

7th International Building Physics Conference

IBPC2018

Proceedings

SYRACUSE, NY, USA

September 23 - 26, 2018

Healthy, Intelligent and Resilient
Buildings and Urban Environments

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Drainage and retention of water in small drainage cavities: Experimental assessment

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ABSTRACT

Water that enters the drainage cavity of a rain screen wall assembly through deficiencies in the cladding will either be drained or retained by absorption or adhesion on the drainage surfaces. The objective of this study is to gain insight into the different factors that affect the quantity of water drained or retained in a drainage cavity. Drainage tests have been conducted for water flowing between two vertical polycarbonate plates with different gap widths to determine the effect on the drainage rate. Tests showed that even small cavities with a width of 1 mm can already drain more water than the amount that would enter the cavity during a rain event. Experiments were performed to determine the contact angle of water on a range of different sheathing materials such as asphalt saturated building paper, spun-bonded polyethylene wrap and cross-woven polyolefin wrap by the use of an optical goniometer. Drainage tests have been conducted for different combinations of these materials to quantify the effect of surface energy on the drainage rate. A larger contact angle results in a smaller quantity of water retained during the drainage test. These tests result in a retained portion of water and a drainage rate for different combinations of materials. The retained portion of water may be considered as a moisture load applied to the outer-most layer of the wall assembly's back-up wall in hygrothermal simulations.

KEYWORDS

Water drainage, small drainage cavities, contact angle, retention

INTRODUCTION

Rain screen wall systems or drained wall assemblies are commonly used to reduce the risk for moisture damage due to rain penetration behind the cladding. If openings or deficiencies are present in the cladding, raindrops may penetrate and enter the drainage cavity during a rain event. Most of the water that enters the drainage cavity will flow down along one of the drainage surfaces or between both as singular droplets, rivulets or multiple streams resulting in a film flow. Also some droplets may be retained in the cavity depending on the surface energy of the materials that define the drainage cavity, the gap width and the initial velocity and volume of the droplets entering the drainage cavity. Accurate knowledge of the retained portion of water is important given that in undertaking hygrothermal and durability analyses, it is considered to be the moisture load applied to the outer-most layer of the wall assembly's back-up wall. According to the Swedish SP Certification Rules no. 021, the quantity of retained water in drained facades should be determined by tests and be applied as input for hygrothermal simulations according to EN 15026 (SP Certification, 2009; Künzle et al., 2008).

Several detailed studies have been completed on film flow dynamics both in the laboratory or by numerical and analytical modelling (Ambrosini et al., 2002). Experimental studies have

been undertaken to investigate the transition from falling film flow to rivulet flow (Martin et al., 2015), rivulet geometry (McCreery et al., 2007) and the transition from laminar to meandering flow on both a single surface (Le Grand-Piteira, 2006) and between two planes (Drenckhan, 2004). As well, the retention of droplets has been studied (ElSherbini and Jacobi, 2006). Research on film flow dynamics has been conducted within the field of chemistry to improve applications such as heat exchangers, the field of geophysics to gain insight into the transport of contaminants in the Earth's substructure (McCreery et al. 2007) or within the field of building engineering mainly focusing on water runoff on a building facade due to wind driven rain (Blocken and Carmeliet, 2012; Van Den Bossche et al., 2015). Research concerning water flow and retention of water in wall drainage cavities however is very limited. Straube and Smegal (2007) performed drainage tests to obtain a better understanding of the drainage capacity in wall cavities given that, as it was stated by Onysko et al. (2007), even when hydrophobic materials are applied not all injected water drains out from the cavity. Drainage tests of smooth non-absorptive materials showed that a drainage gap of 1 mm between two stiff acrylic sheets (23-25 g/m²) stored less water than a single acrylic sheet (65 g/m²). Additionally, spray tests on a polyethylene sheet (35 g/m²) showed a smaller quantity of retained water compared to an acrylic sheet (65 g/m²) which is likely due to the increased hydrophobicity of the polyethylene as compared to the acrylic sheet. It was concluded that several wall assemblies even those having small gaps (< 1 mm) could drain more water than would ever enter the drainage cavity during a rain event as drainage rates exceeded 1 l/min.m. Given that wind driven rain loads on buildings seldom exceed 2 l/m².h, and infiltration rates are typically between 1% up to 10%, it can easily be assumed that the accumulated drainage rate, even for tall buildings, will never exceed 1 l/min/m. Blocken and Carmeliet (2006) performed an experimental study on different vertical surfaces (PVC, PMMA, PTFE, glass, glass with hydrophilic coating and glass with hydrophobic coating) to evaluate the impact of contact angle on the quantity of adhered water. Although it is often assumed that hydrophobic vertical surfaces promote drop run-off and therefore show less adhered water, no clear relation between the contact angle measurements and the quantity of adhesion water could be found.

