PRINCIPLES OF DESIGNING FAÇADE CLADDING BRICK WALLS

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ABSTRACT:

The article outlines the proper methods and design considerations for constructing modern ventilated brick façades. Achieving durable and aesthetically pleasing appearances for our buildings with these façades requires careful planning and execution. The writing discusses these aspects to guide us on what to consider when designing a building with such cladding. It also describes the weather conditions and construction defects that can damage these façades, reducing their lifespan. The article examines how to mitigate most of these damaging processes already during the design phase.

KEYWORDS:

Brick cladding, ventilated masonry, installed brick cladding, brick support brackets, steel corrosion

1 INTRODUCTION

Examples of beautifully clad facades with durable modern ventilated cavity brick walls have become increasingly prevalent not only in the construction of large office buildings and public structures but also in the practice of building family homes. The damages occurring in our buildings can primarily be attributed not to structural issues but to building structural reasons. The construction of prefabricated cladding brick walls requires great attention to detail and precise workmanship. In the early 2000s, we collaborated with Professor Sándor Karacsony and Dr. Peter Nedli, scientific associate, to develop the technical guidelines for the application of the FIXINOX cladding wall fixing system, which paved the way for its introduction in Hungary. Since then, numerous buildings with cladding wall systems have been constructed, yet many cases of inadequate execution, improper material selection, or system simplification demonstrate the damages that could have been avoided with proper care.

2 CONSTRUCTION OF VENTED MASONRY STRUCTURES

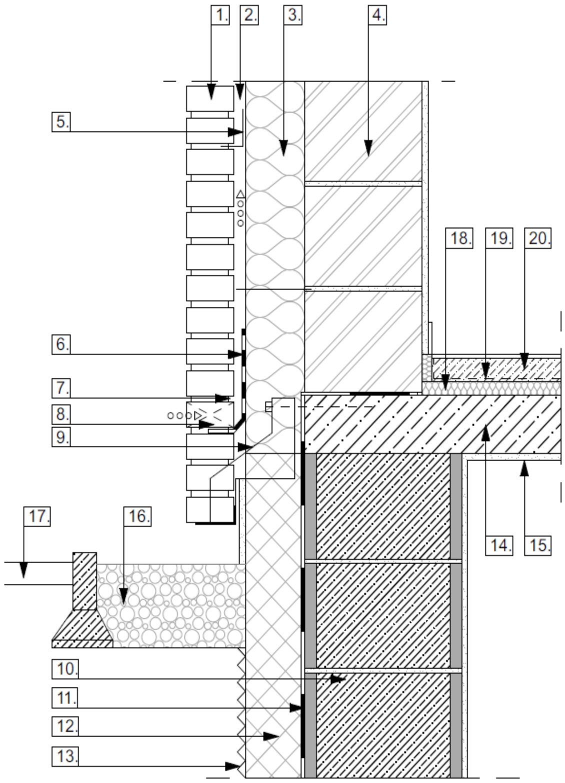
The complex layer structure of the ventilated air-gapped cladding masonry and its support structure and additional elements provide the complete system with which this masonry can be safely built.

The layer structure of modern masonry covered with bricks is as follows:

- (12 cm) external frost-resistant brick covering
- (3-4 cm) ventilated air gap
- thermal insulation
- console element
- load-bearing back wall.

The thickness of the thermal insulation depends on the thermal parameters of the load-bearing masonry. The external frost-resistant brick cladding, which can be paving bricks or sand-lime bricks, is fastened in the desired plane by back-anchor clips and supporting elements, brackets.

In addition to its decorative function, the cladding masonry protects the internal load-bearing structure from external influences and damage, and is therefore subjected to increased stress [1].



