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The Effects of Cyclic Wind-Driven Rain Events on the Brick Masonry Veneers

Mohsen Khanverdi[i] and Sreekanta Das[ii]

ABSTRACT

Masonry is a widely used construction method globally, with building facades being particularly vulnerable to wind-driven rain that combines rainwater and wind pressure. Driving rain is the primary moisture source in buildings, leading to significant damage such as moisture transfer, mold growth, discoloration, erosion, and structural degradation. The effects of driving rain are intensified by climate change, highlighting the need for realistic evaluations under various climatic conditions. Existing studies have explored masonry wall behavior under wind-driven rain, focusing on material properties, rain load, and air pressure effects. There is a gap in the literature regarding the behavior of masonry veneers under cyclic wind-driven rain conditions with varying drying time intervals. This study addresses this gap by experimentally investigating water penetration in large-scale masonry veneers constructed with clay bricks and mortar. The research evaluates the impact of wetting-drying cycles on the performance of these veneers. The findings reveal that total water leakage under cyclic wind-driven rain conditions can increase by more than 85% compared to the reference test. This significant increase highlights the need to account for frequent rain exposure in the design of masonry members, rather than relying on designs intended only for occasional rain events.

KEYWORDS

clay brick, experimental study, masonry veneers, water penetration, wind-driven rain

[i] PhD Student, University of Windsor, Windsor, Canada, khanver@uwindsor.ca
[ii] Professor, University of Windsor, Windsor, Canada, sdas@uwindsor.ca

INTRODUCTION

Masonry construction remains one of the most widely adopted building methods globally. Among the key environmental challenges affecting building envelopes is Wind-Driven Rain (WDR), a phenomenon arising from the simultaneous interaction of rainfall and wind pressure on structural components. The detrimental effects of WDR on building envelopes include impaired hygrothermal performance and compromised durability [1], ultimately influencing indoor air quality, increasing energy demands, promoting mold growth [2], and freeze-thaw damage [3]. Over time, these impacts can lead to deterioration of mechanical properties and even failure of masonry units [4].

A study by Kahangi Shahreza et al. [5] examined the influence of water absorption properties in bricks and different mortar joint profiles on masonry performance. The findings of this study indicated that while brick absorption coefficients played a significant role in water penetration under zero differential air pressure, mortar joint profiles were less critical. In subsequent research, Kahangi Shahreza et al. [6] demonstrated that water penetration primarily occurred once bricks reached 90% saturation under similar conditions. However, these studies did not account for wind effects, which are crucial for realistic evaluations. In a study conducted by Ghanate et al. [7], the study observed a link between brick absorption rates and water ingress in masonry walls.

The wetting-drying behavior of masonry walls is particularly relevant in regions prone to heavy rainfall. However, limited research has investigated the effects of cyclic WDR on masonry. In a study conducted by Calle et al. [8], the study analyzed water permeability in brick walls subjected to cyclic air pressures of up to 600 Pa. The findings of the study suggested that infiltration rates under cyclic pressure were lower compared to static conditions. However, the study did not evaluate the effects of varying time intervals between WDR cycles. Zhu et al. [9] examined the performance of masonry walls treated with surface treatment under cyclic WDR. While results showed that drying intervals of up to 14 hours did not significantly affect relative humidity levels in mortar and bricks, the study did not address leakage rates in walls. Moreover, the behavior of masonry walls under cyclic WDR with time intervals beyond 14 hours were not considered.

Despite extensive research on WDR, there remains a notable gap in understanding the performance of masonry veneers under wetting-drying cycles, particularly those made from clay bricks. This study aims to bridge this gap by evaluating the behavior of clay brick masonry veneers subjected to cyclic WDR with a drying time interval between 2 to 48 hours following the general guidelines of ASTM E514/E514M-2020 [10].

TEST METHODOLOGY

Preparation of Test Specimens

The specimens were constructed with dimensions of 1700 mm in height and 1700 mm in length. They were made using 75 mm thick clay bricks with a 25% void ratio. Each brick measured 255 mm in length, 75 mm in thickness, and 77 mm in height. The Canadian standard CSA A82 [11] was followed to measure the initial rate of absorption for the brick. Additionally, according to ASTM C1794 [12], the water absorption coefficients for both the brick and mortar were evaluated, with the results detailed in Table 1. The mortar used for the specimens was Type N cement mortar according to Canadian standard CSA A179-14 [13], which had an average compressive strength of 16.5 MPa. All mortar joints employed in the veneers were concave.

Table 1: Material Properties

Material Type	Initial rate of absorption, g / (min. 20000 mm^2)	Water absorption coefficient, kg/ $m^2.s^{0.5}$
Brick (75 mm thick)	23.5	0.024
Mortar		0.016

Each veneer specimen, measuring 1700 mm by 1700 mm, was constructed by a certified mason under controlled laboratory conditions. One veneer was built for each type of brick to ensure consistent evaluation. Following construction, the specimens were covered with plastic sheeting for a curing period of seven days to retain moisture. After this initial curing, they were left exposed for an additional three weeks to complete the drying process.

