ROAD MAP to sustainable and cost-effective solutions

FOR PRECAST CONCRETE PRODUCTS

DESIGN GUIDLINES for FACADE SANDWCH PANEL

v1.1

since 1991

GLASS / CURTAIN WALLS / ALUMINIUM FACADES | STEEL | CONCRETE | ENERGY | MACHINERY

AUDIT SHEET

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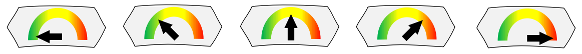


visual indicator of effectiveness

visual indicator for change

CONTENTS

0. Introduction

Purpose of this document is to summarize the UPB knowledge and experience of prefabricated concrete, steel and glass gained in Baltic and Scandinavian countries and to provide designers with an understanding of offsite construction and its concrete products. This document provides recommendations on design details of the product that enables efficient manufacturing process and best site practices.

This document is intended to be a living document with revisions from users' feedback, up to date construction technologies and design practices.

Wide range of aesthetics and performance can be achieved with prefabricated concrete and hybrid elements when designed and executed properly. Various materials, textures and finishes can be used to enrich the visual properties of building envelope elements. Products manufactured in factories enables to eliminate works on construction site to an absolute minimum that brings direct benefits – safety, high quality and defined tolerances as well as indirect – construction rate and cost reduction.

This document cannot replace professional advice. When this guidance is applied in buildings it must be reviewed by experienced facade and structure design engineers and consider specific conditions and design parameters of each building. Specific conditions during professional consultation can lead to other recommendations than proposed in this document.

FACADE PRODUCTS

PRECAST SANDWICH WALL

1. Specification

Product standard: **BS EN 14992** CE

Precast insulated sandwich panels are typically comprised of a minimum of 3 separate layers:
- base panel of precast concrete
- insulation
- face panel of precast concrete

Additional layers such as vapour barrier and air void can be added. The air void layer can be included in insulation by choosing insulation with premade air void grooves.

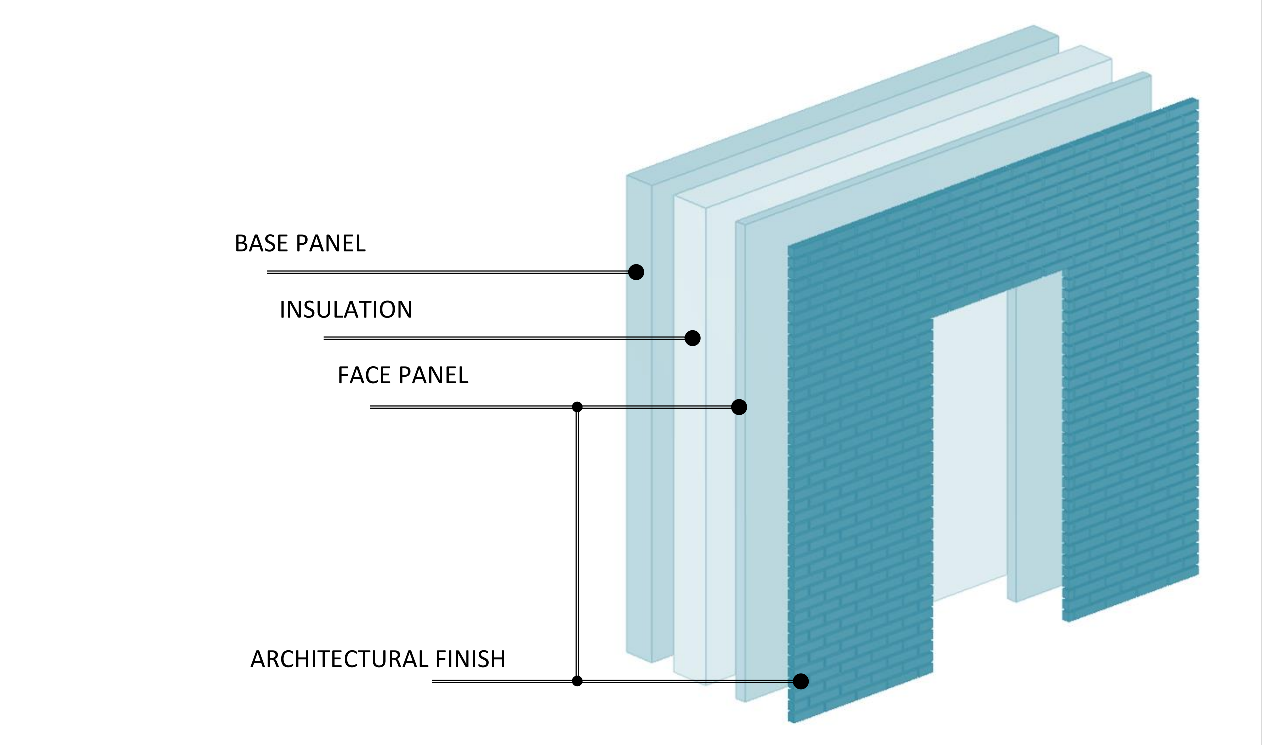


Figure 1.0 Layers of wall ../../..-.., mm *(base panel/insulation/face panel - finish)*

The face panel is attached to the base panel with steel connectors and ties. Panel frame fixings are related to its supporting strategy, typically not placed in face panel.
The face panel has varieties of architectural finishes.

Surface requirements, brick types, patterns, pointing, on-site jointing, and other required **characteristics and properties** should be **selected and tested as early as possible**.

1.1. Geometric data

Project appropriate wall thickness and overall panel sizes are determined after a full project case study as it is dependent on many factors (supporting strategy, fire performance, finish requirements, opening placements, etc.).

Typically,
non-loadbearing insulated sandwich panel section proportion is **80/230/80-x** (x=50 for brick face)), **for U=0.145.**
Loadbearing base panel recommended min thickness is 150 mm, correspondingly section is **150/230/80-x for U=0.144.**

1.2. Materials

Options of layers
- for base panel:
  - normal concrete
- for insulation (non-combustible):
  - rock wool
  - fire barrier
- for face panel:
  - normal concrete
  - visual concrete (pigmented, etc.)
  - Ultra-High-Performance Concrete (UHPC)
  - Glassfibre Reinforced Concrete (GRC)

1.3. Architectural finishes

Base panel surface treatments and finish options
(top-in-form face)
- concrete surface: polished or rolled or decorative rolled or brushed or raked
- concrete surface with paint finish

Face panel surface and finish options
(main form (mold) face ▲ and other form faces)
- exposed concrete surface
- concrete surface with paint finish
- concrete surface with sand blast finish
- **concrete formliner** (*https://www.reckli.com/en/products/concrete-formliners/select*)
- concrete formliner with paint finish
- exposed aggregate
- graphic concrete (*https://www.reckli.com/en/products/concrete-formliners/visuals*)
- **brick, brick slip**
- terrazzo stone tile
- tile
- cladding *(GRC, UHPC, etc.)*

Surfaces and finishes may be **combined** within a panel **and placed in different planes** including spatial layering.

See Section 3 for more detailed information.

1.4. Fire performance

All layers and components of precast insulated sandwich panel are non-combustible: Euroclass A1 or A2 (EN 13501-1).

Minimum **base panel** thickness *(in accordance to BS EN 1992-1-2)*.

NON-LOADBEARING WALLS			
EI 30	**EI 60**	**EI 90**	**> EI 90**
60 mm	80 mm	100 mm	For higher thermal insulation and integrity (EI) values and thinner panels performance test may be required.

LOADBEARING WALLS			
REI 30	**REI 60**	**REI 90**	**REI 120 /180 /240**
exposed to fire on one side			
120 mm	130 mm	140 mm	160 /210 /270 mm
exposed to fire on both sides			
120 mm	140 mm	170 mm	220 /270 /350 mm

Each panel is sealed with fire barrier at the junction between the wall and every compartment floor and around openings to stop smoke or flame entering.

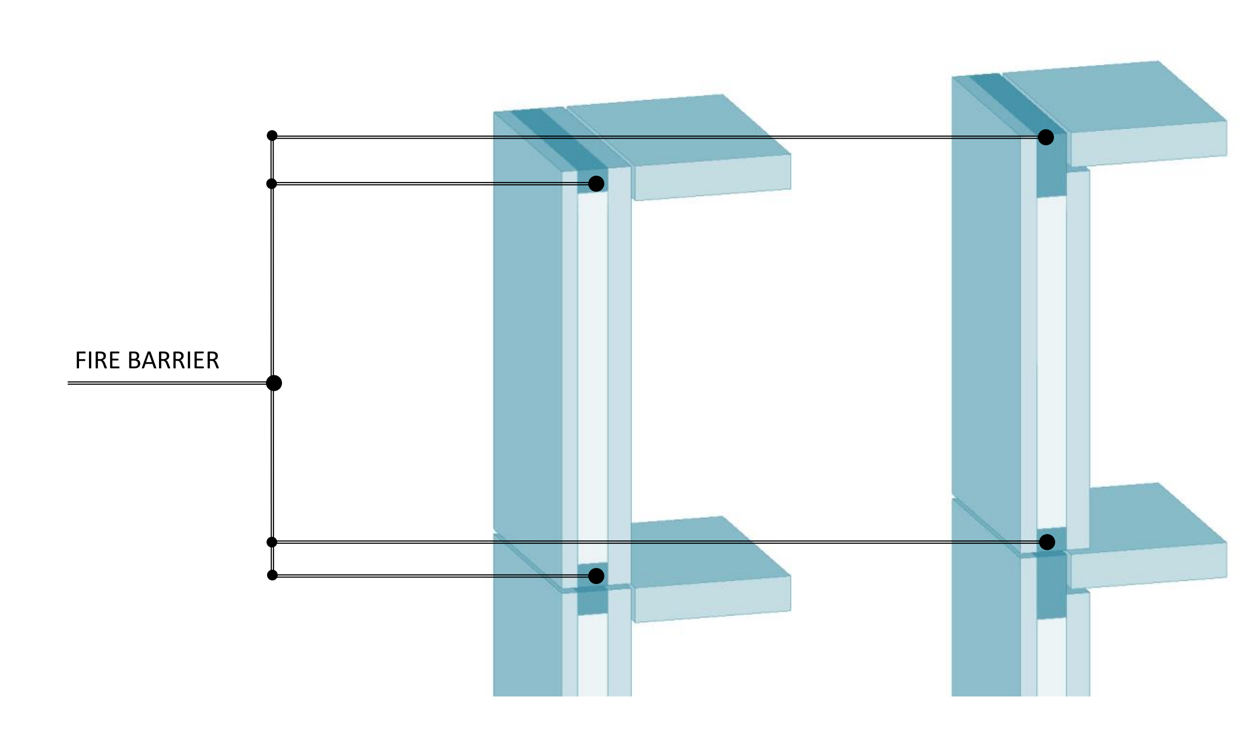


Figure 1.1 Fire barrier

2. Design

Product types in facade may be combined by choosing most effective products for facade design.

2.1. Support strategy

Can be designed to be structurally loadbearing or non-loadbearing.

Loadbearing cladding is part of a structural frame and used instead of perimeter beams and/or columns to transfer the vertical forces down the structure to the ground.	**Non-loadbearing** is cladding with no structural function.