1. 12 cm external cladding brick wall
2. 3 cm air gap
3. 15 cm thermal insulation
4. Internal load-bearing B-30 wall
5. Back anchor element
6. Waterproofing
7. Insect mesh
8. Open vertical joint
9. Supporting element
10. 40 cm formwork stone element
11. 2 layers of bitumen water-proofing
12. Extruded polystyrene (PS)
13. Drainage sheet
14. Reinforced concrete ceiling
15. Plaster
16. Filter gravel
17. Pavement slab
18. Floating layer
19. Technical insulation
20. Base concrete

Figure 1: footing detail drawings of ventilated brickwork[1]

Figure 2: Paving brickwork during construction[2]

[1] The detail drawing is the author's work
[2] The photo was taken by the author

Only masonry materials resistant to external conditions, self-supporting, and frost-resistant, with water absorption below 5%, can be used for cladding brick facades.

The external cladding on facades is subject to various influences:

- wind suction, wind pressure,
- temperature fluctuations,
- frost effects,
- precipitation (rain, driving rain, splashing rain), and
- harmful chemicals in the atmosphere, dust pollution.

Damages can be classified into two major groups. One group includes damages resulting from the aforementioned external influences, while the other group consists of damages stemming from improper construction practices. Many damages caused by external influences can be avoided through skilled and conscientious execution and design.

Figure 3: ventilated facade brickwork, the completed building [3]

Preventing damages starts with the design process. It's the architect's responsibility to specify the construction methods in detail in the plans, draw attention to potential sources of errors for the constructor, and regularly monitor the progress of construction. (Unfortunately, in our country, this cannot always be adhered to because in self-funded construction projects, the client often, due to poorly understood financial reasons, does not require project management from the designer anymore.)

3 THE HARMFUL EFFECT OF AIRBORNE CHEMICALS AND DUST

It is well known that the changes brought about by modern industrial society and new construction methods also affect the facades of buildings. In addition to construction

[3] residential building designed by the author, Balatonszepezd

materials, changes in air composition can also cause negative effects on building materials and elements.

Table 1: Let's examine the composition of 'natural' air according to Table 1. [2]:

Gas Components:	Chemical Sign	Ratio (% by volume)
Nitrogen	N_2	78,10
Oxygen	O_2	20,93
Argon	Ar	0,93
Carbon dioxide	CO_2	0,03-0,04
Krypton	Kr	0,0001
Neon	Ne	0,0018
Helium	He	0,0005
Xenon	Xe	0,00001
Hydrogen	H_2	0,01

In contrast to this, nowadays we can find secondary pollutants in the air, which are responsible for the harmful effects on building materials, such as:

- Sulphur dioxide,
- Nitrogen oxides,
- Ozone,
- Hydrogen fluoride, hydrogen chloride, hydrogen sulphide,
- Dust and soot particles, and
- Carbon dioxide, if its concentration significantly exceeds the natural proportion in the air (0,029%).

As modes of action, we distinguish between dry deposition (gaseous pollutants) and wet deposition (harmful substances dissolved in moisture), as well as particulate matter deposition on the surfaces of building materials.

The damages can include:

- efflorescence,
- material degradation (thickness reduction, rust, disintegration),
- cracking and spalling, frost damage, and
- corrosion of fastening elements.

These add to the construction damages resulting from natural aging (weathering) and the faulty design and execution of external structural components as mentioned earlier.

The resistance of building materials used in external structural elements against air pollution varies greatly. The impact values described in research and literature, which determine the extent of the harmful effects of air pollution, make it difficult to draw a line between natural aging processes and damage caused by air pollution, especially when construction damages are also involved. This is confirmed by the recognition that the deterioration process is accelerated by the effects of harmful substances for most building materials used in external structural elements. Impressive examples include the brick structures of the Babylonians and the Elamites.

Bricks fired at only moderate temperatures between -200-400°C - have proven to be extremely resistant building materials, which have demonstrably remained undamaged for millennia. Nowadays, damage observed on bricks is attributed solely to design and execution errors. Even unsuitable post-construction repairs aimed at preventing moisture penetration (such as water-repellent coatings) have led to damage (frost damage).

The various cumulative detrimental factors lead to a decrease in the stability of brick masonry. It can be concluded that with regular production, design, and execution of visible brick surfaces, they perform well and withstand biological, chemical, and physical stresses excellently, thus ensuring a long service life.

