RESISTANCE OF MASONRY VENEER WALLS AGAINST RAIN PENETRATION

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ABSTRACT

The resistance of masonry veneer walls against rain penetration has been a design issue since centuries. Different local construction details have been developed in affected regions with rainy winters and periodically high wind days, including coastal areas of the United States, Canada, Northern Europe and Australia. Scientifically, two aspects have to be investigated: The rain penetration and the properties of the exterior wall surface. The design rain load on walls depends on local weather conditions, rain impact characteristics (e. g. duration and distribution), height of the building and the topography surrounding the building. In the case of masonry veneer walls main properties of the exterior wall surface are the quality of the joints and the capillarity of the bricks. With a lack of knowledge of relevant wall surface parameters and uncertainties in the characteristic rainfall duration, it is not possible to assess the influence of rain penetration through hygrothermal simulations. Another relevant factor of the resistance of masonry veneer walls against rain penetration is the fitting of windows and door-openings. Additionally, concepts of "barrier-free" or "universal" constructions have to be considered. "Smooth" door openings and floor level windows require adequate construction details for the rain protection of veneers. The paper describes laboratory tests investigating the resistance of masonry veneer walls with windows against rain penetration. Eight specimen with four different flashing-systems between facing wall and backing wall have been tested under laboratory rain exposure. Based on the results, detailing recommendations are given. The assessed water absorption is compared with the recommendations of the ASHRAE Standard 160, that are also applied in hygrothermal simulation models.

KEYWORDS: *masonry veneer walls, wind driven rain, water penetration, laboratory tests, masonry detailing*

INTRODUCTION

This paper focuses on the resistance of masonry veneer walls to wind driven rain penetration. Masonry veneer is defined differently, following local tradition and national standards. The described investigations are referring to masonry veneer walls constructed in accordance with

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Eurocode 6 (EC 6): *Design of masonry structures*. This traditional wall type is typical for residential and small office buildings up to 20 m in height like shown in Fig. 1.

Figure 1: Construction of masonry veneer walls in northern Germany according to Eurocode 6: Backing walls are made of calcium silicate blocks with thermal insulation (mineral wool) and masonry veneer of brickwork

Masonry veneer walls perform as cavity wall masonry with thermal insulation installed inside the air space. The backing load-bearing wall is usually constructed of solid masonry units like calcium silicate blocks. The facing masonry veneer wall is made of brick and is bearing its own weight only. It serves as a weather barrier and is anchored to the backing wall with stainless-steel-ties. Due to its slenderness – the wall thickness is usually about 11.5 cm – vertical support is required, approximately each 6.0 to 12.0 m of height and additionally above openings. Further regulations are describing size and diameters of the anchorage and the spacing of movement joints. The minimum thickness of masonry veneer according to EC 6 is 90 mm. Any thinner facing wall is referred to as *cladding for external walls*, following various national standards. The construction principle is shown in Fig. 2. Eurocode 6 defines 150 mm as the maximum thickness of the air space. With increasing interest in energy economy in buildings, even more insulation is demanded today. A bigger cavity between backing and facing wall requires adequate ties and special hangers and brackets for support above openings.