Supporting strategies

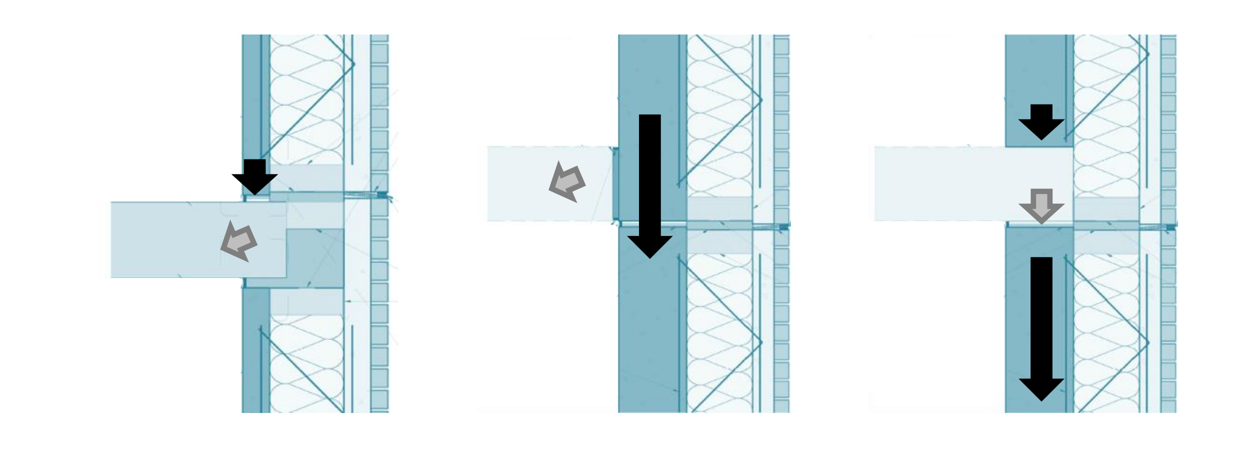


Figure 2.0 Supporting strategies: non-loadbearing, non-loadbearing, loadbearing

Supporting and fixing strategy should be chosen by analyzing all the benefits of the project and developed together with all parties.

Non-loadbearing cladding, when supported on structural slab/perimeter beam, has a thinner base panel that allows increased panel sizes (fewer joints, panels for logistics and assembly) if already there are no other panelization limits.
For such solution structural frame columns/walls must be pushed away from slab edge – minimum distance between structural column/wall and sandwich panel wall is 20 mm.

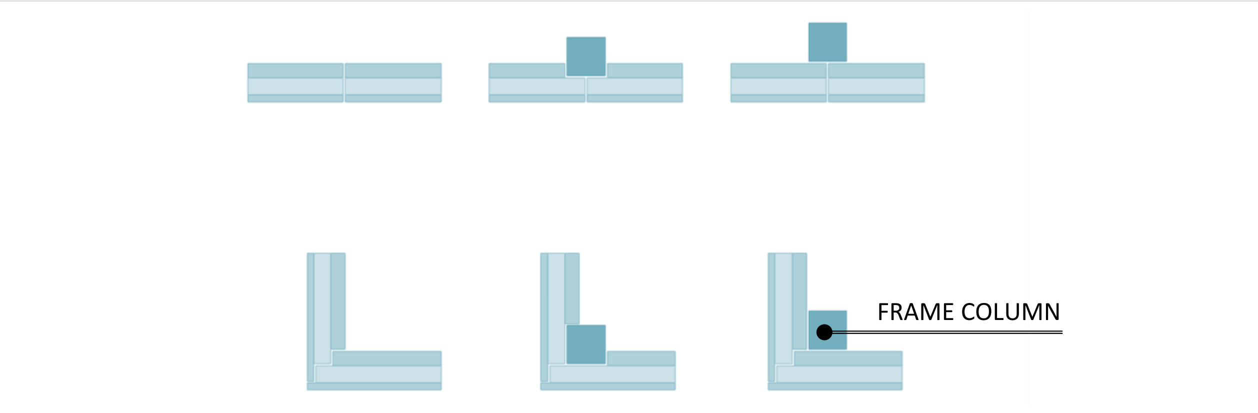


Figure 2.1 Details between two sandwich panels: no column, column placed in and pushed away from panel

Frame columns can be placed in sandwich wall as shown in Figure 2.1. when sandwich wall opening is placed with minimum 200 mm distance from frame column.
Sandwich panels can also have integrated columns as shown in Figure 2.2. Thought most effective solution to integrate column in a way that base panel surface is in one plane (on the right in the picture). This solution ensures smoother quality surface of base panel (easier to treat) and provides much easier casting process.

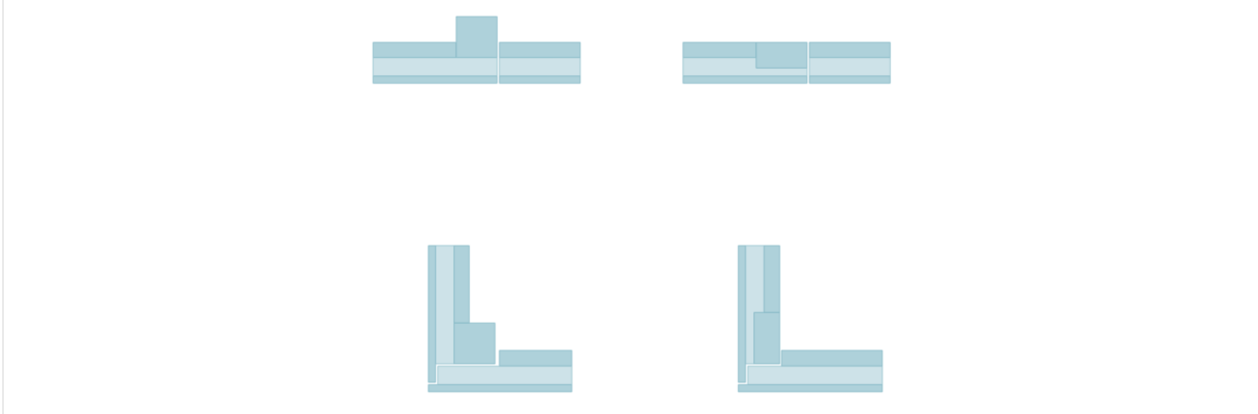


Figure 2.2 Details with column integrated in sandwich wall: raised outwards and inwards

When panels are divided at the columns there will be less strict deflection limits for the structural frame than when divided between columns because it is important to ensure same stiffness for panel supports.
It is possible to connect two sandwich panel walls divided between columns – coupled wall solution. Thought difficult to achieve for walls with door opening.

Loadbearing panel has thicker base panel, minimum 150 mm. It may be more effective to remove perimeter columns/beams and replace them with increased thickness base panel (approx. additional min 70 mm concrete layer). This will require agreed and shared responsibility of base panel design if different frame and facade designers.

Non-loadbearing panels supported on foundation has also thicker base panel since carrying more than one floor selfweight of facade.

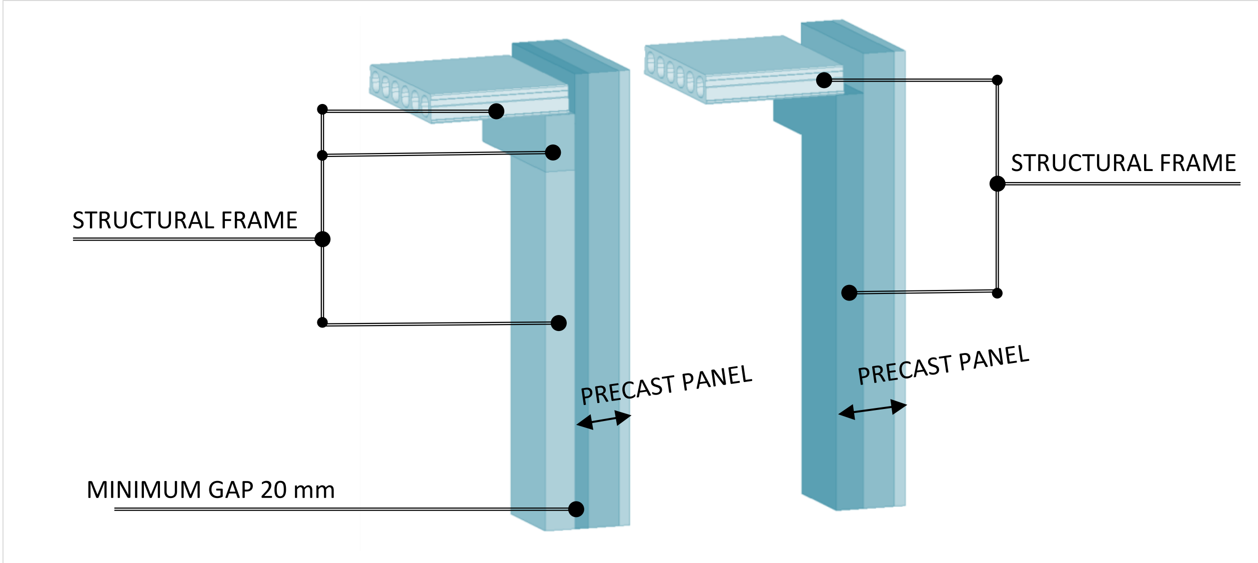


Figure 2.3 Non-loadbearing and loadbearing solutions

Based on chosen support strategy suitable project specific support solutions are designed.

2.2. Window and door opening

Based on chosen architectural surfaces and finishes suitable details are applied. See Figure 2.8.

Inside openings return is recommended to be made of concrete as addition to base panel to ensure smooth and no treatment requiring interior surface around opening.
To improve the thermal performance in opening areas it is recommended to add steel brackets for window/door frame fix in the opening details.

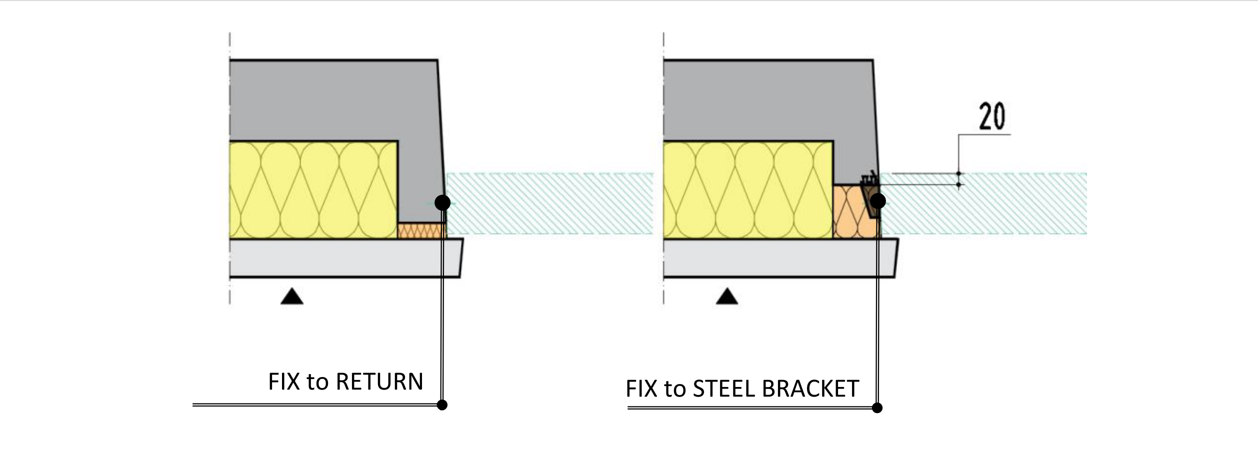


Figure 2.4 Concrete return options for window/door frame fix

To ensure effective production process slope of the window/door opening sides should be designed with 3° slope for at least 3 sides.

Most effective window/ door reveal depth is equal to the face panel depth.
Deeper reveals are more difficult to perform but not impossible. Deeper reveals for visual concrete will require an indent to hide and shade the cold joint of concrete. Indent not needed if the reveal expected to have paint finish where cold joint can be sanded and hidden before painting. Size of indent - 5 mm or more if used as design feature, starts at the deps of face panel thickness.

Drip groove is recommended in opening head details.

Principles of detailing are shown in following figures. Details are relevant to most of the surface and finish option.