4 DAMAGE FROM RAINFALL

4.1 WATER DAMAGE CAUSED BY RAINFALL

If the damages resulting from atmospheric effects are not always clearly identifiable, in recent times, a series of recurring weak points and resulting building damages have been observed that could have been avoided. External walls made of brick, lime-sand brick, or with cladding were damaged with equal frequency. Typical phenomena included cracking, spalling, often leading to complete saturation of the entire cross-section right up to the inner side. Such damages can be avoided by correctly assessing the load on the external wall. The most reliable way to meet this requirement is with a double-skin ventilated wall system, which ensures that the wall is protected against rain while remaining vapor-permeable. With proper design and execution, such a layered wall structure remains waterproof even under heavy rainfall.

4.2 EFFLORESCENCE OF VISIBLE WALL SURFACES

In the case of incorrectly executed external walls clad with bricks, visible or cladded walls exposed to moisture or rain may experience efflorescence. Efflorescence – besides being caused by the building material itself – is often a consequence of poor execution. The porous structure of the brick allows harmful substances such as SO_2, CO_2 to be absorbed into the building material, where they can react with moisture to form sulfuric acid. This acid then reacts with the free calcium carbonate present in the building materials, forming a salt solution that moves towards areas with lower vapor pressure and appears on the surface of the cladding, where water evaporates, leaving behind the salt. This deposition primarily results in aesthetic damage, but if the masonry continues to receive moisture continuously, it ultimately leads to the deterioration of the masonry.

Figure 4: Salt efflorescence on the wall surface[4]

4.3 SALT EFFLORESCENCE ON THE WALL SURFACE

The grouting of visible brick surfaces must also fulfil the role of protecting against atmospheric precipitation.

Grouting is particularly important for both visible and cladded masonry. It serves both as insulation against heavy rainfall and enhances the exterior appearance. For visible brick masonry exposed to heavy rain showers, the composition of the grout, the depth of the joints, the uniformity and position of the grout surface, and the method of grout application are of crucial importance. A significant portion of the damage caused by moisture previously observed can be attributed to deficiencies in grouting – whether it be due to inadequate grouting during construction or subsequent grouting or smoothing of joints. Achieving uniform joint thickness can be facilitated using a steel rod.

The gaps should be carefully excavated to a depth of 1,5 cm using a sharp tool, ensuring that the surface is free from mortar residue. Subsequently, the masonry should be cleaned with a root brush and a diluted solution of hydrochloric acid or acetic acid, followed by thorough rinsing with water to remove any acid residue. The joints are then filled with grouting mortar, either flush with the surface or slightly recessed from the edges of the brick rows. Poorly grouted walls are susceptible to frost damage, with deep joints being particularly disadvantageous as they can retain precipitation for extended periods [3].

At the edges of the joints, remnants of mortar residue, recognizable by their different colour, are often present. Water can penetrate directly into the masonry at these points.

The consequences of this can be as follows: if there are remnants of mortar in the joints, moisture can seep into the mortar layers of the masonry during rainfall. These mortar layers, due to their lime content, are good absorbents of moisture, leading to saturation of the entire masonry. The consequence is efflorescence, caused by salts dissolved from the

[4] The photo was taken by the author

masonry by water. Further damage occurs during freezing conditions when water in the joints causes the outer part of the grouting to spall.

These errors can be relatively "easily" rectified: the outer part of the grouting, approximately 15 mm, should be removed in the case of improper execution.

This task is performed using a specialized tool, a side-spiked flat chisel. A hammer is used to strike the flat chisel from the side, and with the spikes penetrating into the joint, the mortar is levered out of place, while also removing any remaining remnants of mortar from the outer strip. Following this, the cleaning process described earlier is carried out, followed by re-grouting.

Alternatively, the masonry can be carried out with water-repellent mortar, in which case the use of specialized grouting mortar is omitted, and the joint formation is done simultaneously with the masonry. Care must be taken to ensure that the cladding brick masonry is grouted and bonded with mortar [4].