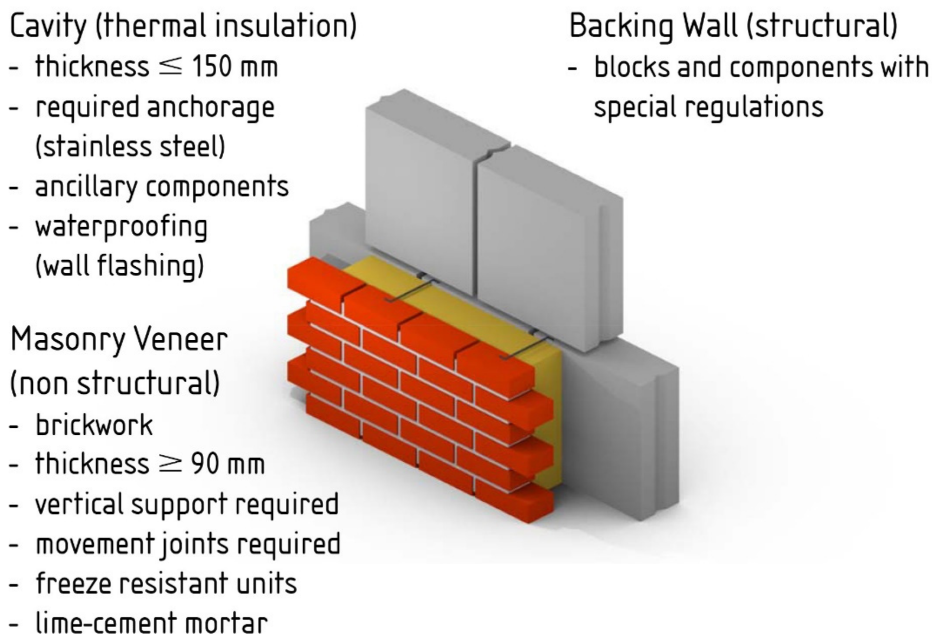

Figure 2: Construction principle of masonry veneer walls according to Eurocode 6

Masonry veneer walls are classified into the highest level of wind driven rain resistance (e. g., German national standard DIN 4108-3: *Thermal protection and energy economy in buildings – Part 3: Protection against moisture subject to climate conditions – Requirements and directions for design and construction*). They are declared to be adequate for regions with annual rainfall of more than 800 mm and exposed buildings. Actually, the water tightness of masonry veneer walls cannot be scored generally. Different building-related parameters have to be assessed. In practice, the wind driven rain resistance depend on the detailing of the masonry, the connection of windows and doors and the quality of the masonry veneer. Good craftsmanship is an essential factor and hardly to be evaluated. The laboratory tests introduced in this paper have been performed to assess the proper detailing of windows and floor level openings.

LITERATURE REVIEW: WATER TIGHTNESS OF MASONRY VENEER WALLS

Basic parameters for the tightness of masonry veneer walls are described by Gigla in [1]: Walls with different types of brick and different types of joints have been exposed to interval water spraying and constant water spraying. The main investigated and quantified parameters were the capillarity of the bricks, the finishing of the joints (tooled and pointed) and the influence of detachments between brick and bed-joint. Detachments were simulated by repositioning of single courses during mortar setting. In practice, they may occur due to inadequate workability of the mortar and repositioning of units ('tapping'). The tests showed that the effect of water penetration via the joints is independent of the type of brick. Even bricks with high capillarity are absorbing water mainly through the brick-joint interface, not through their front sides. Water break-thru of the facing masonry veneer has particularly been observed around cross joints and detachments.

Furthermore, the amount of water absorbed by the bricks depends not only on the amount of applied water but also on the rain exposition time. With the same amount of applied water, the absorption increases with the exposition time at interval spraying. While the finishing of the joints is of less influence, detachments (loss of bond between brick and mortar) are a significant influence on increasing water penetration.

The fact that a secure bond between brick and joints is a crucial factor for the water tightness of masonry veneer surfaces is confirmed by Straka [2] and Hines [3]: Straka [2] evaluated issues related to water penetration from wind-driven rain for four different brick types. She investigated the impact of changes to veneer thickness on water penetration into the wall cavity and water absorption by the wall. The results of her studies indicate that the thickness of veneer wall did not seem as important a variable as the properties of the products and workmanship specifically related to bond between the clay unit and mortar. Straka points out that from the durability point of view, smaller absorption is better for severe environments with many freeze/thaw cycles during each winter. She concludes that the thickness of clay brick veneer does not significantly impact its response to wind-driven rain.