To gain a better understanding of the parameters that affect drainage and retention in wall assemblies, an experimental research program was carried out. The objective of this research program was to evaluate the impact of the drainage cavity width and the surface characteristics of the drainage surfaces on the amount of water that is retained within the cavity. This program and the results derived from the work are described in detail in this paper.

METHODS

Drainage tests were conducted for water flowing down between two parallel vertical polycarbonate (PC) plates (609.6 x 609.6 mm). Gap widths of 0.99 mm, 1.96 mm, 3.12 mm and 4.84 mm (± 0.01 mm) were defined by use of spacers inserted between the PC plates at both vertical edges. A copper tube was installed on top of the test setup and aligned with the position of the rear PC plate. The tube contained 16 evenly spaced openings of 0.5 mm diameter located every 12.7 mm along its length; this arrangement provided an evenly distributed water deposition rate across the drainage cavity. A gutter located beneath the PC plates collected the drained water. To introduce a water flow, a peristaltic pump (Stenner Pumps 85 pump series) was connected to the copper water deposition tube by means of a flexible plastic tube. An average flow rate of 0.769 ± 0.002 l/min.m was applied during 3 cycles of 10 minutes and water deposition was evenly distributed over 16 openings in the copper tube. Both the mass of water that flowed through the pump and the mass of drained water were weighed with an accuracy of 0.1 g. By subtracting the mass drained from that

deposited, the mass of retained water in the cavity could be calculated for each setup. Before each experiment, the pump was turned on for a few minutes in order to reach a steady state for the water content of all tubes both before and after the experiment.

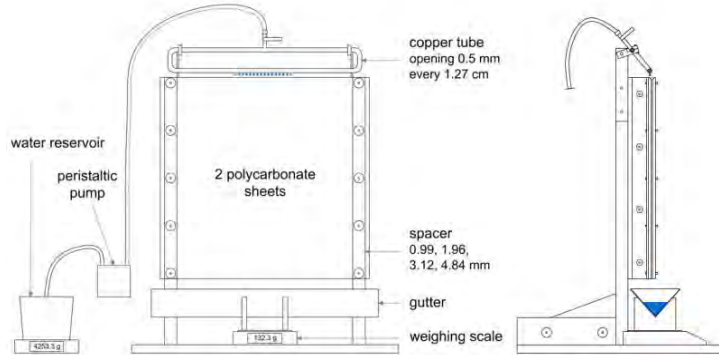


Figure 1: Test setup

Additionally, the drainage capacity of different commonly used sheathing membranes was evaluated. The sheathing membranes were taped onto the PC plate at the back of the test setup with a cavity width of 1.96 mm by means of two vertical strips of double-sided tape (350 mm o.c.). The same procedure as described above was applied to obtain the drainage characteristics of the sheathing membranes. To evaluate the impact of the surface characteristics of the plates or the sheathing membrane on the retention of water in the cavity, the contact angle of a distilled water drop on the different sheathing membranes was measured by means of a goniometer (Ramé Hart model 100-00-115). The optical sessile-drop method was applied to determine the static, advancing and receding contact angle. The reported values are the average of 8 contact angle measurements of different locations on the sample; these are in Table 1.

RESULTS

As water drops flow down, they leave behind smaller droplets, i.e. trace droplets. The impact of gap width on the volume of these trace droplets is evaluated by introducing water flow in between two PC sheets with different gap widths. During the test, the amount of water added to the drainage gap and the drained amount was measured and the retained portion is calculated. Results for the different gap widths and a single sheet are shown in Figure 2a).

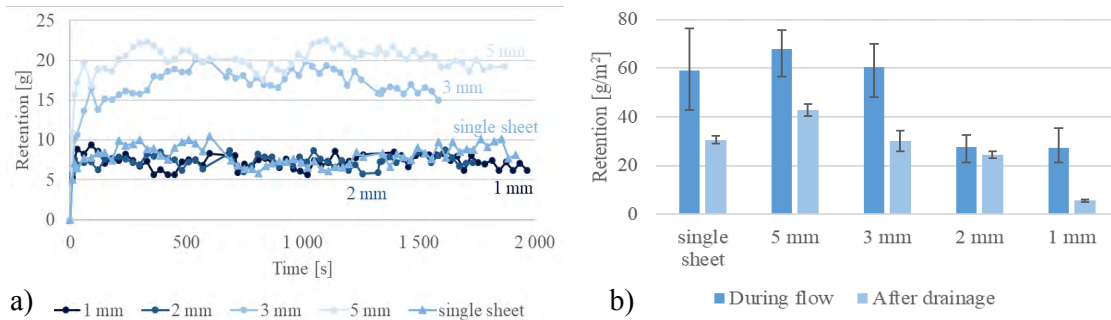


Figure 2: Drainage tests on PC a) Retention during test, b) Retention during test and after drainage has finished per m^2