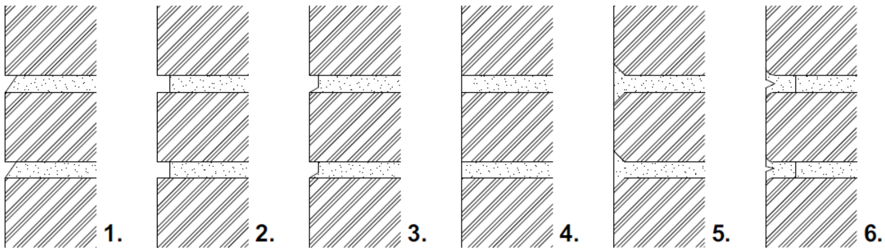


Figure 5: joint designs[5]

Here are some examples of grouting methods for masonry walls:

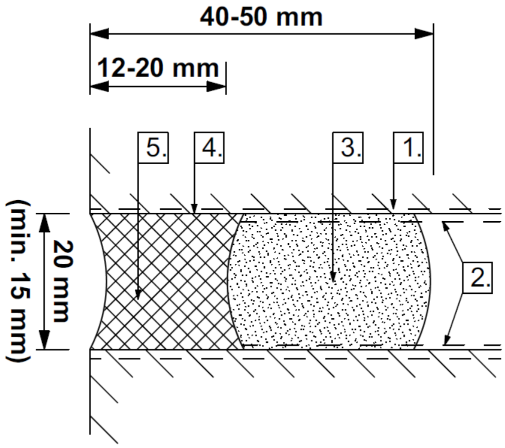
1. "Flush" deep grouting: This is used exclusively for new structures and high-quality bricks.
2. Recessed grouting: Never use for walls made of old or reclaimed bricks, as it poorly drains rainwater from the joints.
3. Slightly recessed, semi-circular grouting: Particularly suitable for old brick structures, especially if the edges are slightly worn.
4. Full grouting: Recommended for walls exposed to rain.
5. Full grouting with rubbing: Requires a lot of mortar for re-grouting, and if the bricks are already in poor condition, excess mortar often ends up on the masonry.
6. "Horned" grouting, which is drawn into the joints afterwards, looks nice if the external grouting is made of clean lime mortar.

[5] The drawings are the author's work

5 EXPANSION JOINTS OF MASONRY

The sunlit side of the building heats up and expands. Since this expansion occurs on the sunlit side of the building and does not affect other parts of the building, significant stresses are generated in the walls. The lack of vertical expansion joints leads to cracks. While the flexibility of the masonry joints (the horizontal and vertical joints filled with mortar) is sufficient to absorb these forces in small buildings, larger buildings require special expansion (dilatation) joints to accommodate these forces [5]. In multi-layered walls, especially those made of dark red bricks that absorb solar radiation, the outer brick wall heats up significantly. Due to the presence of an air gap and insulation, the absorbed heat energy cannot be transferred to the inner wall structure, causing the outer wall to expand. Without vertical expansion joints, the wall cracks. Water easily finds its way through the cracked wall surface, leading to the freezing of the masonry and its surface during winter.

The correct design of the vertical expansion joint:



1. joint expansion
2. joint contraction
3. closed-cell foam profile
4. suction bridge
5. gap sealing compound

Figure 6: Vertical expansion joint[6]

[6] The drawing is the work of the author

Possible joint designs

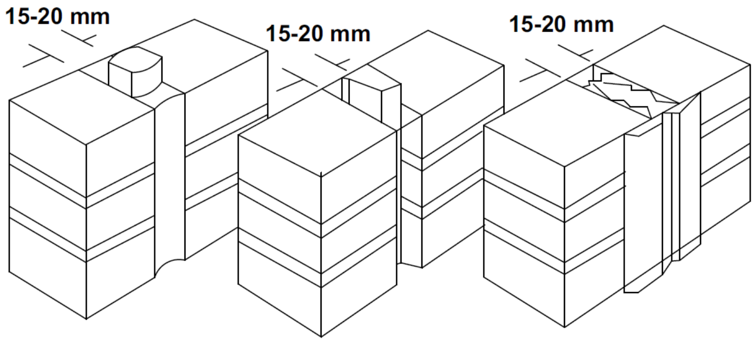
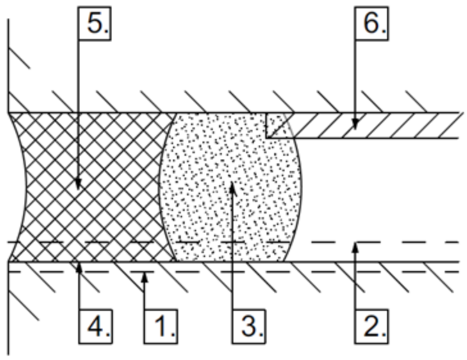


