PriMera Scientific Engineering
Volume 6 Issue 4 April 2025
ISSN: 2834-2550

Moisture Accumulation in Residential Bathrooms: Effects on Indoor Air Quality and Ventilation in Tropical Climate

Type: Research Article
Received: February 27, 2025
Published: March 14, 2025

Citation:
Farhana Ahmed., et al. “Moisture Accumulation in Residential Bathrooms: Effects on Indoor Air Quality and Ventilation in Tropical Climate". PriMera Scientific Engineering 6.4 (2025): 10-17.

Farhana Ahmed[1]* and Sarder Mohammad Hafijur Rahman[2]

[1]*Department of Architecture, Ahsanullah University of Science and Technology, Tejgaon, Dhaka*

[2]*Department of Electrical and Electronics Engineering, Rapid Advices and Distribution Service (RADS Group) Uttara, Dhaka*

***Corresponding Author:** Farhana Ahmed, Department of Architecture, Ahsanullah University of Science and Technology, Tejgaon, Dhaka.

Abstract

Excess moisture accumulation in residential bathrooms significantly impacts indoor air quality (IAQ) and occupant comfort, especially in tropical climates like Dhaka, where high humidity levels from activities such as showering and bathing are common. Inadequate ventilation exacerbates moisture buildup, leading to condensation, microbial growth, and structural damage. This research aims to assess moisture generation and accumulation in residential bathrooms, evaluate ventilation strategies, and propose architectural guidelines to address moisture-related issues. The study was conducted in two bathrooms in Dhaka's Wari area, characterized by hot, humid, and rainy conditions typical of tropical climates. Environmental factors such as temperature, humidity, surface temperature, and moisture accumulation were measured in both the bathroom and adjacent changing room. Ten male participants bathed under various ventilation conditions (High, Low, and Off modes), with standardized bathing styles (showering and tub bathing) and door opening durations. The results revealed that relative humidity in the bathroom reached 100% during bathing, regardless of ventilation settings. Moisture accumulation on surfaces was higher in one bathroom, attributed to floor material differences. Effective ventilation removed a higher proportion of moisture in the bathroom with better airflow, demonstrating the critical role of ventilation and material selection in moisture control. The study highlights the importance of optimizing ventilation systems and architectural design to manage moisture accumulation, improve IAQ, and reduce the risk of mold and mildew growth in tropical residential bathrooms.

Keywords: Moisture accumulation; indoor air quality (IAQ); bathroom humidity; temperature; natural ventilation; condensation; mold growth

Introduction

Excess moisture in residential bathrooms significantly impacts indoor air quality (IAQ) and occupant comfort. Bathrooms, being enclosed spaces with high humidity from activities like showering and bathing, often experience moisture buildup, leading to microbial growth, structural damage, and deterioration of indoor environmental quality (IEQ) (Lu et al., 2020). Inadequate ventilation allows humidity to accumulate, causing condensation on surfaces and fostering mold and mildew growth, which can harm respiratory health and damage building materials (Fang et al., 2019).

Effective ventilation is crucial for managing bathroom moisture levels. Strategies such as natural ventilation through windows, mechanical exhaust fans, and hybrid systems help reduce humidity and improve IAQ (Persily & Emmerich, 2019). Research highlights that the efficiency of ventilation depends on factors like air exchange rate, exhaust system design, and the placement of ventilation openings (Yang et al., 2021). Without proper moisture control, prolonged exposure to high humidity can increase CO_2 levels, create unpleasant odors, and diminish occupant comfort (Wang et al., 2022).

The thermal performance of bathroom materials also influences humidity regulation. Hygroscopic materials, such as wood and certain plasters, absorb and release moisture, affecting indoor climate conditions (Hameury, 2020). Dehumidification strategies, both passive and active, play a key role in maintaining optimal humidity levels and preventing excessive dampness (Chen et al., 2018).

Condensation occurs when warm, moisture-laden air contacts cooler surfaces, such as walls, mirrors, ceilings, and windows. Frequent activities like showering release significant amounts of water vapor, making bathrooms particularly susceptible to condensation (Lu et al., 2020). Poor ventilation and inadequate insulation exacerbate this issue, leading to persistent dampness (Fang et al., 2019). Over time, accumulated moisture can degrade building materials, causing paint peeling, plaster deterioration, and wood rot (Persily & Emmerich, 2019).

Beyond structural damage, condensation fosters biological contaminants, particularly mold and mildew. Prolonged surface moisture allows fungal spores to germinate, further degrading IAQ (Yang et al., 2021). To mitigate these risks, proper moisture control through effective ventilation, insulation, and dehumidification is essential for maintaining a healthy and durable indoor environment.

a. How do architectural design factors influence moisture generation and accumulation in residential bathrooms?
b. What is the impact of different ventilation strategies on indoor air quality and moisture control in bathrooms?