Hines [3] investigated the effect of different types of mortar joints ('concave', 'vee', 'weather" and 'rake', compare Fig. 3) on the water permeance of walls.

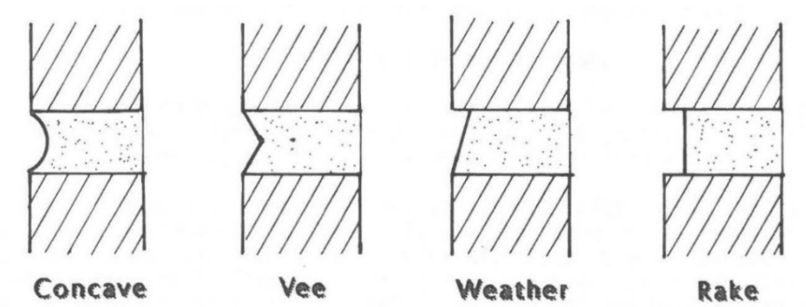

Figure 3: Different type of mortar joint profiles investigated by Hines [3]

He tested 24 clay brick masonry walls following *ASTM E 514-86: Standard Test Method for Water Penetration and Leakage Through Masonry*. Hines reports that the observed leakage developed as a result of the movement ('tapping') of units, that have already been laid into the mortar bed. He recommends that particularly high absorptive brick should not be moved once laid. The results seem to suggest that a tooled concave mortar joint is the most water resistant profile. Additionally, the size of joints should be reduced: a 10 mm thick joint performs more favorably than a 20 mm thick joint. Therefore, a 10 mm thick concave mortar joint will yield the most watertight masonry wall. He summarizes that his data also highlights the importance of good workmanship in masonry.

WATER TIGHTNESS OF MASONRY VENEER WALLS CONSIDERING WINDOWS AND WALL FLASHING

The wind driven rain resistance of the complete wall system depends on the following parameters:

- water tightness of the masonry veneer
- water tightness of the windows or doors
- sealing between windows and masonry veneer
- proper flashing at the footing of the cavity, beneath sills and above lintels
- appropriate sealing of the windows

Figure 4 shows a cross section of a masonry veneer wall with windows following EC 6. The architectural masonry detailing on the right follows local standards, tradition in workmanship and available components for masonry. The windows are mounted at the backing wall and are part of the insulation level. To minimize heat loss, adequate connections are required. Typically, windows are framed with bars of factory made extruded polystyrene foam (XPS), like to be seen in figure 5 (left). Those bars are part of the insulation layer and typically mounted at the outside of the backing wall, requiring skillful window connections. Above window openings the masonry veneer is supported with concrete lintels. The lintels usually are cladded with slices of brick. Flashing for weatherproofing is required at the footing of the cavity, beneath sills and above lintels. Components for flashing are standardized (EC 6). Typically, sheets of welded polymerized bitumen or adequate felts are applied (Fig. 5, right).