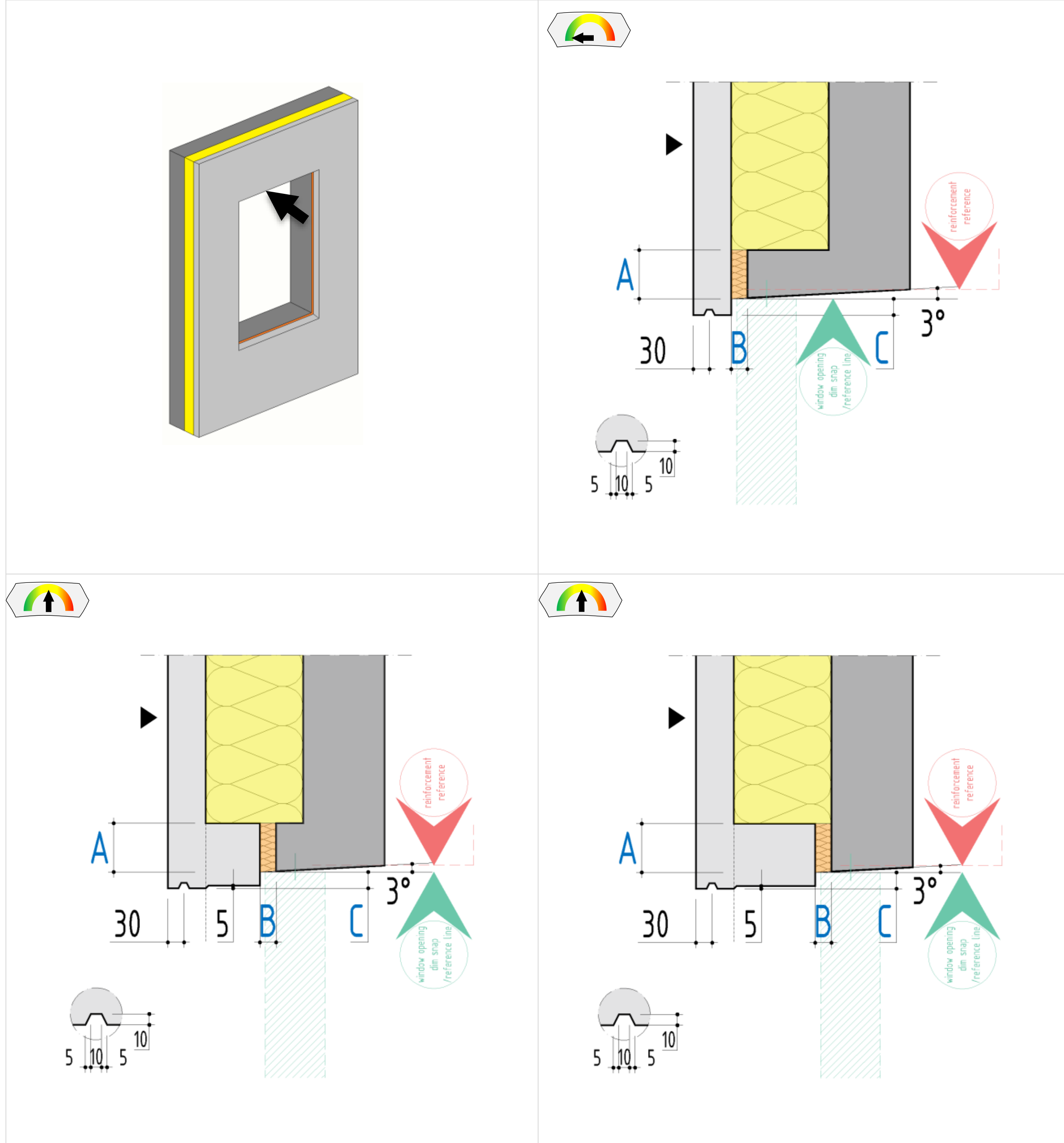


Figure 2.5 Window opening head detail options: C=0 or 30 mm

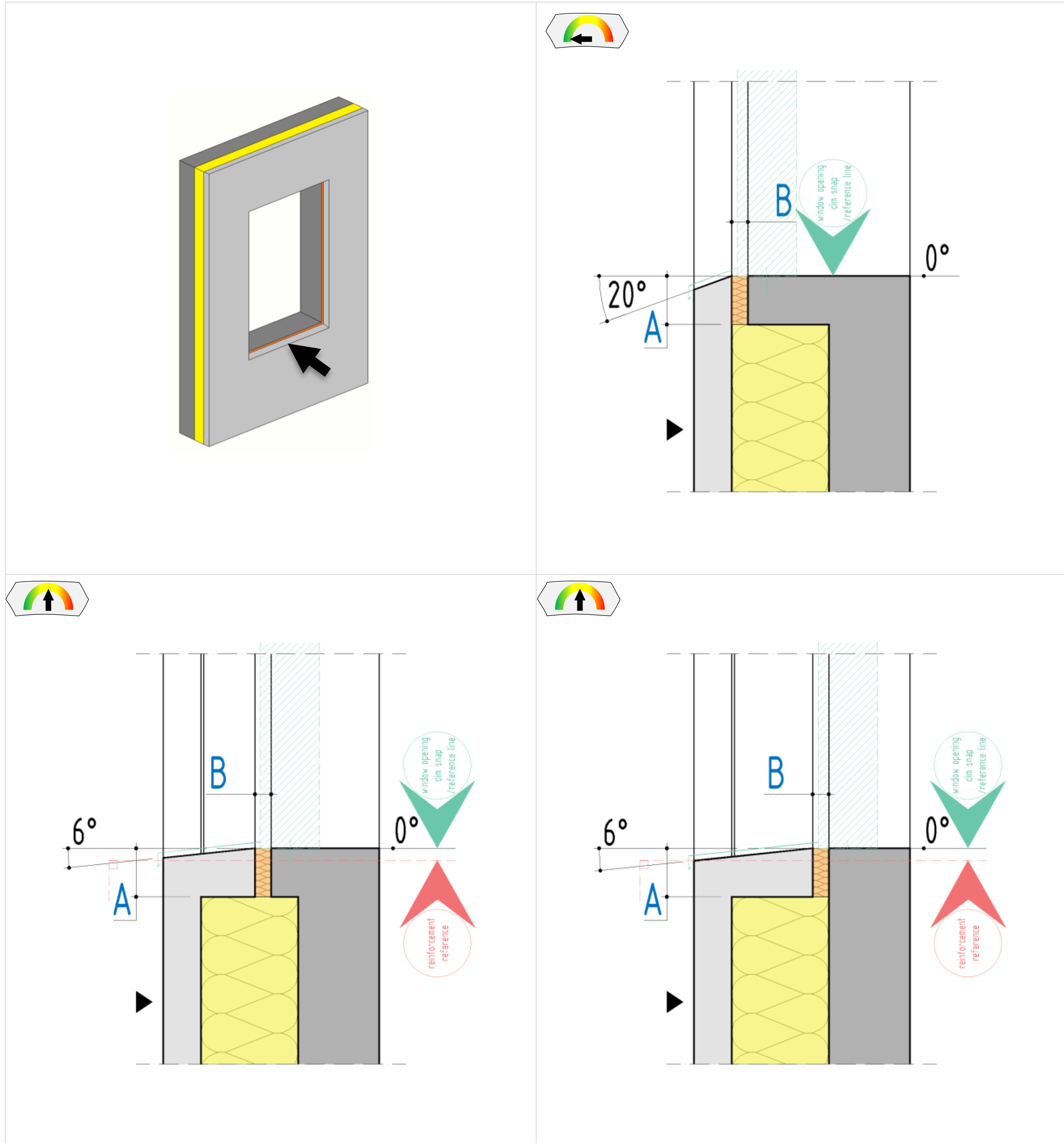


Figure 2.6 Window opening sill detail options

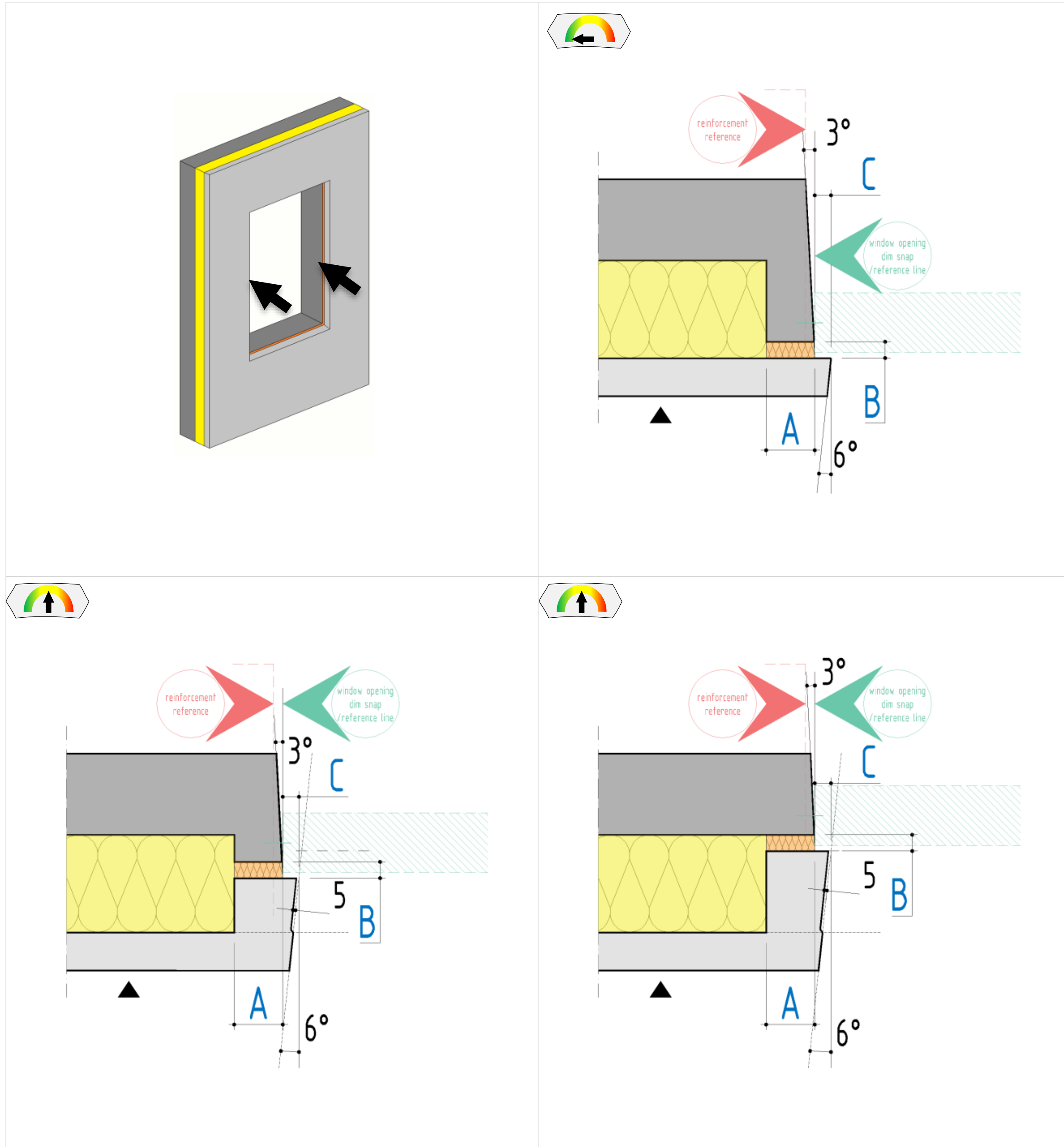


Figure 2.7 Window opening side effective detail options: C=0 or 30 mm

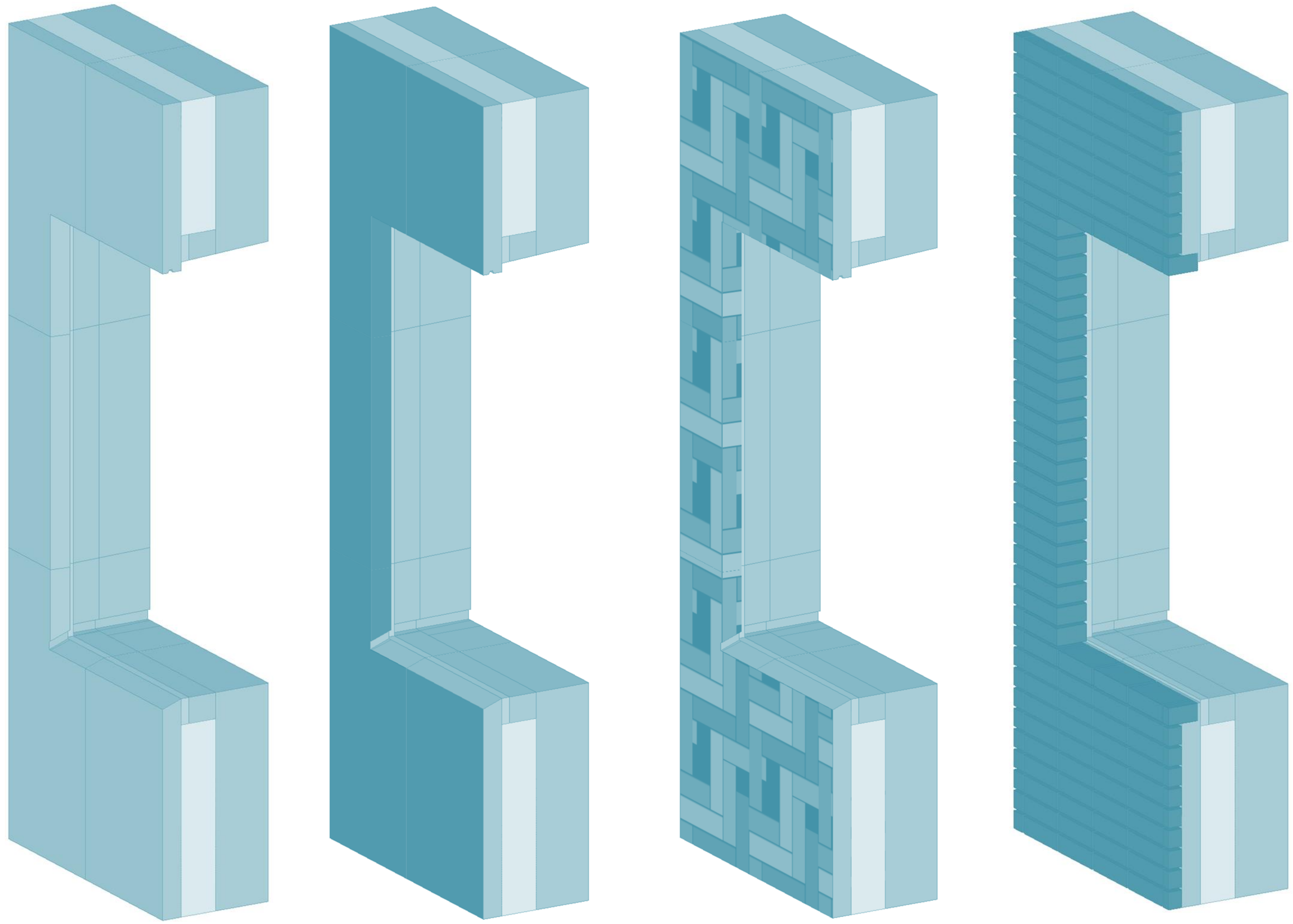


Figure 2.8 Opening details per different surface and finish

2.3. Electrical and ventilation installations/embeds

Electricity boxes and pipework possible to be embedded in base panel and throughout wall thickness.

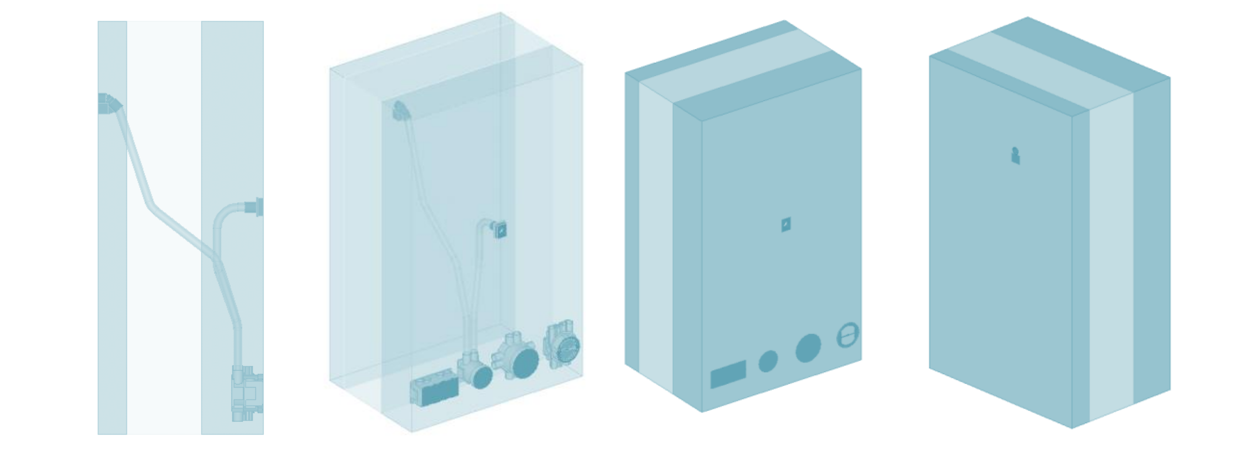


Figure 2.9 Electric piping

Most common size for electrical piping is Ø20 mm.

Figure 2.10 Example of electric piping materials – conduits and outlets, and boxes

All installations and embeds structurally are treated as local openings and have low impact of bearing capacity of wall (no change in wall thickness).
Installations and embed placement may be limited at narrow columns (between openings) and beams (above openings) where they may interfere with reinforcement.