Figure 7: joint constructions [7]

Expansion joints must be placed on the outer casing wall both vertically and horizontally. It is always placed horizontally at the support of the outer covering masonry, the distance between the support brackets is max. It can be 12 m at most.

The correct design of the horizontal expansion joint:



1. joint expansion
2. joint contraction
3. closed-cell foam profile
4. suction bridge
5. gap sealing compound
6. steel support bracket

Figure 8: horizontal expansion joint [8]

The location of the vertical expansion joints depends on the orientation, as usually the western wall of the building heats up more, so here the vertical expansion joints must be created at a distance of 7-8 m, on the north side this distance can reach 12-14 m.

Other parts of the building at risk are window parapets, corners, surface breaks, expansion joints must be included here as well.

[7] The drawing is the work of the author
[8] The drawing is the work of the author

Example of thermal expansion of brickwork

dark red clinker brick — Western wall

$\alpha = 24 \cdot 10^{-6} \frac{\mathrm{m}}{\mathrm{m}} \mathrm{°C}$ — min. temperature: 10°C

max. temperature: 40°C

$$\Delta l = \alpha l \Delta t = 24 \cdot 10^{-6} \frac{\mathrm{m}}{\mathrm{m}} \mathrm{°C} \cdot 8\ \mathrm{m} \cdot 30\mathrm{°C} = 0.0058\ \mathrm{m} = 5.8\ \mathrm{mm}$$

In the case of a temperature difference of 50°C, which can easily occur in the summer, the thermal expansion of the wall can reach the order of 0,5 cm. (The minimum joint compression between the bricks was not taken into account in the approximate calculation.)

6 THE ROLE OF THE VENTILATED AIR GAP

As I already wrote about the wetting of masonry caused by rain, the ventilated air gap prevents the masonry from becoming wetting, as the air flowing behind the paving brick masonry continuously dries the masonry. In addition, the multi-layer masonry with air gaps also has a thermo-technical role. Since the ventilated air layer and the thermal insulation do not allow the internal load-bearing masonry to heat up in the summer, the entire thermal capacity of the internal wall can provide for the cooling of the rooms, if it cools the load-bearing masonry every night by ventilating the cool air at night.

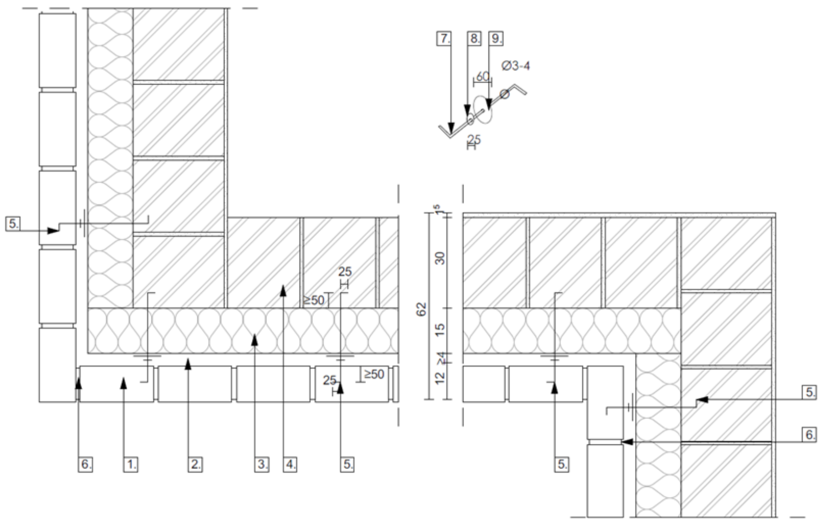


Figure 9: positive and negative corner design [9]

[9] The drawing is the work of the author

1. external cladding brick wall
2. air gap
3. thermal insulation
4. internal B-30 load-bearing wall
5. rear anchor element
6. expansion joint
7. element "Z" (thickness 3-4 mm)
8. metal drip disc
9. plastic clamping disc

To ventilate the wall, ventilation openings must be provided at the bottom and top. 150-150 cm^2 for 20 m^2 or a ventilation opening must be left, which can be achieved by leaving a suitable number of vertical joints open.

