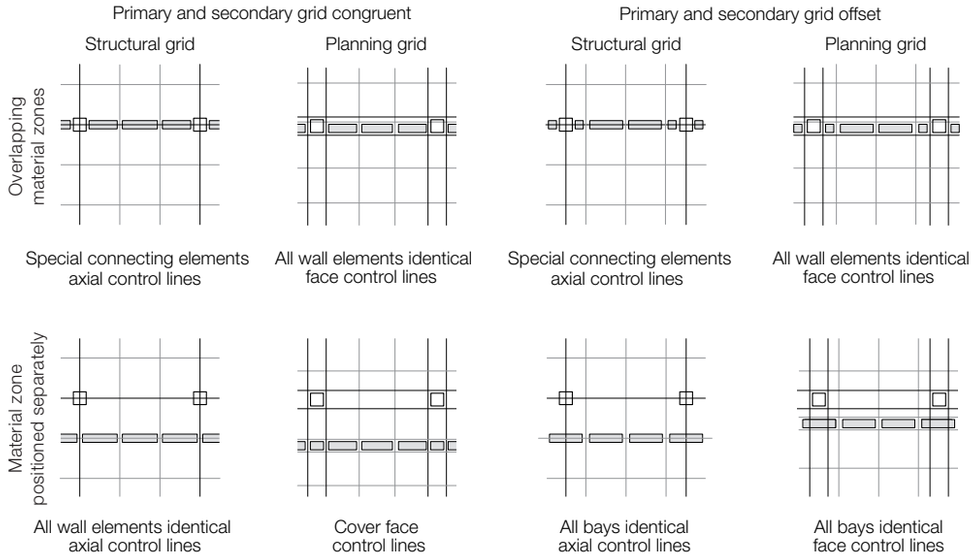
A 2.3.8



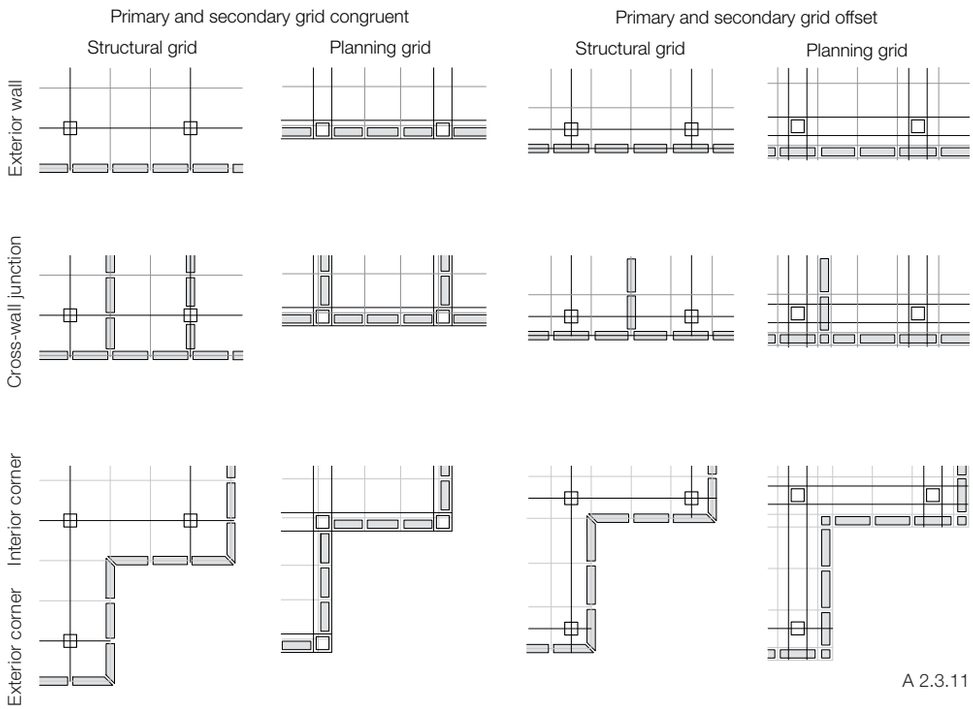
A 2.3.9

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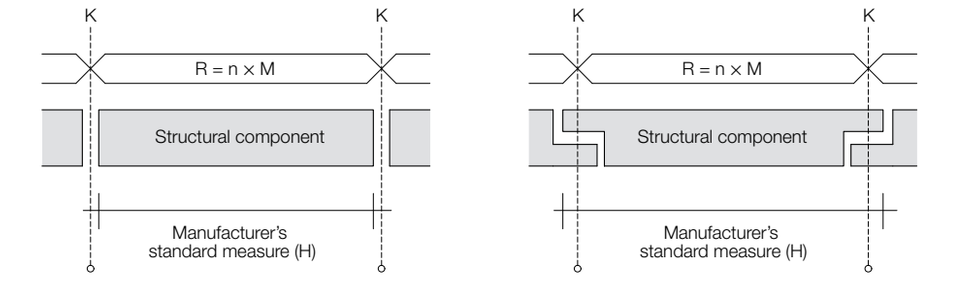
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A 2.3.10



A 2.3.11



a b

A 2.3.12

coordination lines. Here structural components of different dimensions have the same reference plane. Central or inner position and peripheral or outer position are usually used in conjunction with axial and face control lines. If a structural component varies from the normal position, the dimensions for adjoining structural components will also vary, making special formats necessary (Fig. A 2.3.9, p. 49) [11].

Geometric specifications

Modular systems are created by alternating the spacing of parallel coordination lines with one or more modules, so modular grids can be based on one or on different modules in each of the three spatial dimensions.

Primary and secondary grids

Coordinating individual structural components requires superimposed planes of reference, so they have to be prioritised, i.e. a primary and a secondary grid must be defined. Usually the structural grid is identified as the primary grid and the fit-out grid as the secondary grid. The most common geometrical relationships between a facade and a structural grid are offset and congruent positions.

When material zones overlap, as with axial control lines, the differing dimensions of adjoining fields make special element formats (shortening) necessary. Separating material zones enables the load-bearing structure and facade to be positioned independently of each other, so the same elements can be used (Fig. A 2.3.10).

Junctions and corner joints

Overlapping or independent positioning of modular zones (material zones for the load-bearing structure and facade / fitting out), combined with a congruent or offset positioning of the reference system, imposes various different structural conditions on the dimensions and connections of structural components and on connections between a load-bearing structure and a facade, especially in and around internal and external corners (Fig. A 2.3.11).

Dimensional coordination

The dimensions specified in modular orders are only general, so the production of special structural components requires coordinating or standard measurements (R), which regulate the spacing of reference planes defining the structural component's position and dimensions and are usually a modular measurement (R = n × M). The manufacturer's standard measure (H) can be deduced from these measurements, taking the proportion of joints, the structural component's connecting planes, and dimensional tolerances into account: H < R.

Depending on the formation of connections, the manufacturer's standard measure can also extend beyond the modular space: H > R. In this case a fitting dimension, which regulates the dimensions between structural components, must be taken into account (Fig. A 2.3.12).

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