See Annex ii.

2.4. Thermal performance

Simplified layered precast product U-value calculation

$U_{TOT} = U_1 + U_2 + U_3$

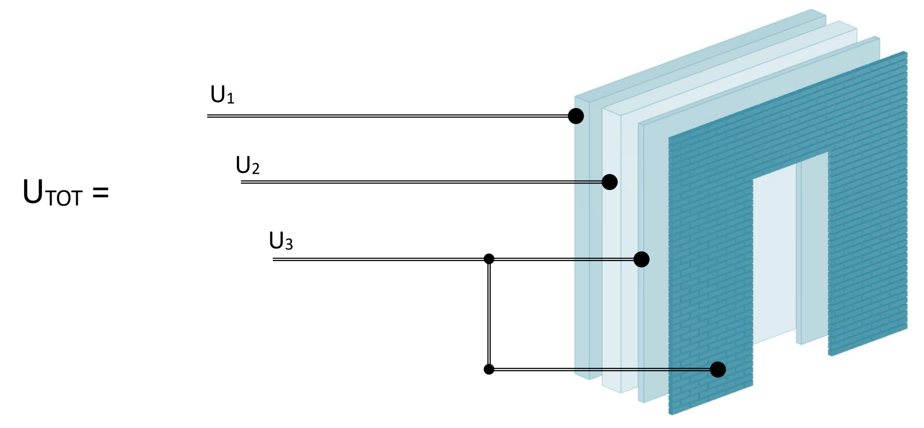


Figure 2.11 Total precast product U-value

Concrete does not act as vapour barrier. Vapor migration takes place through insulation which is ventilated trough air void grooves.

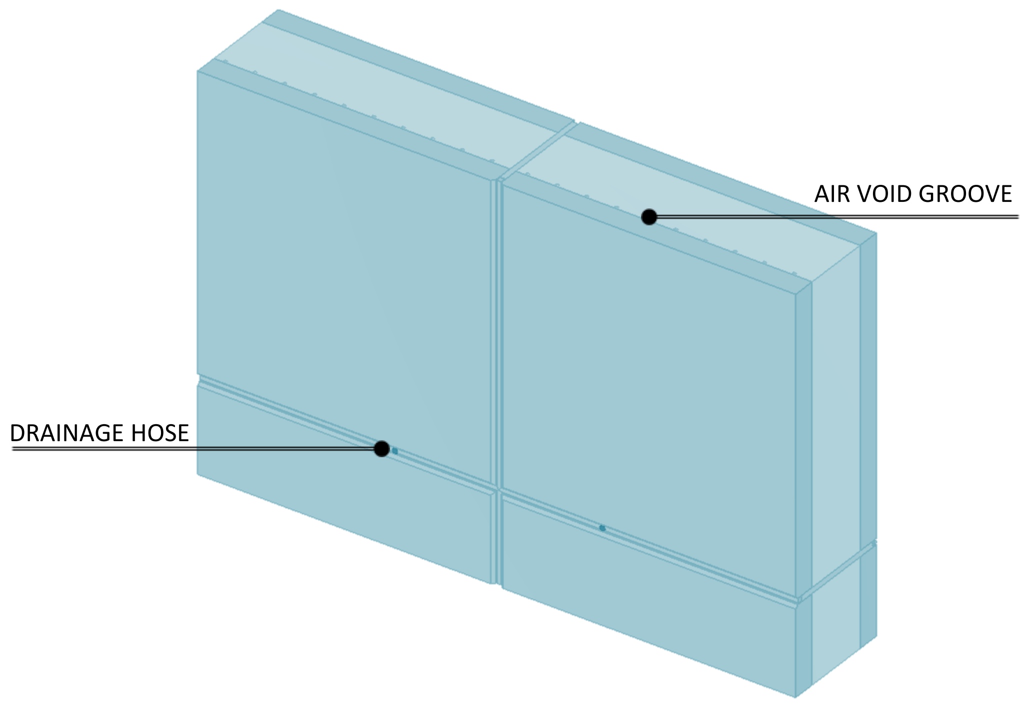


Figure 2.12 Ventilation grooves and drainage hose (spacing 3.0 m, 0.5-1.0m from panel edge)

The interior concrete is prevented from reaching the temperature at which condensation may occur, thereby reducing the potential for mould. Concrete is not organic; it does not promote organic growth even if wetted.
Thermal mass and lag effects of concrete panels provide reduction and delays of the peak temperatures affecting a building.

Thermal bridges need to be considered in U-value calculations.

Panel connector effect on the dew point is minimum. Dew point is crossing the connectors but since it is made of stainless steel it is not an issue.