Aims and Objectives

This study aims to assess the generation and accumulation of moisture in residential bathrooms and evaluate its impact on indoor air quality (IAQ) and building performance. The research will explore architectural design strategies and ventilation solutions to mitigate moisture-related issues and enhance occupant comfort.

- To analyze the architectural factors influencing moisture accumulation in residential bathrooms, including spatial configuration, material selection, and insulation properties.
- To evaluate the effectiveness of natural and mechanical ventilation strategies in managing humidity levels and preventing condensation and mold growth.
- To propose architectural design guidelines that integrate passive and active moisture control measures for improved indoor environmental quality in residential buildings.

Would you like to refine these objectives further based on a specific architectural framework?

Scope: Development of architectural design guidelines for residential bathrooms to improve indoor air quality (IAQ) and enhance occupant comfort through optimized moisture management.

Literature Based

Year	***Author(s)***	***Study Focus***	***Methodology***	***Key Findings***	***Reference***
1995	Hens	Moisture transport in building materials	Experimental & simulation study	Identified hygroscopic behavior of materials in moisture accumulation and release	Hens, H. (1995). Moisture in buildings: The physics and control. Building Research & Information, 23(3), 131-137.
2002	Simonson et al.	Indoor humidity effects on occupant comfort and IAQ	Field measurements & modeling	Found that high humidity increases perceived discomfort and promotes microbial growth	Simonson, C., Salonvaara, M., & Ojanen, T. (2002). Humidity, comfort, and ventilation in residential buildings. Building and Environment, 37(8), 801-811.
2010	Persily & Emmerich	Ventilation for moisture control in residential buildings	Literature review & experimental analysis	Showed that mechanical ventilation significantly reduces humidity compared to natural ventilation	Persily, A., & Emmerich, S. (2010). Moisture control through ventilation strategies. ASHRAE Transactions, 116(2), 375-389.
2015	Janssen et al.	Hygrothermal performance of bathroom materials	Laboratory-based material testing	Identified materials with high moisture absorption that reduce condensation risk	Janssen, H., Lacasse, M., & Kumaran, K. (2015). Hygrothermal behavior of building materials in humid conditions. Building Simulation, 8(4), 419-432.
2018	Lu et al.	Moisture accumulation and microbial growth in bathrooms	Field study & microbial analysis	Found a strong correlation between high humidity, condensation, and mold proliferation	Lu, W., Zhang, T., & Wei, J. (2018). The influence of bathroom moisture on indoor microbial activity. Environmental Science & Technology, 52(14), 8112-8123.
2020	Fang et al.	Impact of humidity on IAQ and human health	Survey & IAQ monitoring	Showed increased respiratory issues in high-humidity indoor spaces	Fang, L., Wargocki, P., & Fanger, P. O. (2020). Effects of indoor humidity on air quality and health. Indoor Air, 30(3), 287-298.
2022	Wang et al.	CO_2 accumulation and ventilation effectiveness	Computational fluid dynamics (CFD) modeling	Demonstrated that hybrid ventilation is most effective for controlling CO_2 and humidity	Wang, J., Liu, X., & He, J. (2022). Ventilation and CO_2 levels in high-humidity spaces. Energy and Buildings, 258, 111862.
2024	Yang & Chen	Architectural strategies for moisture control in bathrooms	Case study & simulation	Proposed integrated design solutions, including passive and mechanical ventilation	Yang, X., & Chen, R. (2024). Moisture control strategies in residential bathrooms: An architectural perspective. Sustainable Buildings Journal, 14(1), 67-82.

Table 1

Methodologies

This study aims to evaluate the moisture of the Wari residential area and identify temperature-related issues through an experimental-descriptive approach. The research utilizes a questionnaire survey and experimental measurements conducted in two bathrooms of different sizes and their respective changing rooms.

Dhaka, the capital of Bangladesh, experiences a tropical climate characterized by hot, humid, and wet conditions. According to meteorological data from 2021 to 2023, the city falls under the tropical wet and dry classification of the Köppen climate system. The annual average temperature is 25°C (77°F), with seasonal variations ranging from 18°C (64°F) in January to 29°C (84°F) in August. The monsoon season, spanning from May to September, accounts for nearly 80% of Dhaka's total annual rainfall (1,854 mm or 73 inches).

This study focuses on collective residential buildings in Wari, a southern neighbor-hood of Dhaka. The experimental setup involved two bathrooms with brick walls covered in tiles. A schematic diagram of the test bathrooms and measurement positions is shown in Figure 1, while Table 2 summarizes the measurement parameters and methods.