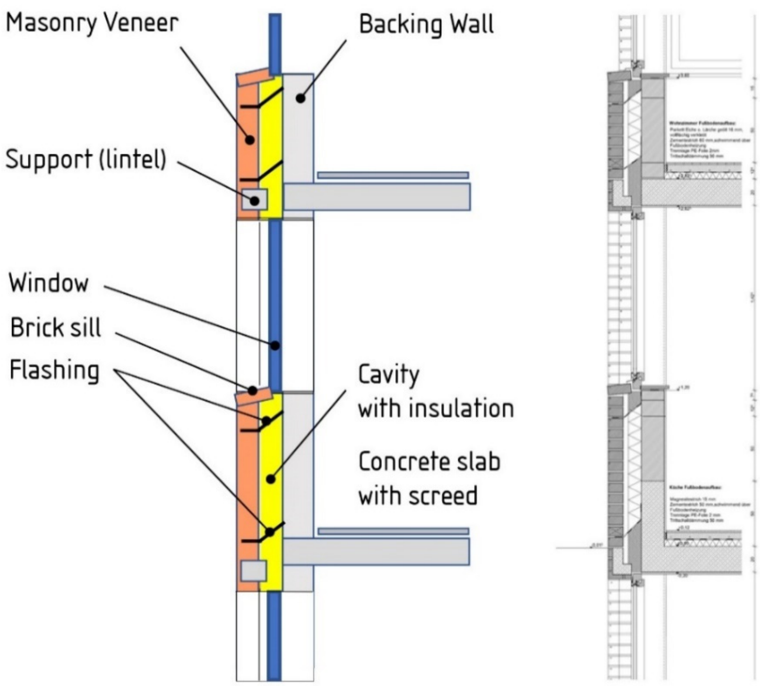

Figure 4: Cross section of a masonry veneer wall with windows:
Schematic drawing (left) and architectural masonry detailing (right).
Flashing for weatherproofing is required at the footing of the cavity and at sills and lintels.

Figure 5: Left: Backing wall (calcium silicate-blocks) with anchorage and bars of extruded polystyrene foam (XPS), framing openings for floor level window to minimize heat loss. Right: Flashing for waterproofing at the footing of the cavity of a masonry veneer wall (sheets of welded polymerized bitumen). Because the sheets have to be manually resealed around edges, the water tightness at corner sections is critical.

Alongside wall sections, flashing with adequate sheets is simple craftsmanship. In comparison, flashing of wall footings around edges or niches requires advanced skills, because flashing sheets cannot be 'bent' horizontally around corners (compare Fig. 5, right). Therefore, adjustments like cutting and resealing are necessary. Such adjustments are not standardized and sensitive to failure. Careful detailing and construction inspection have to be recommended. At corner sections and beneath sills flashing works have to be planned and understood 'three dimensionally'. Floor level openings are frequently sensitive to failure when flashing sheets are cut improperly and not resealed appropriately. In such cases, rain water might accumulate between screed and ceiling plate, damaging the flooring system. A special briefing for the workmen has to be recommended.

The water tightness of the windows or doors is the most fundamental parameter for the wind driven rain resistance of the complete wall system. It is tested in accordance with European standard *DIN EN 1027 Windows and doors – Water tightness – Test method*. The standard defines water tightness as a function of air pressure. During testing a continuous water film is sprayed onto the object with defined 2 l/min nozzles. The air pressure is increased from 0 to more than 600 Pa in intervals of 50 Pa at 5 min. The specification of water tightness equates to the highest level of pressure without leakage. It is usually much higher than the effective wind driven rain action.

The sealing between windows and masonry veneer is a critical point for the wind driven rain resistance of the complete wall system. Different elastic joint sealants are used. The water tightness depends on the suitability of the sealant-system and the craftsmanship. The durability of such joints is another important issue for masonry veneer walls, because some joints are difficult to access at the finished building. The integrated sealing sheets of the window have to be connected appropriately to the backing wall to ensure an airtight joint and to reduce water vapor convection.

TEST SERIES

The investigations are focussing on the detail of watertight construction of window and ground-level door openings at masonry veneer walls. Those are required increasingly in practice due to accessibility of buildings. Eight test walls with masonry veneer and four different types of flashing and waterproofing have been constructed on concrete bases. The concrete bases have been moulded like a standard ground slab with lower footing. Figure 6 describes the detailing of the walls [4]. Figure 7 gives an impression of the construction works.