These measurements show that a steady-state is achieved after less than 100 seconds for all gap widths. Small peaks are visible which represent the droplets injected to the cavity from discharge of the copper tube. For gaps of 3 and 5 mm a larger variation is visible due to a smaller relative impact of forces due to surface tension compared to gaps of 1 and 2 mm

which causes larger deviation of the flow of drops after collision with other drops along their downward path. As a result, a larger wetted area is achieved for larger gap widths, i.e. the wetted area of the test setup with a 5 mm gap is 11.51% larger compared to the 1 mm gap. Figure 2b) shows the average amount of water retained per m^2 during the test including droplets adhered to the plate and drops flowing downwards. The error bars represent the minimum and maximum values. Additionally shown in Figure 2b) is the amount of water retained per m^2 after drainage has finished, i.e. the number of water droplets adhered to the PC plates. The latter was based on pictures captured after the test, assuming that the volume of the trace droplet is half a sphere (Blocken and Carmeliet, 2006). The amount of trace droplets and the average base area was measured at different locations of the test setup as it was observed that values at the top of the setup differed from values at the bottom. The error bars show the standard deviation of the retained amount of water based on three different experiments for each gap width. The graph illustrates that for an increasing gap width, an increasing amount of water was retained in the gap both during flow and after drainage. The retained volume during the test for a gap width of 2 mm was similar to the retained volume in a gap of 1 mm. However, it should be noted that this value also includes the capillary retained portion at the bottom of the test setup which was significantly larger for the 1 mm gap (3.3 g) compared to the 2 mm gap (< 1 g). The increasing amount of retained water for an increasing gap width was mainly due to an increasing amount of drops per m^2 . The average drop base area ranged from $1.155 \pm 0.045 \text{ mm}^2$ for a 2 mm gap to $1.300 \pm 0.108 \text{ mm}^2$ for a 5 mm gap. Only the average base area of the trace droplets of the 1 mm gap was significantly smaller, i.e. $0.563 \pm 0.044 \text{ mm}^2$. The vertical spacing between the drops ranged from 3 – 5 mm. It was visually observed that most of the drops adhered only to one of the plates. Only some drops were retained between both plates for the 1 mm gap.

The same measurements were conducted for test setups with a 2 mm gap and a sheathing membrane adhered to the back plate of the setup thus permitting evaluating the importance of membrane contact angle and surface roughness on retained water.

Table 1. Contact angles distilled water on sheathing membranes

No. Sample	Description	$\theta_{C, \text{static}}$	$\theta_{C, \text{advancing}}$	$\theta_{C, \text{receding}}$
0	Polycarbonate	79.1 ± 1.5	83.3 ± 1.5	48.7 ± 1.5
1	Cross-woven polyolefin wrap	77.7 ± 5.8	85.1 ± 4.0	50.8 ± 4.7
2	Spun-bonded polyethylene, grooved	84.2 ± 4.0	88.4 ± 1.8	57.3 ± 3.6
3	Spun-bonded polyethylene, continuous	90.4 ± 2.1	96.5 ± 3.3	73.1 ± 2.7
4	Asphalt saturated Kraft building paper	105.4 ± 6.4	111.3 ± 2.1	74.9 ± 2.1

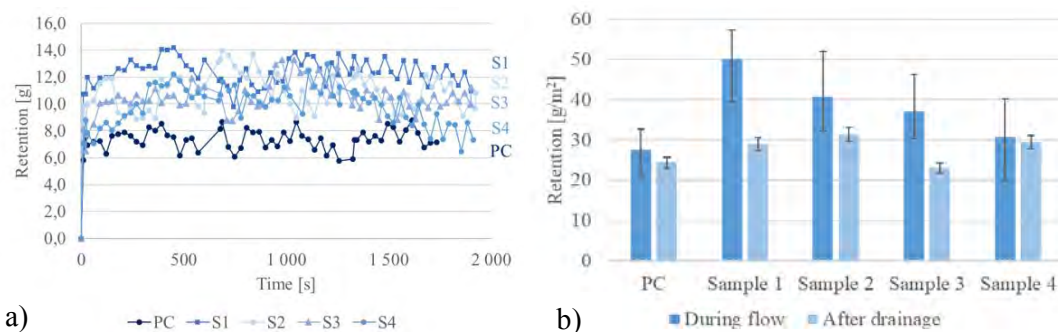


Figure 3: Drainage tests on sheathing membranes a) Water retained during test, b) Water retained during test and after drainage had finished per m^2