Two rows of water collection troughs (flashings) were installed on each veneer to assess water penetration. These collectors were positioned to capture water infiltrating from the pressure chamber through the veneers (as shown in Figure 1a). The upper collection trough was mounted at a height of 360 mm from the base of the veneer to gather surface water runoff. Meanwhile, the lower flashing was installed 180 mm above the bottom of the veneer and extended entirely through the wall. The lower flashing was installed to collect water that had infiltrated inside the veneer structure.

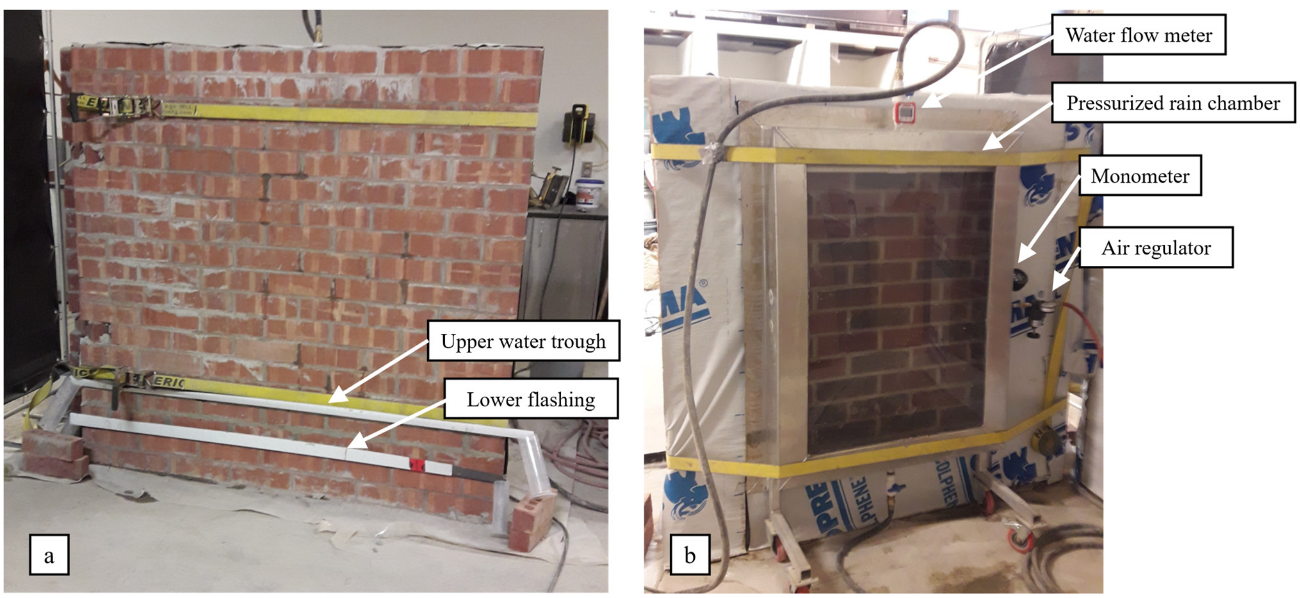

Figure 1: (a) Upper Water Trough and Lower Flashing Installation on Brick Veneer, and (b) Rain Chamber Setup

Test Procedure

The procedure outlined in the ASTM E514/514M [10] for evaluating water penetration and leakage through masonry was employed to assess wind-driven water infiltration through veneers. A testing chamber with internal dimensions of 900 mm in width and 1200 mm in height was constructed. The chamber edges in contact with the specimen were lined with a compressible gasket, ensuring an airtight seal during testing. Simulating rainfall conditions, a spray pipe connected to a water supply regulator and gauge was installed at the top of the chamber according to ASTM standard. A drainage outlet was positioned at the base of the chamber, preventing water accumulation. Pressurized air from a laboratory air supply system was used to provide the required air pressure inside the chamber. An air regulator and a manometer were incorporated, maintaining the pressure at the desired level of 500 Pa as per ASTM recommendation. Figure 1b illustrates the various components of the testing chamber utilized in this research. Water collected from the upper water trough and lower flashing was recorded at 15-minute intervals using a series of graduated cylinders. Figure 1a shows a specimen undergoing testing.

Five WDR tests were conducted to investigate how varying time intervals between simulated rainfall events influence brick veneers. The first test, designated as the reference, was performed on a dried wall. Subsequent tests were conducted after intervals of 2, 12, 24, and 48 hours. The term "time interval" is defined as the duration between the conclusion of one test and the initiation of the next. Details of the test specifications for this phase are provided in Table 2. In the table, each test is identified by a name starting with "CycT" for cyclic testing, followed by a number indicating the time interval in hours between consecutive tests. The first test in the sequence, identified as the reference test, is labeled as "CycTR" in Table 2.