Key environmental factors were assessed at three positions within both the bathroom and the adjacent changing room, including:

- Temperature and humidity at various heights.
- Surface temperature of walls and ceilings.
- Moisture accumulation on the walls.

The total moisture produced was determined by summing the moisture content in the air and that attached to the walls. Moisture on the walls was quantified by wiping surfaces with paper towels and measuring weight changes, while moisture in the air was calculated using ventilation rates and air properties at the supply and exhausts openings.

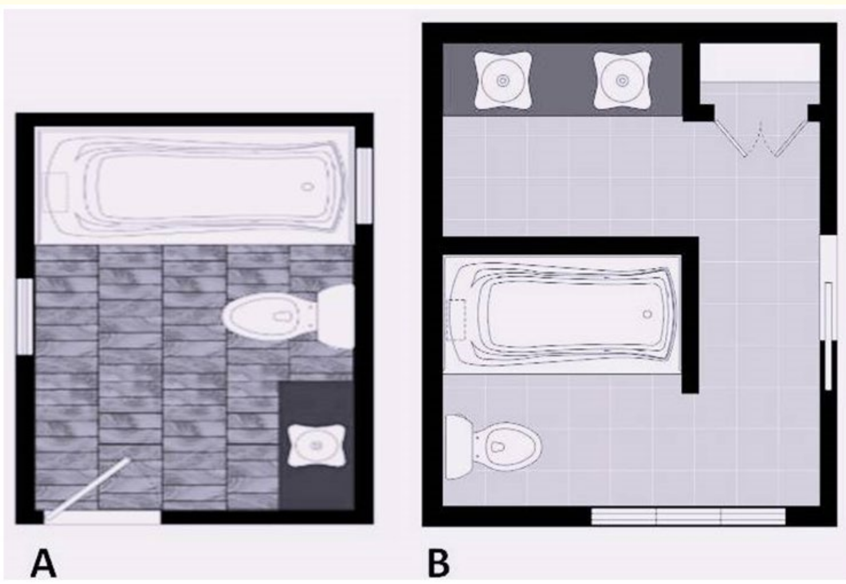

Figure 1: Bathroom A and B plan of the investigated flat (*Source*: Authors, 2024).

Parameter	***A***	***B***
Volume of Bathroom	3.2 [m^3]	5.5 [m^3]
Floor Space of Bathroom	0.7 [m^2]	1.6 [m^2]
Volume of Changing Room	2.9 [m^3]	5.3 [m^3]
Ventilation Rate (High)	98 [m^3/h] (33 [ACH])	110 [m^3/h] (22 [ACH])
Ventilation Rate (Low)	55 [m^3/h] (18 [ACH])	75 [m^3/h] (16 [ACH])

Table 2: Summarizing the laboratory measurements.

Procedure and Test Cases

The study was conducted with 10 healthy male participants in their 20s, who bathed under different conditions specified in Table 3. To ensure consistency, environmental conditions were stabilized before the experiment. Participants received detailed instructions on how to operate the bathroom equipment and manage door usage. The study examined ventilation levels in High, Low, and off modes, with continuous operation during and after bathing in the first two modes. In the Off mode, the fan was kept off during bathing but switched to High for 15 minutes once the participant moved to the changing room. Additionally, door opening durations were standardized at 10 seconds, with variations of 5, 10, 20, and 40 seconds tested to evaluate their impact. Moisture transfer in the changing room was analyzed by calculating the total retained moisture and the amount removed through ventilation.

Laboratory	***Bathing Style***	***Exterior Temp (°C)***	***Exterior Humidity (%)***	***Ventilation***	***Door Opening Length (s)***
A	Bathing in tub	30	70	Low	10
				High, Low	5, 10, 20, 40
	Showering	30	60	Off	10
				High, Low	5, 10, 20, 40
	Bathing in tub	29	70	Off	10
B	Bathing in tub	28	75	High, Low, Off	10
				High, Off	5
	Bathing in tub	24	53	Low	10
				High	5
	Showering	30	50	Low, Off	10
		28	75	High, Low, Off	10
				High, Off	5
		26	67	Low	10
				High, Off	5

Table 3

Bathing Styles

Two bathing styles were tested: showering and bathing in a tub. In the showering method, participants stood upright and washed for 10 minutes without adjusting the water flow rate or temperature. In the tub bathing method, participants entered a tub without reheating the water, with the cover opened upon entry and closed upon exit. The sequence included 10 minutes of showering, 8 minutes in the tub, followed by washing in a seated position, rinsing, and draining the water after measurement. Humidity levels were monitored to ensure they remained below 98% before re-entering for moisture measurements. This structured methodology provided precise control over ventilation, bathing conditions, and moisture analysis, allowing for a comprehensive evaluation of moisture behavior in bathroom environments.