Figure 3a) shows the retained amount of water in the cavity as a function of time for the different sheathing membranes tested. For all sheathing membranes a steady-state is reached as for the PC plates with small peaks. However, a larger variation about the average value is apparent due to the surface roughness which causes deviation of the flow of drops and a difference in wetted area (woven pattern of sample 1, grooves of sample 2, ink on sample 3, bulging of sample 4). Sample 4 shows the largest wetted area (0.323 m^2) with an increase of 12.5% compared to the setup with two PC plates. The building paper, due to water absorption, bulges that in turn causes locally reduced thickness of the gap width. As a result, drops will not flow in a straight downward path but will follow the path of smallest resistance in between the bulged areas. Sample 1 on the other hand shows the smallest wetted area (0.248 m^2) which is 7.8% smaller than the wetted area of the PC. Due to the vertical threads of the sheathing membrane, the deviation of drops from their downward path is significantly less compared to drops flowing down, e.g. over sample 4 that were affected by the bulged areas on their way down. By comparing the average retention during the test for the different sheathing membranes (Figure 3b), it can be stated that the quantity of retained water decreased for increasing contact angle. The error bars of the measurements during flow represent the minimum and maximum values. After drainage had finished this trend was less apparent. The largest amount of retained water was measured for sample 2 and 4. The surface of sample 2 contained grooves resulting in locally reduced thickness of the gap width ($< 1 \text{ mm}$) which caused capillary retention at the top portion of the grooves. Locally reduced gap width is also observed for sample 4 due to bulging of the building paper resulting in a larger amount of retention. The larger contact angle of sample 3 ($\theta_{C, \text{static}} 90.4 \pm 2.1$) compared to polycarbonate ($\theta_{C, \text{static}} 79.1 \pm 1.5$), results in a smaller drop base area as well as fewer drops per mm^2 . In contrast, sample 1 had a contact angle similar to polycarbonate but the number of drops per mm^2 was larger. This is also apparent when the vertical spacing between the drops is compared (PC: $4.27 \pm 0.29 \text{ mm}$; S1: $3.41 \pm 0.32 \text{ mm}$). This is caused by the woven pattern of the sheathing membrane resulting in trace droplets every other thread.

DISCUSSIONS AND CONCLUSIONS

Drainage tests performed on two polycarbonate plates with different gap widths, showed that smaller quantities of water are retained in the cavity for gap widths of 2 mm and 1 mm compared to the retained quantity on a single sheet or in a gap of 3 and 5 mm. This confirms the results found by Straube and Smegal (2007) who stated that a drainage gap of 1 mm between two acrylic sheets stored less water than a single acrylic sheet. Further analysis should reveal whether this can also be stated for gaps smaller than 1 mm as more water drops will presumably be retained between both plates as a result of larger quantities of capillary retained water. The average base area and consequently the trace drop diameter differed over the area of the setup. This is in contrast with the observations of Blocken and Carmeliet (2006) who stated that the base diameter was fixed. This is probably due to a different method of adding water to the test setup, i.e. spraying of water onto the vertical sheet or water drops flowing downwards only from the top of the setup. De Vogelaere and Pacco (2012) developed a numerical model at Ghent University to simulate runoff patterns on building facades. By use of a micro model, a simulation was conducted of the cumulated runoff volume on a PMMA surface over time. The shape of the resulting graph is very similar to the graphs obtained from the experiments in this paper including a steady-state with small peaks achieved after less than 100 seconds. Further analysis should be carried out to confirm the results of the simulation model.

Drainage test were also performed for different sheathing membranes. These tests showed that the quantity of water in the gap between the polycarbonate plate and the sheathing membrane

during water flow depends on the contact angle of the sheathing membrane. After drainage has finished, this is however less apparent. As stated by Blocken and Carmeliet (2006) not all retained water is present in the gap as single drops, but also some portion is retained in between the PC plate and the membrane due to locally reduced thickness of the gap. Future research should include a broader range of contact angles and smooth surfaces as it was observed that the presence of grooves and threads affects the quantity of retained water and the size of the wetted area.

Overall, measurements showed that less than 0.5 % of water added over the course of the test (+/- 4.8 l) was retained in between the plates or on a single sheet both during water flow and after drainage has finished. Future research will focus on the development of a drainage model to predict the drainage capacity required for a drainage gap in function of the applied materials and gap width necessary to prevent the build-up of hydrostatic pressure which may cause water to penetrate further into the wall assembly.

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