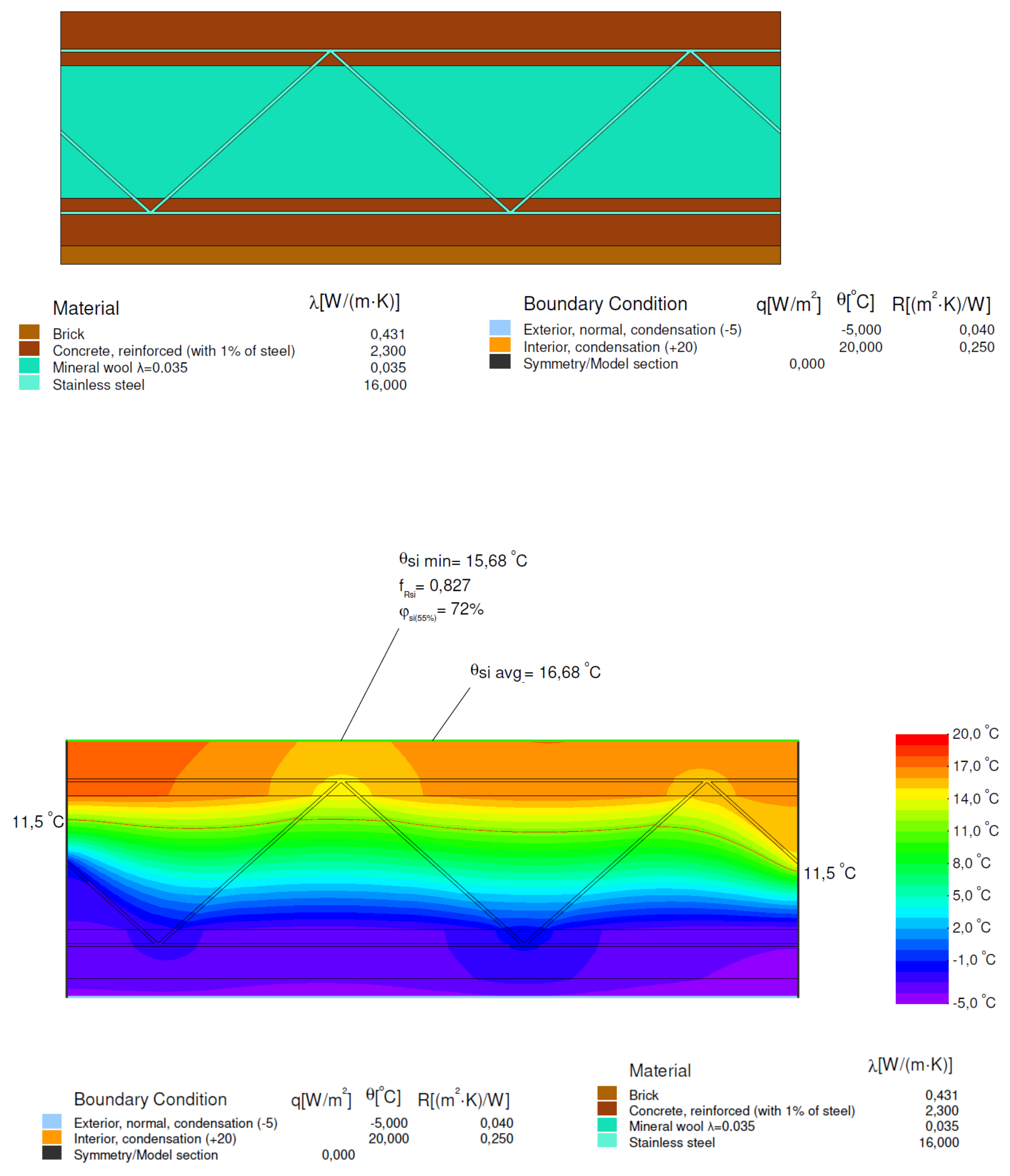
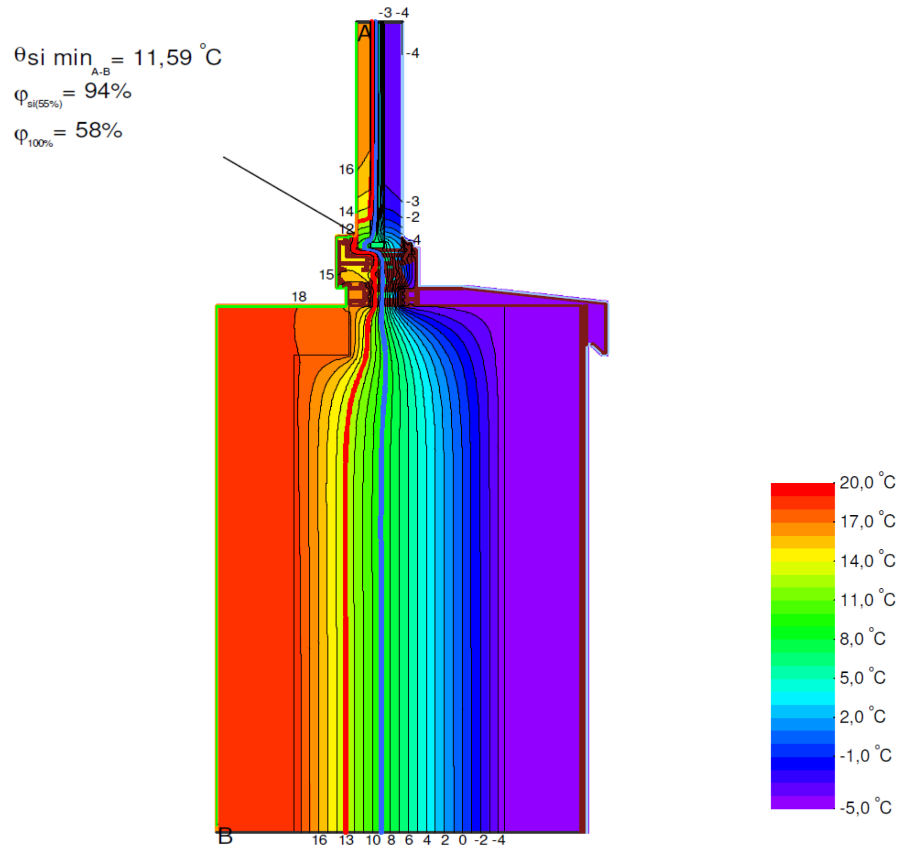


Figure 2.13 Typical connector section condensation analysis

Condensation risk analysis must be performed for specific project solutions and checked if there is a risk of condensation and dew point is located within the frame.



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]	ε
Epsilon 0.9				0,900
Exterior, normal, condensation (-5)		-5,000	0,040	
Interior, condensation (+20)		20,000	0,250	
Interior, window, condensation		20,000	0,130	
Symmetry/Model section	0,000			

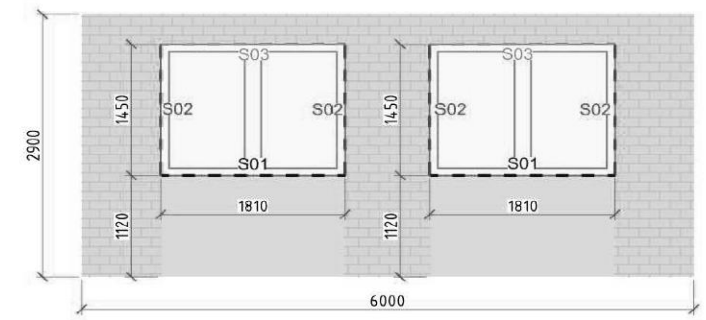
Material	λ[W/(m·K)]	ε
Aluminium (Si Alloys)	160,000	0,900
Aluminium (Si-Legierungen)	160,000	
Butyl (Isobuten), heissgeschmolzen	0,240	
Concrete, reinforced (with 1% of steel)	2,300	0,900
EPDM (ethylene propylene diene monomer)	0,250	0,900
Foam rubber	0,060	0,900
Gasfillin(4)	0,020	
Mineral wool λ=0.035	0,035	0,900
Polyethylenschaum 040 (Schuco)	0,040	0,900
Polysulfid (1)	0,400	0,900
Polythermid 0.15 (schuco)	0,150	0,900
Silicagel (Trockenmittel)	0,130	
Slightly ventilated air cavity **		
Soda lime glass	1,000	0,900
Unventilated air cavity **		

** EN ISO 10077-2:2017, 6.4.3/anisotrop

Figure 2.14 Typical detail condensation analysis

Product final U-value should be determined by considering all wall components, sections, sizes and its local thermal bridge effects.

Unit type - A01	Width (mm)	Lenght (mm)	Area (m²)
	6000	2900	17.40



Thermal transmittance

F1: Sandwich panel wall U_p=0.15 (W/m²K)

F2: Sandwich panel wall U_p=0.15 (W/m²K)

G1: Window system U_w = 1.40 (W/m²K)

Thermal bridging

S01 Window sill Ψ (W/m*K)
S02 Window jamb Ψ (W/m*K)
S03 Window head Ψ (W/m*K)

No.	Panel	Section	Quantity	U_p -value (W/m²K)	Width (mm)	Lenght (mm)	Area (m²)	UxA (W/K)
1	Sandwich panel	F1	1	0.15			8.10	1.21
2	Sandwich panel	F2	2	0.15	1120	1810	4.05	0.61
3							-	-
							12.15	1.82

No.	Windows	Section	Quantity	U_w -value (W/m²K)	Width (mm)	Lenght (mm)	Area (m²)	UxA (W/K)
1	Window	G1	2	1.40	1810	1450	5.25	7.35
2							-	-
3							-	-
4							-	-
5							-	-
							5.25	7.35

No.	Thermal Bridges	Section	Quantity	Ψ (W/m*K)	Lenght (mm)	ΨxL (W/K)
1	Sill	S01	2	0.06	1810	0.11
2	Jamb	S02	4	0.05	1450	0.07
3	Head	S03	2	0.05	1810	0.09
4						-
5						-
						0.27

Results	Σ Area (m²)	Σ Heat transfer (W/K)	% part of unit	U-value part (W/m²K)
Σ Wall Panel	12.15	1.82	70%	0.15
Σ Window	5.25	7.35	30%	1.40
Σ Thermal Bridges		0.27	0%	0.02
Total	17.40	9.44	100%	

Total heat transfer coeficient U (W/m²K)	0.54	W/m²K

Figure 2.15 Total U-value calculation per specific product

2.5. Panelization

Panelization is based on:
- **overall dimension** limits (logistics, plant production space)
- **design** limits (constraints, fixed joint placement)
- **weight** limits (site crane capacity, plant crane capacity)
- other **project-specific** limitation

Dimension limits

Panel size should be as large as possible but recommended not to exceed H= 4150 mm due to transportation and fabrication limits and H=3080 due to transportation costs.

The most effective panel size is with H ≤ 3080 mm and W≤ 9200 mm, followed by H ≤ 3430 mm, W ≤ 9000 mm, and H ≤ 4150 mm, W ≤ 8000 mm.

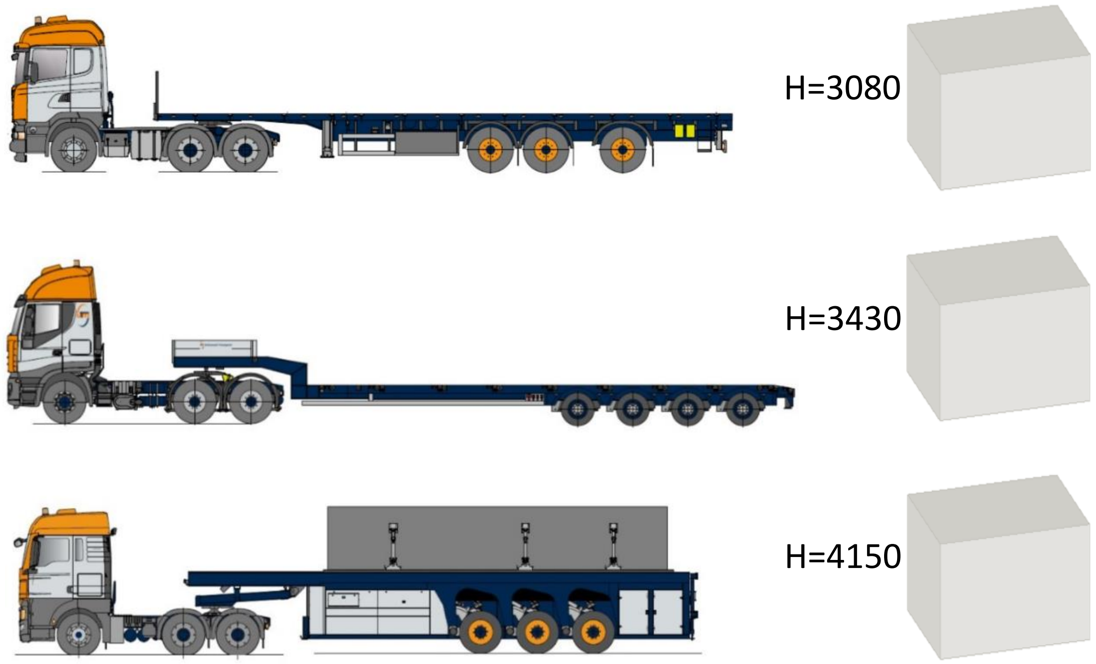


Figure 2.16 Max transportation heights for panels per truck type

Design limits

Typically, panelization is performed in floor-to-floor height for face panel (outer layer). This means that floor-to-floor height choice will determine which transportation truck will have to be used (not valid for overlap solution).