The distance between the load-bearing wall and the cladding wall layers can extend up to 250 mm structurally. If the air gap is d=40 mm, then the thickness of the insulation material can be up to 210 mm. Opting for an external wall with two-layer insulation allows the void between the external cladding layer and the internal load-bearing wall to be filled with insulation material up to 250 mm. Any moisture that penetrates behind the masonry must be directed away, which can accumulate on the backside of the cladding masonry and on the tie hooks. The tie hooks are equipped with plastic drip discs to prevent moisture condensed on the metal from entering the insulation or masonry.

Existing ventilation openings can serve to expel any infiltrated moisture (approximately 50 cm^2 of drainage opening per 20 m^2). Therefore, the construction and masonry of the ventilated wall require increased attention and diligence, as it is inevitable during the masonry process that mortar falls into the air gap and potentially obstructs it [6].

Figure 10: arrangement of inlet and outlet openings [10]

If ventilation and drainage openings are blocked by falling mortar debris, the desired air circulation and water drainage cannot occur, rendering the benefits of the air gap ineffective. Additionally, the mortar bridges can interrupt the insulation and conduct heat from the internal wall structure to specific points (thermal bridges form). Moisture from

[10] the photo was taken by the author

the external wall can migrate into the internal wall structure through the mortar bridges, potentially leading to mold growth on the internal wall surface along with the thermal bridges.

7 CORROSION PROBLEMS OF BRACKETS AND CONNECTING ELEMENTS

The external facade-cladding brick wall is held in the desired plane by anchoring elements and brackets. The fixation of the facade brick wall to the backing wall usually occurs along the crown line, and the brick wall is tied back to the load-bearing structure with anchoring hooks. Five pieces are required per square meter. However, if the brick wall above the support bracket reaches 12 meters, seven anchoring hooks per square meter should be placed [6].

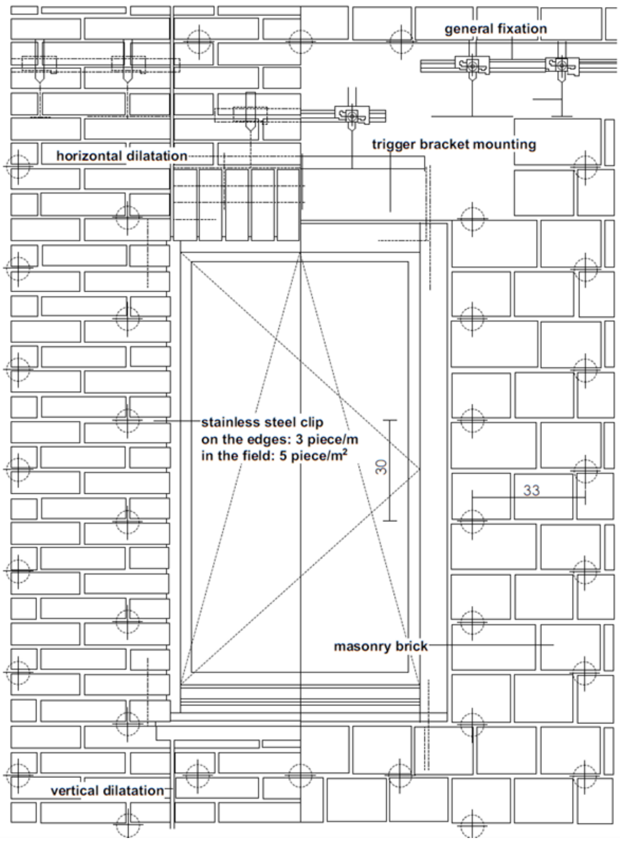


Figure 11: arrangement of support brackets and connecting hooks[11]

[11] the drawing is the work of the author

The switch and load-bearing metal elements are made of corrosion-resistant and high-strength steel alloy composed of 18% Cr (Chromium) and 10% Ni (Nickel). This alloy is resistant even to weak acids [7].