Table 2: Cyclic WDR Tests Specifications

Test name	Drying time, hr	Water flow rate, l/min	Chamber air pressure, Pa
CycTR	0	2.5	500
CycT2	2	2.5	500
CycT12	12	2.5	500
CycT24	24	2.5	500
CycT48	48	2.5	500

Results and Discussion

The results of the cyclic WDR tests on the 75 mm wall are summarized in Table 3. This table shows the amounts of water leakage collected from the upper water trough (L_1), lower flashing (L_2), and the total leakage (L_{sum}). The trends of these parameters are also compared in Figure 3.

Table 3: Leakage Results During Cyclic Test

Test name	Surface leakage (L_1), ml	Through leakage (L_2), ml	Total Leakage (L_{sum}), ml
CycTR	3410	1650	5060
CycT2	3705	1930	5635
CycT12	5440	2455	7895
CycT24	6695	2830	9525
CycT48	4870	2225	7095

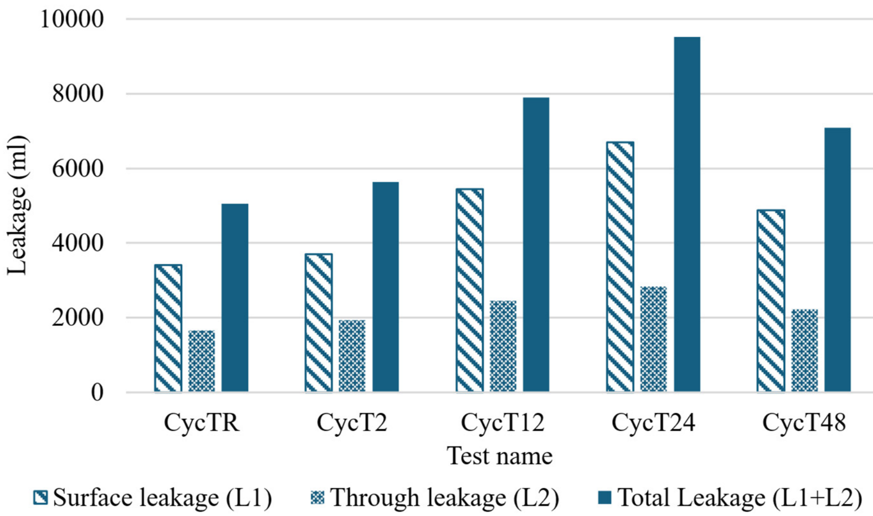

Figure 3: Comparison of Leakage Amounts Across Different Drying Time Intervals

Table 3 shows that the total leakage (L_{sum}) increased from 5,060 ml during the reference test (Test CycTR) to 5,635 ml in a test performed two hours later (Test CycT2). The third test (Test CycT3), conducted after a 12-hour interval, showed a larger increase to 7,895 ml. After a 24-hour interval, the fourth test (Test CycT24) recorded 9,525 ml of total leakage. This increase in leakage for tests conducted with shorter intervals can be explained by the cumulative effects of water on the veneer specimen. When intervals are shorter, the wall materials absorb more moisture, preventing the specimen from fully recovering its water-resistant properties. Test CycT48 illustrated a decrease in leakage. This observation indicates that a 75 mm thick brick veneer assembly requires a drying period exceeding 24 hours to minimize cumulative water leakage under cyclic wetting-drying conditions.

The results presented in Figure 3 suggest that masonry veneer exposed to cyclic wind-driven rain with little drying time in between are likely to see increased water leakage over time. In the fourth test (CycT24), the total leakage increased by more than 85% compared to the reference test. This observation indicates that the ability of the veneer to resist water leakage depends on how often it is exposed to water. These findings suggest that masonry members like veneers designed to handle occasional water exposure may not perform well under continuous or frequent exposure to WDR. This highlights the need to design veneers that can endure both short and long gaps between rain events to maintain durability and functionality.

The data in Figure 3 also show that surface water leakage accounts for about two-thirds of the total leakage, regardless of the time intervals between tests. This consistent ratio indicates that surface leakage is a major contributor to total leakage for 75 mm thick brick, suggesting that veneers remain vulnerable to surface water penetration despite changes in time intervals. The persistent contribution of surface leakage, as shown by this ratio, highlights the importance of addressing surface water penetration in wall design and maintenance to improve overall performance.

Summary and Conclusions

This study investigated the water leakage behavior of 75 mm thick masonry veneer assemblies subjected to cyclic wind-driven rain (WDR) tests under varying drying intervals. The key findings of this study include:

- Total water leakage increased after a series of cyclic wetting-drying WDR tests. The total leakage rose by more than 85% after the fourth test with a 24-hour interval compared to the initial test on a dry wall, highlighting the cumulative effects of moisture retention in the veneer materials.
- Results suggest that a minimum drying period of over 24 hours is necessary to reduce water leakage in 75 mm thick veneers under cyclic wetting-drying conditions. Shorter drying intervals result in reduced recovery of water-resistant performance, increasing the vulnerability to leakage.
- Surface water leakage contributed to approximately two-thirds of the total leakage observed across all tests, regardless of the time interval between them. This emphasizes the importance of proper treatments to minimize surface leakage and reduce the overall water penetration to the other side of the veneers.

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