Reliability and adequacy of current watertightness test standards used to evaluate the performance of façades

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Abstract. Watertightness test standards are used to evaluate enclosure components in terms of water penetration resistance. Currently, there is a wide variety of watertightness tests in use for façades elements and wall systems. However, recent research has revealed many inconsistencies in the possibility of current test standards to reproduce real exposure conditions. As such, the main test parameters specified in watertightness test standards have been called into question. Nonetheless, these studies do not pay attention to the protocols and the technical specifications incorporated in the test standards. Neither to the influence that these aspects could have on the watertightness results. The present paper provides a general overview of current watertightness tests standards from around the world. Thereafter, a thorough comparison of the technical specifications incorporated in the protocols of the test standards has been carried out. Finally, an evaluation and discussion of some parameters suggested in the tests standards is undertaken based on the state of the art and laboratory experiments over diverse mock-ups.

1 Overview of existing watertightness test standards

The stages over a product's lifetime during which watertightness testing principally occurs are: (i) product design and development; (ii) recently installed products, and; (iii) during the useful service-life of the product [1]. In the early-life stages of the product, testing is completed to determine performance limits, to establish certification levels and to help ensure quality control. For this purpose, a mock-up is built and thereafter tested in laboratory conditions. Alternatively, over the product's mid- and later-life stages, testing clearly occurs on-site. Mid-life stages are considered those prior to the issuance of the building occupancy permit and no later than six months after the installation of the component [1]. Watertightness testing in mid-life stages is for quality assurance of the workmanship, whereas the testing is intended to reproduce actual leakage that has been observed during in-service conditions of the installed product in later-life stages.

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1.1 Field test standards

On-site watertightness test standards use three distinct approaches in which wind-driven rain and driving rain wind pressures are decoupled and independently treated, these being the hose, the spray bar and the cabinet.

The hose test generates a strong jet of water with a penetrating power far in excess of normal wind-driven rain exposure conditions [2]. Although the hose test does not reproduce the effect of wind pressure, it is assumed that the effect of kinetic energy can be simulated by the calibrated nozzle operating at a prescribed pressure at a specific distance from the test surface and moved at a specified sweep rate [3].

A spray bar is a long pipe fitted with holes or nozzles at regular intervals along its length. The spray bar will spray water at a set working pressure range, ensuring a constant film of water is sprayed onto the face of the façade test specimen and not forcing water into the joints, like in hose testing. Spray bar nozzles can be directed at specific joints but the standards usually recommend directing them at points above the joint, as it is a test for resistance against water penetration from water runoff.

Spray bar testing and hose testing may not simulate all of the effects of differential pressure and the ability of air moving through cracks or openings to transport water by percolation [3]. By contrast, site cabinet testing is supposed to reproduce better the extreme weather conditions and the action of both wind-driven rain and driving rain wind pressures. In site cabinet testing an air chamber is either mounted on the external or internal face of the façade test specimen, incorporating a means of pressurising or de-pressurising the cabinet, respectively. The basis of cabinet testing is to create a pressure difference on the façade test specimen, whilst spraying water onto the external face [2].

Chew [4] presented a review of the existing on-site watertightness tests standards for masonry walls. This overview of the currently available European and American field test standards is extended to every type of façade system and façade element in [5].

1.2 Laboratory test standards

Whereas field tests are useful to ascertain the performance of on-site workmanship, laboratory tests are useful to evaluate the design of the component (i.e. blocked drainage pathways and wrong detailing of joints). Laboratory tests are applied in the early stage of the product life to rate it with a performance class or performance level. While the performance class is generally prescribed as a direct function of peak wind pressure on the building, the performance level is obtained in respect of the ultimate limit state for resistance to wind loads of the product.

Laboratory test methods can be categorized into four distinct classes: static, cyclic, dynamic and wind tunnel testing. The first three test methodologies use a similar approach; wind and rain are decoupled and treated independently [6]. Whereas wind effects are reproduced by pressure differences generated by a fan, a water spray system placed in front of the specimen simulates the rain. The fourth method although is based on an integrated approach in a wind tunnel [40]. In it, water droplets are introduced into a high velocity air stream far enough from the test specimen. This allows the droplets to achieve the required velocity prior to impact and to simulate raindrops trajectories. Consequently, this is the most realistic effect of the actual weather conditions that may act over a wall or roof element.

Sahal and Lacasse [7] presented an overview of several laboratory water penetration test standards, which are classified according to the type of test procedure, applied test pressures, water spray rates and duration of tests. Based on the previous authors, a

lengthened overview of the European, American, Asian and Australian laboratory test standards is given in [5].