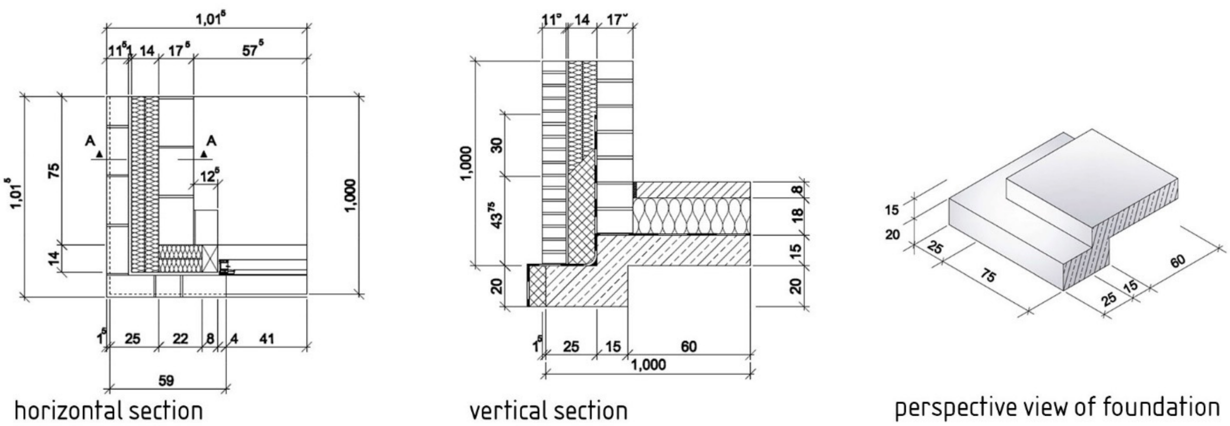

Figure 6: Detailing and foundation of the test walls to investigate the watertight construction of windows and ground-level door openings considering corners and edges [4]

Figure 7: Test walls to investigate the watertight construction of windows and ground-level door openings considering corners and edges under construction

The test walls were constructed by professional mason-apprentices during an international project at Lübeck Masonry Training Center. The mason-apprentices were briefed as to the purpose and importance of the construction and supported and surveyed by a professional Meister. Tests were defined into four series with two identical test walls each. The series have been defined as follows:

1. ‘standard’: Typical regional construction of masonry veneer walls with standard flashing
2. ‘distributor 1’: Solution from distributor 1, specialized for the flashing of masonry veneer walls
3. ‘distributor 2’: Solution from distributor 2, specialized for the flashing of masonry veneer walls
4. ‘innovative’: Approach to optimize waterproofing by relocating the XPS-bars to the jambs

The detailing of the four test series was similar. Variations were the components for the flashing of the wall footing (felt with bonding system or polymer thick coating with manufactured infinity cove), different type of sill (stone plate and brick sill), detailing of the sill and window sealing and the position of the framing XPS-bars. A total of 16 tests with laboratory rain exposure have been performed. Table 1 summarizes main parameters of the test walls. Following the concept of entire prevention of any water break-thru, the effect of weep holes has not been investigated.

Table 1: Main parameters of the test walls

	Masonry veneer (tested in lab)	**Backing wall (declaration)**
1. Masonry units	Brick, 240x115x52 mm	Calcium silicate, 240x175x113 mm
Gross dry density (DIN EN 772-1)	1780 kg/m³	DIN EN 771-2/DIN 20000-402 - Class 1,8: 1610 to 1800 kg/m³
Net dry density (DIN EN 772-1)	2110 kg/m³	
Area of voids in masonry units	12,5 %	
Compressive strength (DIN EN 772-1)	76,1 MPa	DIN EN 771-2/DIN 20000-402 - Class 12: f_{st} = 15 MPa
water absorption coefficient by partial immersion (DIN EN ISO 15148)	0,57 $kg/m^2h^{0,5}$	
Cold water absorption (DIN EN 772-21)	8,9 %	
2. Mortar	Lime-cement DIN EN 998-2 ‘M5’	Lime-cement DIN EN 998-2 ‘M2.5’
Dry bulk density of hardened mortar (DIN EN 1015-10)	1830 kg/m³	
3. Cavity	Air space: 15 cm with 14 cm thermal insulation (2 layers of mineral wool, 6 cm and 8 cm and XPS-bars)	
Anchoring	DIN EN 1996-2/NA stainless steel, diameter: 4 mm	
Sealant: window - sill	elastic, self-adhesive, butyl rubber on poly-propylene non-woven fabric	
Sealant: window - frame	Impregnated polyurethane foam tape	
Sealant: window - backing wall	polyester felt	