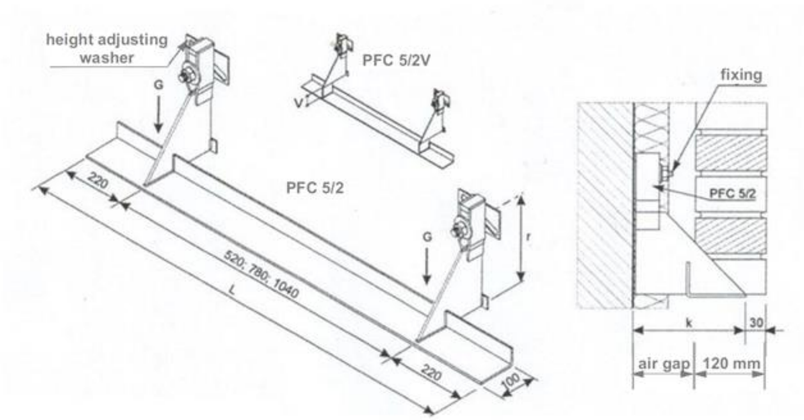


Figure 12: masonry support brackets[12]

In Hungary, in some cases - especially on smaller construction sites - it is a common issue that due to the high cost of steel alloys, anchoring fittings equipped with tie rods are used, which are dipped in zinc or tin melt to ensure their rust resistance. Connections made this way are sensitive to galvanic corrosion in the case of tin, as the coating metal is more noble than iron (it has a higher electrode potential). In the case of zinc coating, it's the opposite: iron is more noble than the coating metal, so first the coating deteriorates, and only then does the steel structure begin to rust.

For corrosion to occur, the following conditions are necessary:

- presence of oxygen,
- relative humidity greater than 40%,
- mechanical (surface) damage, and
- contact between metals with different electrode potentials.

The further apart the electrode potentials of the two metals are, the faster the corrosion process. Corrosion can be further accelerated by air pollution (chlorides, nitrates, sulphides), sulphur dioxide, nitrogen oxides, hydrogen fluoride, hydrogen chloride, hydrogen sulphides, etc. [8].

The progression of corrosion is a slow process, and its danger primarily lies in the fact that it affects concealed structures that cannot be periodically inspected, yet are exposed to moisture and pollutants.

[12] Fixinox design guide

8 CONCLUSIONS

When designing modern ventilated brick claddings, many conditions and regulations must be taken into account. Careful planning is necessary to ensure that the brick walls meet all the requirements placed on them because a properly constructed modern facade cladding consists of complex engineering thinking and high technical quality building structures. It is also important to note that the outer shell of the building made of facade bricks consists of very small elements relative to the size of the building, and the chosen sizes and proportions of these elements are crucial for the appearance of the facade, so the distribution of elements and proportions must be predetermined.

When arranging the bricks, it is important to consider the size of the bricks so that as few cut bricks as possible are used.

Attention must be paid to the creation of expansion joints to avoid damage from thermal expansion.

For concealed structures, it is important in the design phase to ensure that only corrosion-resistant steel structural elements are used, as any damage to these structures may not be visible and can be repaired afterwards with great difficulty.

Moisture entering the structure must be expelled as soon as possible to prevent potential damage from precipitation.

To avoid overheating in summer, it is important to maintain the permeability of the air gap and plan the necessary inlet and outlet openings.

Equally important is the role of grouting and the avoidance of grouting gaps in case of enclosing masonry, so as not to lead water into the masonry, which can later lead to freezing or signs of surface efflorescence.

As more and more buildings with facade claddings are being built in Hungary as well, it is important to pay attention to the proper design and precise execution of such materials and structures.

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