1.3 Test parameters

Test conditions tend to eliminate all influencing parameters but three main variables for water-penetration testing: water application (named as water spray rate), air pressure difference between the interior and exterior surfaces of the test specimen [1] and duration of the pressure application. These variables are enforced and have a great impact on the water penetration performance of the test specimen as they directly affect some of the acting forces in support of water infiltration (kinetic energy, pressure differential and local air currents).

Water penetration test standards also incorporate some technical specifications, whose value ranges are typically suggested. These other related variables are: the conditioning of the laboratory (temperature of the water, surface tension of the water, relative humidity of the laboratory and temperature of the laboratory), the conditioning of the test specimen (amount of time a test specimen should be stored in the laboratory prior testing), the test equipment used to project water over the outermost surface of the test specimen (water spraying system, model of nozzle, method for applying the water load to the surface of the test specimen, working pressure range of the nozzle, spraying angle of the nozzle, distance to the outermost surface of the specimen, spray bar position, nozzles spacing and spray direction), the type of test procedure (static, cyclic, dynamic and wind tunnel testing) and the duration of the inspection for leakages.

Table 1 gives a comparison of the most typical value ranges provided for the main and related test parameters defined in American, Australian, Asian and European laboratory water penetration test standards.

Table 1. Overview of the most typical value ranges provided for the test parameters defined in American, Australian, Asian and European laboratory test standards used to assess the watertightness of facades and façade elements.

Standards			American	Australian	European	Asian
Main variables	Water flow rate		3.4 L/min	3 L/min	2 L/min	4 L/min
	Main Pressure		137Pa	300Pa	50-100-150-200-300-450-600Pa	3 steps to 30% of d.w.p.
	Pressure application per stage		10/15min	15min	5/10min	5min
Other variables	Laboratory conditioning	Water temperature	-	-	4-30°C	-
		Water surface tension	-	-	60×10^{-3}N/m	-
		Relative humidity	-	-	-	-
		Temperature	-	-	23±5°C	-
	Specimen conditioning		-	-	4h at 10-30°C & 25-75%	-
	Spraying system	Device	Matrix of nozzles	Matrix of nozzles	Matrix of nozzles / Spray bar	Matrix of nozzles

	Height	NA	within 100mm from the top of specimen	within 75mm from the top of chamber	NA
	Distance to the surface (d)	Uniform	90 cm	25 cm 40 cm	40cm
	Nozzles spacing	Uniform	180 cm max.	If d=25, 40 cm If d=40, 70 cm	
	Nozzle spray direction	0°	-	0° 24(+2)°	0°
Nozzles	Wetting pattern	-	Solid cone	Full cone	Full cone
	Spraying angle	-	Wide angle	Wide angle	-
	Working pressure	-	-	200-300 kPa	-

2 Experimental method

Recent research has primarily studied the relationship between the three main variables for water-penetration testing (refer to Table 1) and the real exposure conditions of the facades in the built environment. Nonetheless, it is still uncertain how can the performance class or performance level be affected by the value ranges provided to the other related test parameters. For this purpose, an experimental approach was adopted to study the impact on the results of water penetration of the following test parameters:

- Method for applying the water load to the test specimen surface: wind-driven rain or surface water flow.
- Distance of the spraying system to the outermost surface of the test specimen: 25cm or 40cm.

3 Results and discussion

3.1 Method for applying the water load to the test specimen surface

American and Australian laboratory watertightness test standards typically suggest a matrix of nozzles to project water over the test specimen surface, refer to Table 1. However, some European test standards (e.g. EN 12865 [8], NT BUILD 116 [9], NT BUILD 421 [10] and FprEN 15601 [11]) make a distinction in the method for applying the water to the outermost surface of the test specimen, being these:

(i)   Surface water flow, in which water flows down the vertical face of the test specimen by gravity. In this case, a horizontal row of nozzles spraying evenly above the top of the test specimen is proposed (e.g. EN 1027 [12]).

(ii)   Wind-driven rain, in which it is intended to deliver water droplets over the surface of the test specimen with a certain kinetic energy load. Accordingly, a matrix of uniformly spaced spray nozzles is suggested (e.g. EN 12865 [8]).

Lacasse et al. [13] acknowledged these methods as (i) the cascade mode and (ii) the full spray configuration, respectively. The full-spray configuration results in a water load increase in proportion to the wall height due to migration downward of water along the face of the test specimen. Alternatively, water applied in a cascade mode prevents that non-

absorptive test specimens are exposed to cumulative water loads at the lower portion of the test specimen. The water load on non-absorptive test specimens is independent of vertical location of the spray bar in the cascade mode [13].