Base panel (inner layer) can be adjusted based on project-specific:
- shortened to fit in between structural slabs,
- same size as face panel or
- shifted to provide panel overlap – increased panel overall height.

At the bottom of panel face panel should always be in same level or higher than base panel due to transportation to avoid damage.

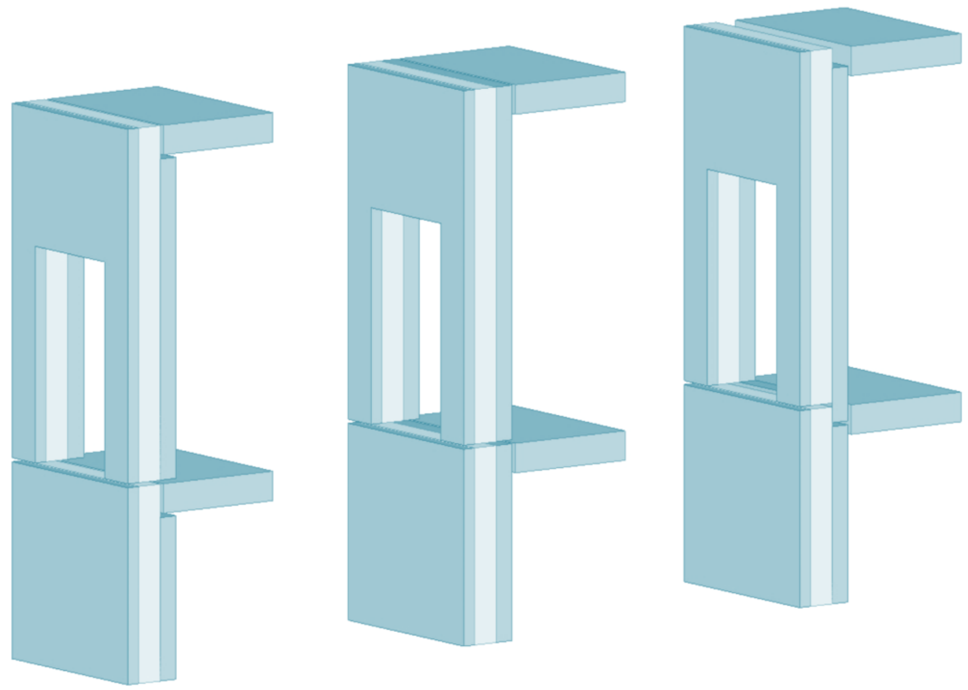


Figure 2.17 Base panel height options

Closed shape (punched opening) panels are easier to handle than open shape panels due to their rigidity. Mandatory if door/window must be included in the panel.

The most **effective solution is to have punched panels with build-in window/door** and with concrete threshold at the same time not increasing overall height of panel (no panel overlap).
This may be achieved when distance between finished floor level and supporting structural slab is minimum 100 mm. Or by having recess in structural slab edge locally in threshold area or along the entire length of the panel.

Panelization in width is dependent on many factors (weight limits, pattern, joint limits, supporting strategy, openings, handling, etc.). Typically face panel is the same size as base panel. Thought shifted layers (overlap) of sandwich panel is also common.

In general facade panelization must be carefully developed together with panel designers and fabricators by considering supporting strategy and all other factors relevant to the specific project.
Result of the effective panelization is to provide **as much repetitive panels** as possible for efficient production and budget purposes.

Opening limits

For large openings such as sliding doors options:
- separate precast insulated sandwich panel: lintel beam and on-site assembled sliding door/window
- panel with built-in door/window and temporary additional supporting braces for the transportation and erection (threshold support provided by the concrete base panel (punched panel) or additional integrated steel beam)
- floor-to-floor wall with panel overlap and built-in window/door (usually not possible for non-loadbearing panel).

Minimum optimal height dimension for panel lintel above window/door is 200 mm. With window/door fixing strategy only on sides lintel min height can be reduced.
Minimum optimal distance for adjacent window/door openings of separate adjacent panels is 400 mm.

Joint placement limits

For effective facade solution joint placement should be designed wisely in the facade.
Facade made of panels will have panelization joints and may require additional joints in face panels (area > $20m^2$).
False joints may be included in large area face panels to avoid constraints and cracking.

For bricks, brick slips, tile surface horizontal joint of face panel usually is not an issue and can be easily included in the pattern. Vertical joints will be more noticeable if they will cross the pattern. It is possible to include them in the pattern and/or place in shaded areas like corners.

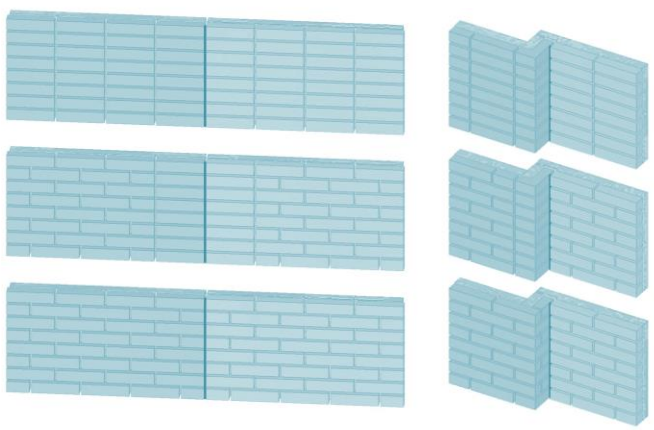


Figure 2.18 Joint placements for different brick pattern

For plain surfaces and finishes it is recommended to emphasize the joint lines by placing them into the recesses or hide them in corners or places where plane or surface type is changed or introduce shadow effects. This will remove attention from all the deviations of flatness.

Weight limits

Project appropriate weight limits are determined after a full project case study together with constructor as it is dependent on many factors (site restrictions, logistics, building sequence, crane capacity, handling, etc.).

Panel **sizes should be** maximized in accordance with **crane capacities.**

Simplified panel weight calculation

$$W_{PANEL} = (W_1 \bullet A_1 + W_2 \bullet A_2 + .. + W_i \bullet A_i) + W, kg$$

where:

W_i- weight of layer per 1 m^2; density (kg/m^3) multiplied by layer thickness (m)
A_i – area of layer (openings excluded), m^2
W – weight of flashing, cladding, window/door, kg

Densities

MATERIAL	DENSITY kg/m^3
Reinforced concrete	2500
Mineral wool	150 - 170
Brick	1500 - 1800

Example of approximate panel weights are shown for 6.0 m long an 3.0 and 3.5 m high panel with 3 types: no window, one window, two windows.

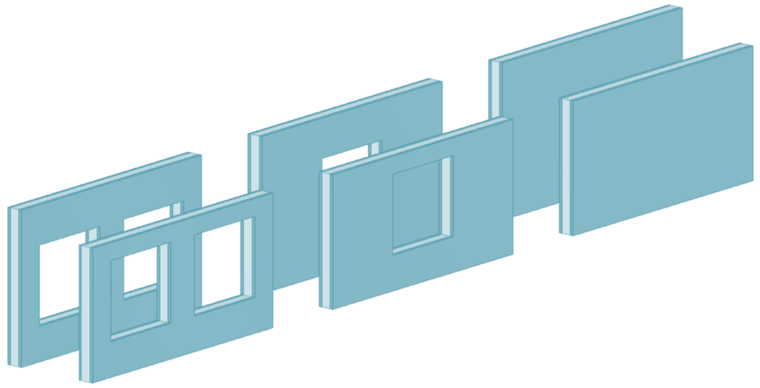


Figure 2.19 Visualization of panels for the weight chart below

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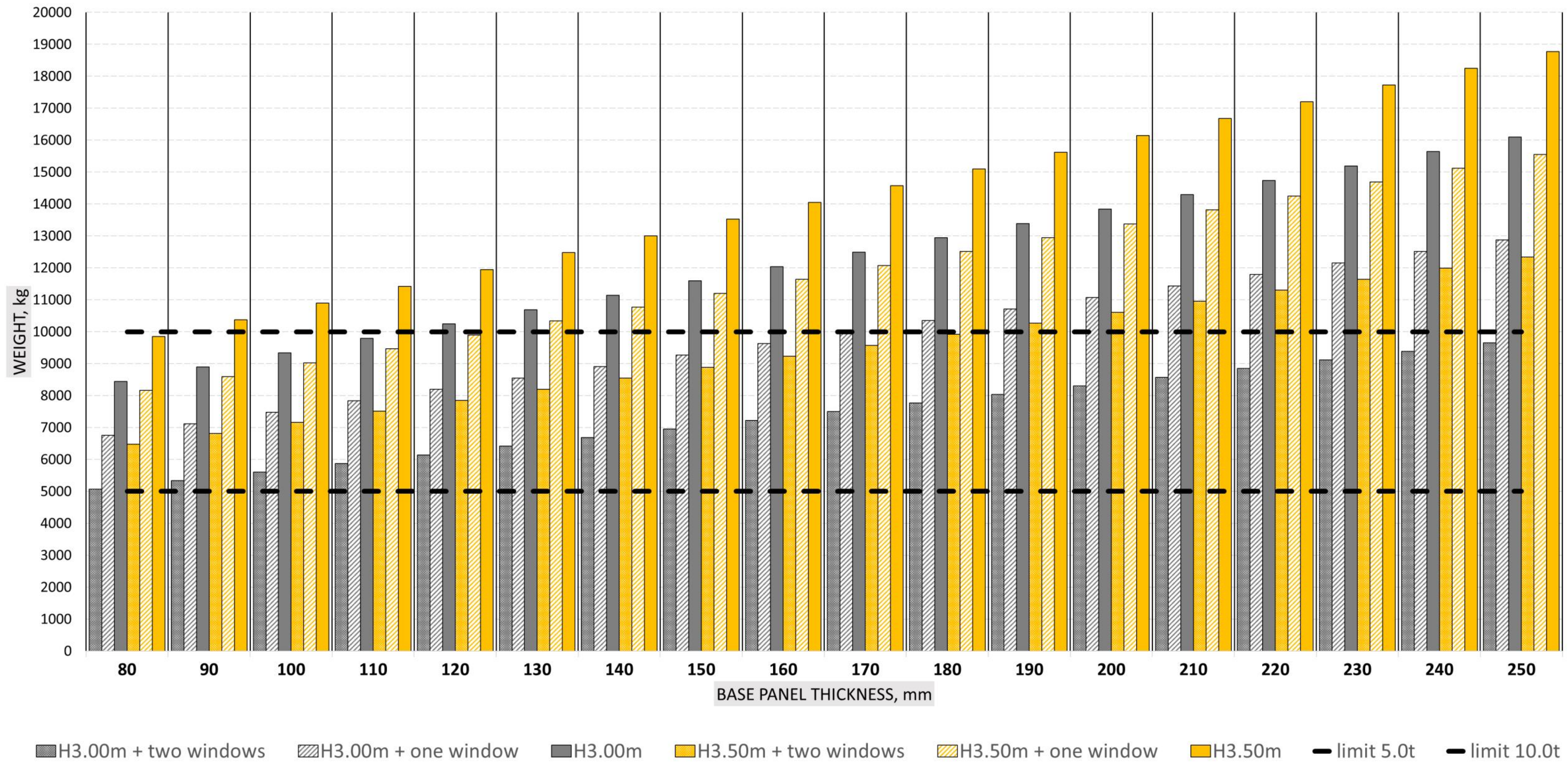

Figure 2.20 Rough panel weights for panel length 6.0m

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2.6. Tolerances and movement

Product tolerances in accordance with product precast wall element standard BS EN 14992, BS EN 13369 and execution of concrete structures BS EN 13670.
Tolerances must be accommodated by adjustable connection details for all horizontal and vertical conditions. Connection details and joint widths should also be able to accommodate thermal and structural movements in case of primary structure.