Particular attention was paid to the detailing between the bars of factory made extruded polystyrene foam (XPS) and the masonry units for the sill at the bottom of the window. The masonry units have to be moved below the mounted window to ensure water tightness of the masonry veneer and are colliding with the framing XPS-bars of the insulation. Series 1 defines a standard flashing solution with components typically provided by masons. Specialized distributors offer advanced flashing solutions for masonry veneer walls. Solutions from two distributors were tested to compare the achieved level of water tightness. Flashing works at the test walls of series 2 and 3 have been done with approval from the distributors. Series 4 tried to achieve the best level of water tightness under laboratory conditions by mounting the XPS-bars at the jambs.

LABORATORY RAIN EXPOSURE

To evaluate the water absorption during wind driven rain exposition, a custom test set up has been used [1]. It was the target to generate a continuous water film on the surface of the masonry veneer. Air pressure was not evaluated because its influence for masonry veneer walls is considered less important in comparison with windows or thin surfaces.

Test rain was sprayed from a defined frame with four spray nozzles at two beams. The applied amount of water was based on a precipitation that is expected one time a year (5 l/m² in 5 minutes). The test rain has been created with tap water filled into a reservoir. The required pressure of 6 bar ($6 \cdot 10^5$ Pa) was generated with a custom wet-pit pump inducing a constant flow of 0.5 l/s. The spraying distance was adjusted to obtain realistic wind driven rain drop diameters (d = 2 mm) and was constant during the tests. The test rain might be categorized intense to heavy rain referring to standard *DIN IEC 721-2-2: Classification of environmental conditions; Part 2: Environmental conditions appearing in nature; Precipitation and wind*. Fig. 8 shows two variations of test walls.

Figure 8: Test walls with masonry veneer and window surface after lab rain exposure [4]
Left: Sill plate and installed humidity sensors. Right: Brick sill.

Sides and top of the test walls have been sealed with an acrylic glass frame before the application of rain. A total water amount of 150 l/m² was applied at interval spraying during 5 seconds per minute at 0.5 l/s. The applied water amount correlates with precipitations between 14 and 30 mm/m²/h. Water break-thru was detected as a function of time via three implemented digital probes for measuring humidity and temperature and a data logger. The sensors were installed at different levels of the flashing at the wall footing. Additionally, leakage was checked visually.

TEST-RESULTS AND DETAILING RECOMMENDATIONS

The test results are too comprehensive to be presented in detail within the scope of this paper. Main results and recommendations for the water tightness of masonry veneer walls considering windows and wall flashing are:

- The amount of penetrated water depends significantly on flashing or sealing leakage. The water penetration via the joints of the masonry veneer (compare [1]) was found less significant. Leakage of the masonry veneer occurred at maximum rain load.
- Inappropriate sealant between window and sill causes heavy leakage during test rain, particularly at the connection to the jambs. The sill flashing should be turned upside enclosing the jambs and forming a 'trough'.
- The quality of the sealant between window and jambs and window and backing wall is another relevant source for water break-thru. Specially trained craftsmen may reduce the risk of leakage.
- Water break-thru correlates with flaw in waterproofing works (e. g. improperly cut sheets, twisted felts or missing sealant). Tight construction supervision has to be recommended.
- Standard flashing of the wall footing with felts is more watertight than a polymer thick coating.
- Stone plate and brick sills are both suitable for watertight masonry veneer walls.
- Alternative mounting of the XPS-bars at the jambs (compare Fig. 9, right) increased the water tightness but might be too effortful and expensive in practice, according to the brick jambs.
- A ground slab with footing (compare Fig. 9, left) is less sensitive to inadequate waterproofing than a continuous ground slab (compare Fig. 9, center), especially for "smooth" door openings.