Nine water penetration tests were conducted over two full-scale mock-ups with non-absorptive claddings to study the impact of each method on the water ingress within the pressure-equalized façade systems. The first mock-up had one open vertical joint and five open horizontal joints. Alternatively, the second mock-up comprised one open horizontal joint and five open vertical joints. A joint profile blocked the opening of the horizontal joint in the second mock-up. A row of evenly spaced nozzles was used to deposit water at a rate of 2L/min per m^2. The surface water flow and the wind-driven rain effect were simulated by means of the placement of the row of nozzles in relation to the horizontal joint.

During the tests, it was measured the water infiltrated into the cavity and the water reaching the back wall of the façade specimens. The average results obtained are summarized in Table 2. Note that the percentages presented have been determined from the total amount of water sprayed onto the surface of the test specimen.

Table 2. Average water infiltration percentages obtained for each façade mock-up in relation to the method for applying the water load to the surface of the test specimen.

	Surface water flow		Wind-driven rain	
	Water infiltrated into the cavity (%)	Water reaching back wall (%)	Water infiltrated into the cavity (%)	Water reaching back wall (%)
Mock-up 01	22.05±0.42	0.09±0.01	21.32±0.31	0.29±0.10
Mock-up 02	1.84±0.10	-	1.47±0.09	-

Very similar percentages of water infiltration into the cavity were obtained in mock-up 01 regardless of the method used for applying the water load. However, an increase of 0.20% in the water entry rates onto the back wall was observed when the test specimen was sprayed with wind-driven rain. On the other side, a decrease of 0.37% in the amount of water infiltrated into the cavity was recorded in mock-up 02 when the façade specimen was sprayed with wind-driven rain. This reduction in the water infiltration rate into the cavity might be due to the effect of blocking the opening of the horizontal joint. The wind-driven rain approach provides water droplets with more kinetic energy load. Consequently, a greater amount of water droplets can splash away from the profile at the horizontal joint not entering into the cavity. These results suggest that blocked horizontal joints are more sensitive to runoff water than to wind-driven rain and wind driven rain causes higher water entry rates onto the back wall in both open vertical and horizontal joints.

3.2 Distance of the spraying system to the outermost surface of the test specimen

European watertightness test standards typically suggest a distance of the spraying system to the exterior surface of the test specimen of either 25cm or 40cm; refer to Table 1. Research by Hoigard and Kudder [14] shown that as the nozzle distance from the test surface decreases, the water pressure impinging on the test surface increases. By consequence, the water droplets acquire more kinetic energy load and are able to reach longer infiltration distances. To evaluate to what extend the infiltration rates are affected by the distance of the spraying system to the outermost surface of the test specimen, we conducted four watertightness tests over the mock-up with one open horizontal joint and

five open vertical joints. A joint profile blocked the opening of the horizontal joint. The façade specimen was subjected to surface water flow at a spray rate of 2L/min per m^2. This surface water flow was generated by a bar of nozzles evenly spaced and placed above the horizontal joint. The distance of the nozzles to the exterior surface of the test specimen was varied from 25cm to 40cm in every other test.

An average rate of 7.69±0.82% of the sprayed water was found to be infiltrated into the cavity through vertical joints for a distance of 25cm of the spraying system to the exterior surface of the test specimen. This percentage increased to an average rate of 9.09±1.08% for the distance of 40cm. Regarding the infiltration rates through horizontal joints, it was obtained that 1.88±0.09% of the sprayed water infiltrated into the air cavity through horizontal joints for the distance of 25cm. Alternatively, an average rate of 1.83±0.27% was obtained for the distance of 40cm.

Very similar infiltration rates through horizontal joints were obtained for the distances of 25 cm and 40cm. These results suggest that the distance of the spraying system to the exterior surface of the test specimen has not an impact on the water entry rates through horizontal joints, when the opening is blocked and the surface of the specimen is wetted via surface water flow. In contrast, increasing the distance of the spraying system to the exterior surface of the test specimen yielded to higher infiltration rates through vertical joints. It appears that open joints are sensitive to the splash and bounce effect created when the distance of the spraying system to the surface of the test specimen is smaller and the water pressure impinging on the test surface increases.

4 Conclusions

The comparison of the different watertightness test standards and the subsequent critical evaluation of some of the related test parameters has called into question many of the technical specifications incorporated in the standards.

Being the first concern observed, the variance in the value ranges provided for the test parameters and technical specifications. These inconsistencies suggest that there is not a common criterion on the way of simulating the exposure conditions in the test procedures used to determine the resistance to water penetration of facades and façade elements. Furthermore, it has been shown that the technical specifications incorporated in the standards are sometimes too vague and can greatly affect the water penetration results. Therefore, we believe that the degree to test parameters defined for watertightness test standards impair the outcome of the test is an issue that requires further research on other types of façade systems and façade elements, to assist in the determination of the impact of such parameters on the performance class or performance level of the tested specimens.

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