For non-loadbearing sandwich panel deflection limit of supporting slab is min (10 mm; span/500) after construction. v1.1

2.7. Handling

Handling should be planned and reduced to a minimum.

Design should consider handling, temporary supporting and lifting equipment available at all stages – production, transportation and erection.
Closed shape panels are the most effective for handling. Lifting points for panel should be placed by panel mass centre of gravity to avoid swaying during lifting and in case of non-loadbearing panel access and collision free solution with supporting structural slab.

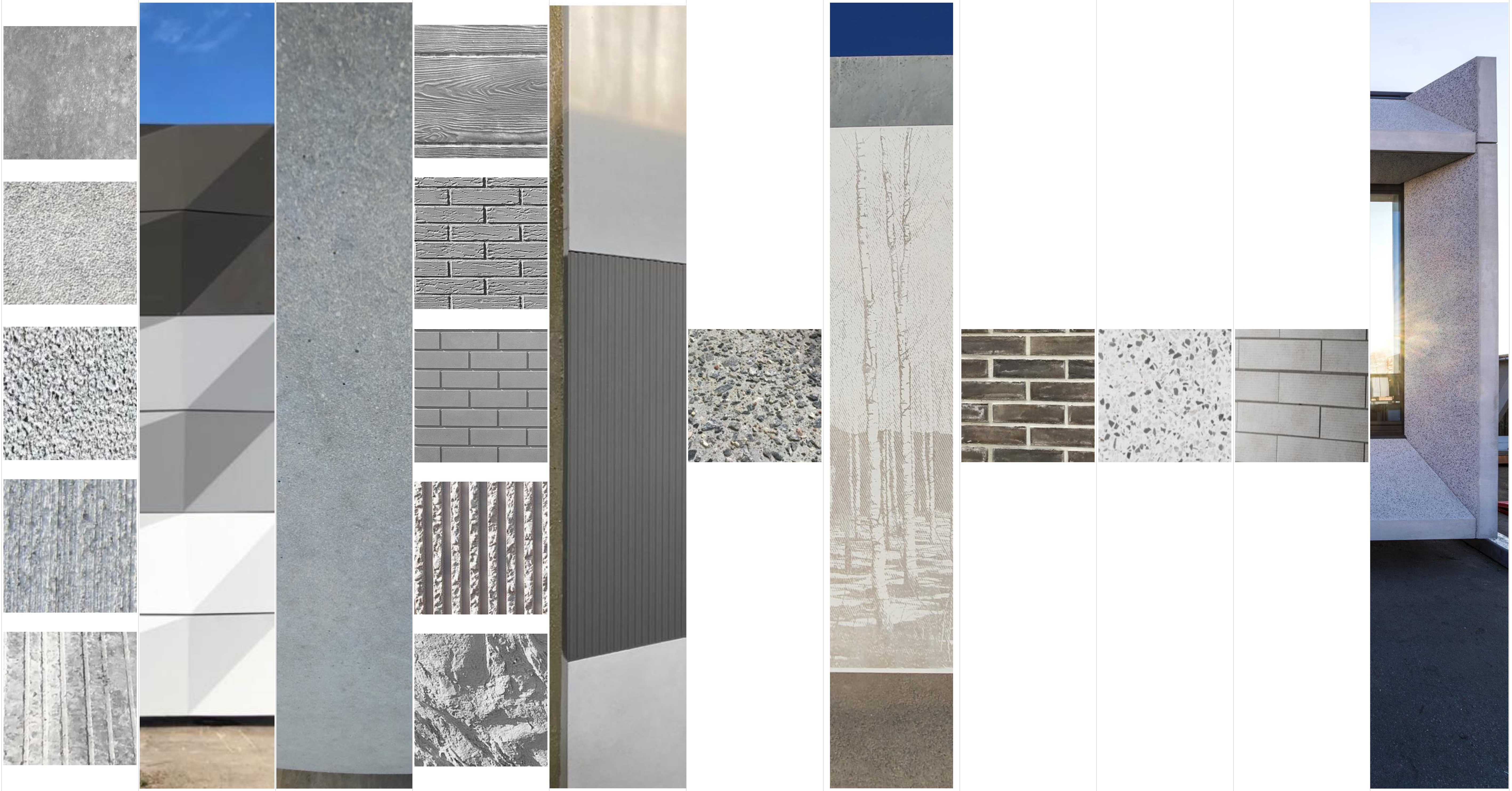
Handling equipment weight should be added to panel weight when checking crane capacities.

2.8. CO2 strategy

Carbon emissions in construction materials are evaluated as GWP (global warming potential) in CO2 kg per ton of material. CO2 reduction strategies focusing on the material can improve GWP, however, most significant improvement of emissions can be achieved when calculated for the whole building.
As an example - higher GWP for material with better tensile properties and radically thinner cross-section can be an alternative solution to reinforced concrete with lower GWP. Objective evaluation of developed solutions can be made when reviewed by professional and calculated either in CO2 kg per square m or in absolute kg values for the whole building.

MATERIAL STRATEGIES	DESIGN STRATEGIES
A Partially substitute CEM I with supplementary materials or alternative binders (ground slag, fly ash, limestone, silica fume), not always suitable for aggressive environment classes and negatively impacts concrete hardening time, production cycle time **B** Replace CEM I with CEM II cement (negatively impacts concrete hardening time, production cycle time) **C** Optimize concrete recipes to reduce cement content (usually suffers workability and hardening time)	**D** Use minimum concrete compressive strength, use minimum exposure class requirements or protect structures to reduce requirements for concrete, therefore cement amount **E** Increase concrete compressive strength to reduce element cross sections and concrete amounts

3. Architectural finishes



polished or rolled or decorative rolled or brushed or raked concrete	concrete with paint finish	concrete with sand blast finish	formliner	formliner with paint finish	exposed aggregate	graphic concrete	brick, brick slip	terrazzo stone tile	tile	cladding *(GRC, UHPC, etc.)*

Figure 3.0 Face panel surfaces and finishes

3.1. Brick, brick slips

The difference between bricks and brick slips is mainly in thickness. Both bricks and brick slips can be used embedded in a concrete face panel.

Brick for prefab is made of actual brick by cutting it usually in half.

Brick slips are thinner cuts of bricks or purpose-made brick tiles.

Brick and brick slips can be laid on a conventional concrete panel face layer as well as on Ultra-High-Performance Concrete or Glassfibre Reinforced Concrete cladding faces.

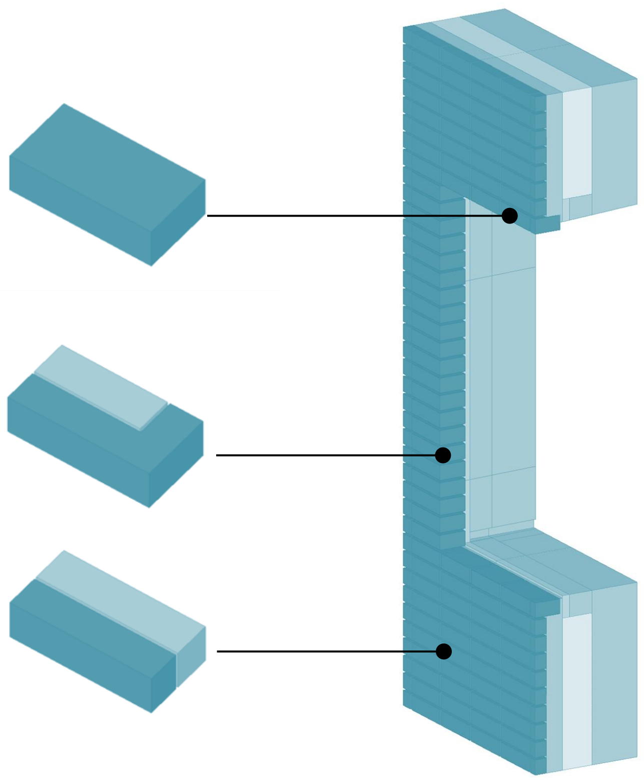


Figure 3.1 Brick cut shapes and the use of them

Pattern

All same brick pattern precast panels should fit and be positioned on the **master brick pattern.**

The project may have more than one brick patterns if necessary.

The master brick pattern is a brick pattern form (size AxB, mm, A = max 4200 and B = max 10000) where all project the panels with their panel pattern can be located within the master brick pattern.

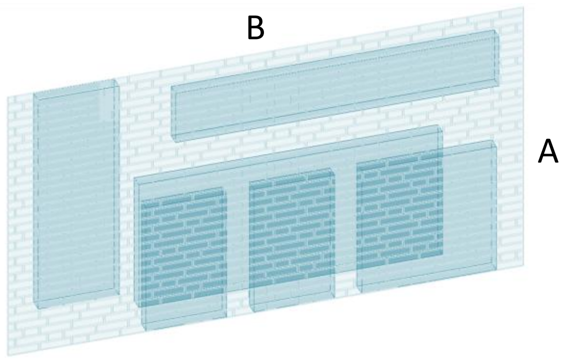


Figure 3.2 Panels laid out on master pattern (AxB)

Master brick pattern may consist of more than one repetitive pattern (also other surface and finish type) blocks.

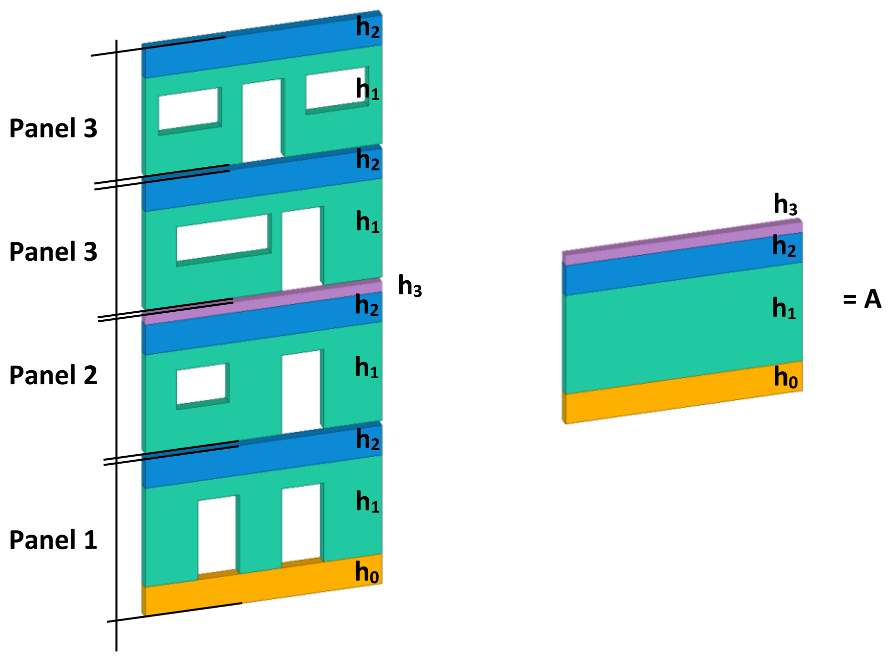


Figure 3.3 Facade panels with different patterns (marked with colour) and master matrix

Another option (less effective though) is to have a **brick pattern** designed for **specific geometries.** This method is used when columns between window and door openings differ in a way were the chosen brick pattern requires different and unique joint widths for each column.