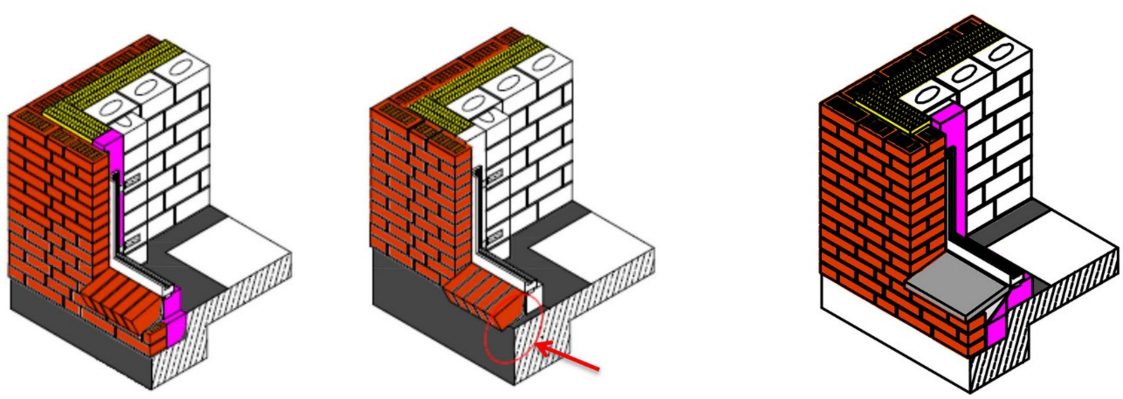

Figure 9: A ground slab with footing (left) is less sensitive to inadequate waterproofing than a continuous ground slab (center). Right: XPS-bar mounted at the jambs [4]

RAIN PENETRATION WITHIN HYGROTHERMAL SIMULATIONS

ASHRAE®-Standard 160, *Design Criteria for Moisture-Control Design Analysis in Buildings*, suggests: 'In the absence of specific full scale test methods and data for the as-built exterior wall system being considered, the default value for water penetration through the exterior surface is 1% of the water reaching that exterior surface'. Hygrothermal simulation software systems like Fraunhofer 'WUFI®' are utilizing additional parameters like horizontal rainfall, surface inclination and average hourly wind speed to quantify wind driven rain action [5]. The introduced test results show that the value for rain penetration in the case of masonry veneer walls including windows and wall flashing depends significantly on the quality of waterproofing and sealing. The real rain penetration may be much higher than the calculated wind driven rain action. Assumptions based on ASHRAE®-Standard 160 or even more precise meteorological data are a rough approach, limited to the absorption of straight masonry veneer surfaces. Due to the expected accuracy of hygrothermal simulations, the utilization of wind driven rain action should be carefully considered. Numerical results of wind driven rain action for any masonry veneer wall façade including windows, doors and flashing will be limited to an approximate level.

SUMMARY

The paper is focusing on the resistance of complete masonry veneer walls including windows and flashing against wind driven rain penetration. The described investigations are referring to masonry veneer walls constructed in accordance with Eurocode 6. Eight similar test walls with four different types of flashing and waterproofing have been tested under laboratory rain exposure. Main parameters during testing were the flashing components of the wall footing, type of sill, sill detailing, window sealing and the position of the framing XPS-bars. Water penetration was assessed visually and via implemented humidity sensors. The test results show that the amount of penetrated water depends significantly on flashing or sealing leakage. Water penetration via the joints of the masonry veneer was found less significant. Based on the results, detailing recommendations are given. Because the value for rain penetration of masonry veneer wall façades depends significantly on the quality of waterproofing and sealing, the calculation of wind driven rain action within numerical hygrothermal simulations will be limited to an approximate level.

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