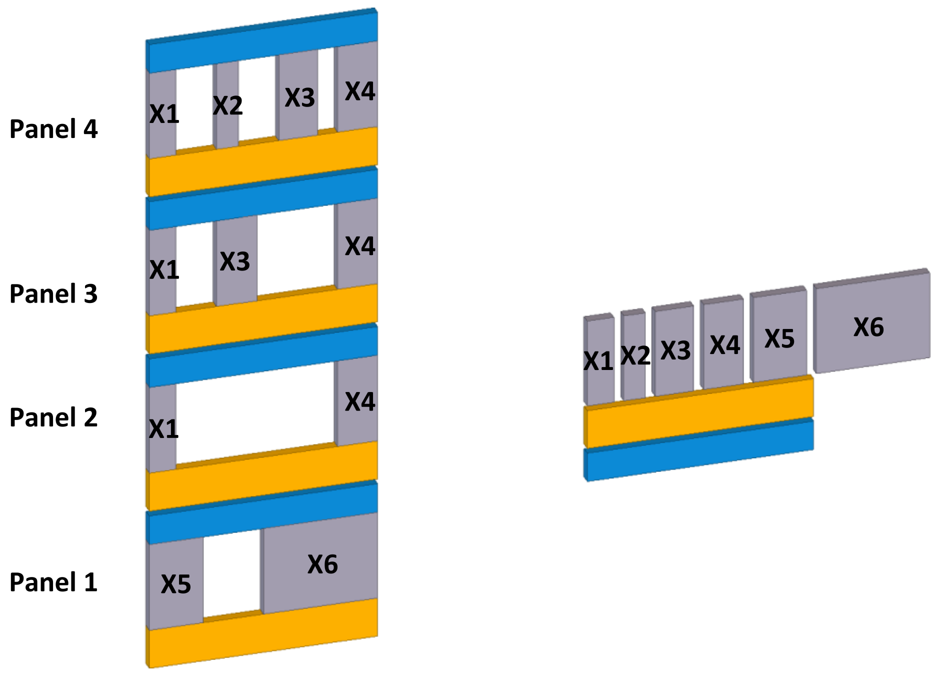


Figure 3.4 Facade panel patterns combined from different pattern blocks

It is good practice to make the pattern with repetition both horizontally and vertically. This will ease up the positioning of the panel within the pattern to ensure the continuity of the pattern of the facade. The number of brick rows should divide with the number of repetitive rows. If the facade consists of panels that are 36 brick rows in high it is recommended to choose a pattern where every 2nd, 3rd, 4th, 6th, 9th, 12th, 18th, or 36th row repeats.

The prefabricated panel brick pattern must start with a brick edge not with a joint.

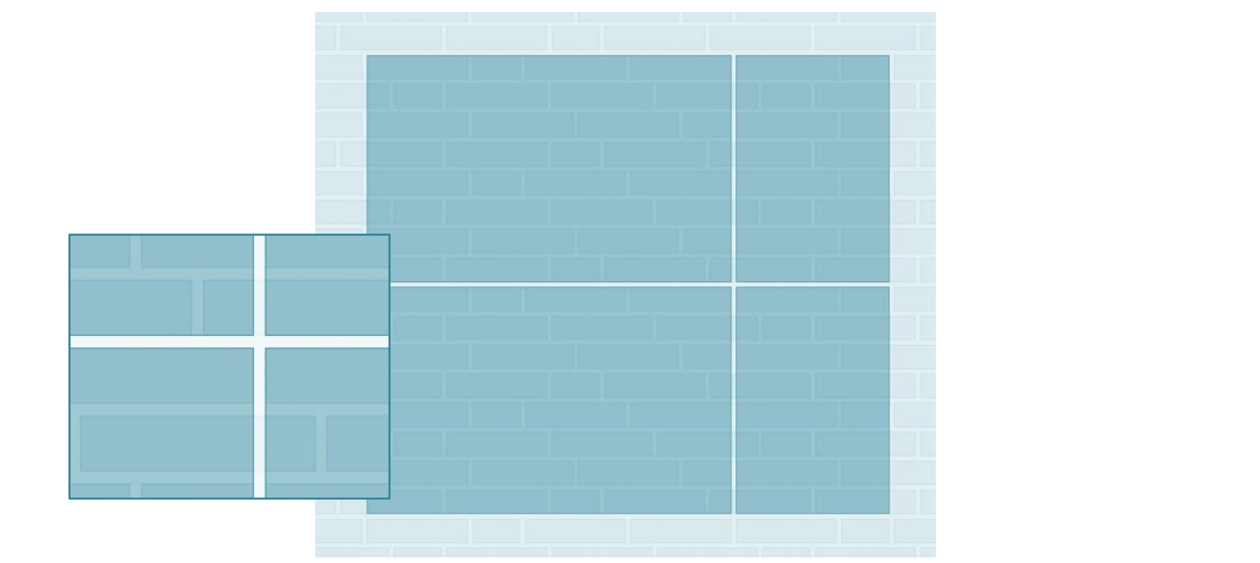


Figure 3.5 Panel assembly (on-site) joint placement

Joints

Joint dimensions are no different than masonry joints. The recommended joint thickness for face panel is 15-20 mm.
Joint size 12 mm may be achieved with additional measures and special tolerance requirements added for product and execution. It is not recommended to do less than 12 mm joint between elements for panel assembly. The width of joint in any case should be greater than calculated movement.

The **vertical joint** should be chosen to match the brick module (joint intended by brick manufacturer is L – 2•b). This will allow to create a brick pattern where module size panel openings can be placed freely within the pattern without the need to shift the bricks and continue the brick pattern in perpendicular surfaces like corners of the building and window/door openings.

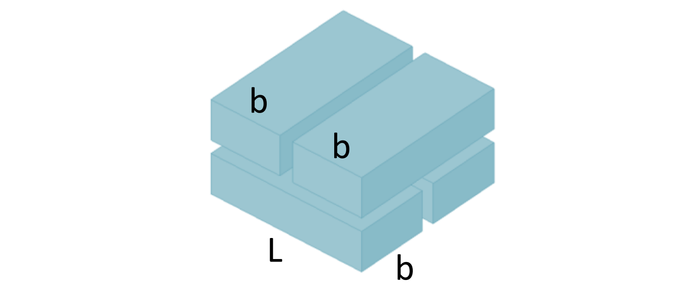


Figure 3.6 Brick module. Joint: L – 2•b

The width of the **horizontal joint** is defined by the height of the prefabricated panel and the height of the chosen brick.

$$t_h = [\,H - (h_b \cdot n_b)] / (n_b - 1)$$

where:

t_h - width of the horizontal joint, 0.00 mm precision;
H – height of the face panel /brick pattern zone;
h_b – height of the brick;
n_b – number of brick rows in one panel.

Openings in the pattern

For the master brick pattern door and window openings should be fitted into the pattern. This means that opening should be adjusted to match the brick edges in the pattern - sides and top are the most crucial, bottom – might not because usually it is covered by the sill.

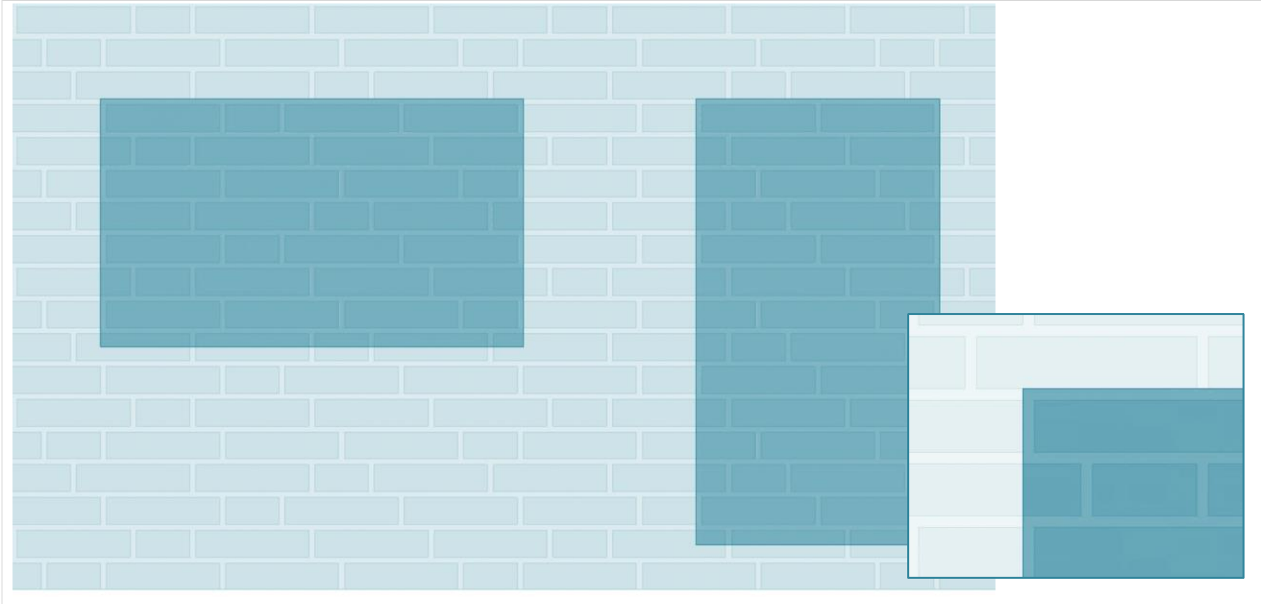


Figure 3.7 Opening placement on a brick pattern

Pointing

Options
- pointing during the casting of panel (concave mortar joint)
- pointing after casting (flush or concave mortar joint)

On-site joint

Options
- sealant or sealant together with sand (elastic, movement joints)

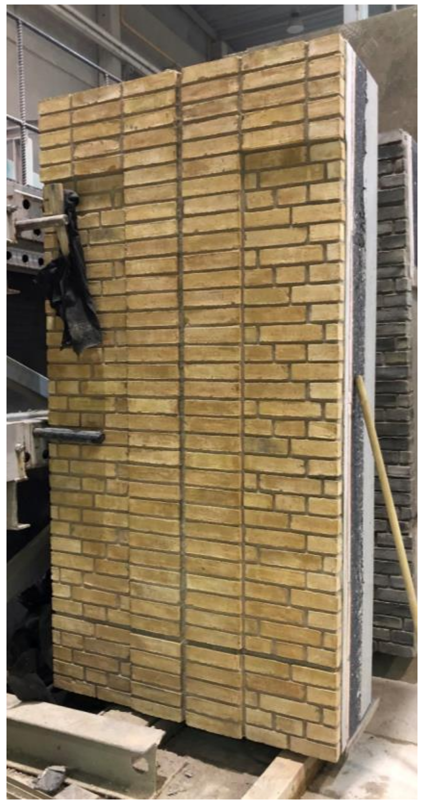
See Annex iii.

3.2. Brick look-a-like

Brick look-a-like surface is achieved by using formliner.
Most effective is to use formliner from catalogue. Thought custom made formliners are possible.

ANNEX i

BRICK FACE



ANNEX ii

ELECTRICAL OUTLET in BASE PANEL	ELECTRICAL OUTLET in FACE PANEL
	

ANNEX iii

JOINT STRATEGY

CORNER /SHADED AREA JOINT	SEALANT WITH and WITHOUT SAND	SEALANT WITH SAND