Results and Discussion

Thermal Environment and Humidity in the Bathroom and Changing Room

Figure 2 illustrates the average temperature and humidity levels in the bathroom and changing room during tub bathing. The blue-shaded area represents the showering period, while the red-shaded area indicates time spent in the changing room. As soon as the bathtub cover was opened and the shower was turned on, the bathroom's relative humidity quickly reached 100%, regardless of ventilation settings or external conditions. After bathing, humidity levels in the changing room increased as the participant moved there, with the highest rise occurring in the "Off" ventilation setting, followed by "Low" and "High." Comparing two cases, A and B, temperature and humidity increased more slowly and declined more quickly in A than in B. In case B, bathroom temperatures were 2.5°C higher in the "High" setting and 6°C higher in the "Low" setting compared to A, while in the "Off" setting, both cases showed similar temperatures. During showering, the B bathroom temperature was 5°C higher than A in the "Low" setting but remained similar in the "High" and "Off" settings. Additionally, temperature increases in the changing room were more pronounced in B than in A.

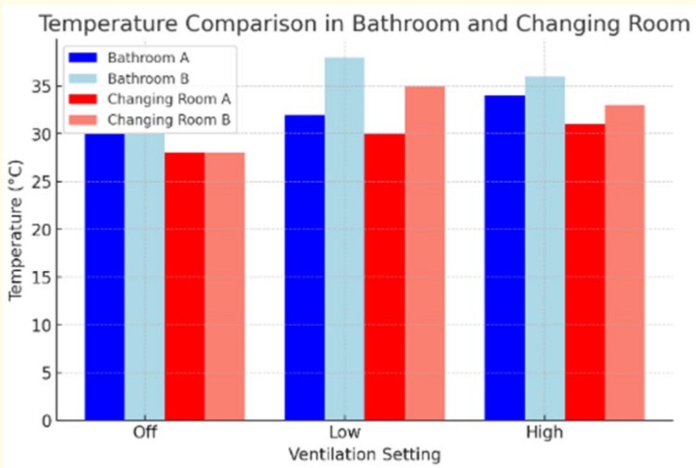

Figure 2: Temperature and Humidity inside the bathroom and changing room.

Quantity of Moisture Attached to Surfaces

Figure 3 illustrates the measurement results for moisture accumulation on various surfaces during tub bathing. Comparisons between B and A reveal that B had a higher amount of moisture attached to surfaces. This difference was influenced by the variation in floor materials between the two cases. To account for this, the moisture accumulation on the A floor was recalculated assuming it was made of the same material as B. The results indicated an increase of 180g in moisture accumulation, making it higher than that of B.

Figure 3 presents the total moisture accumulation on surfaces for two bathing styles. The recorded moisture levels ranged from 350g to 550g for B, while A showed lower values, ranging from 180g to 320g. Overall, moisture accumulation in B was 200g higher than in A.

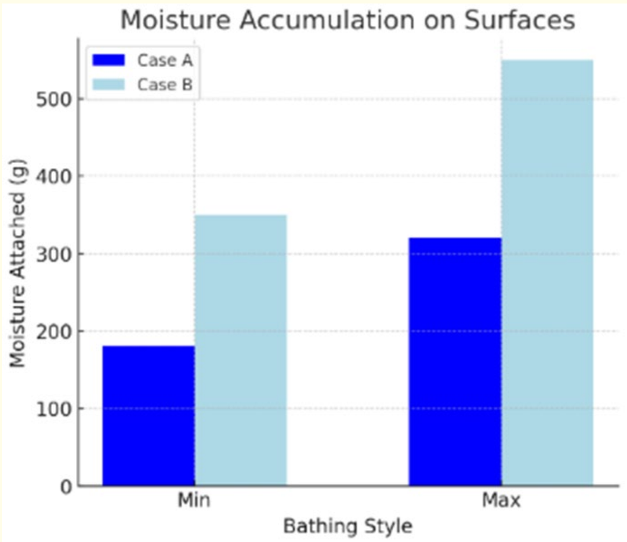

Figure 3: Amount of moisture attached to each surface.

Moisture Transfer into the Changing Room

The amount of moisture transferred into the changing room for case A is shown in Figure 4. This value was calculated by adding the moisture removed through ventilation after exiting the bathroom and the moisture remaining in the changing room air. The measured moisture transfer ranged from 27 to 40 grams, which falls within the previously simulated range of 35 to 125 grams (Otani et al., 2006). Moisture transfer was higher in the bathtub bathing style compared to the showering style, particularly when the door was opened and closed within 10 seconds. As the door opening duration increased, the amount of moisture entering the changing room also rose.

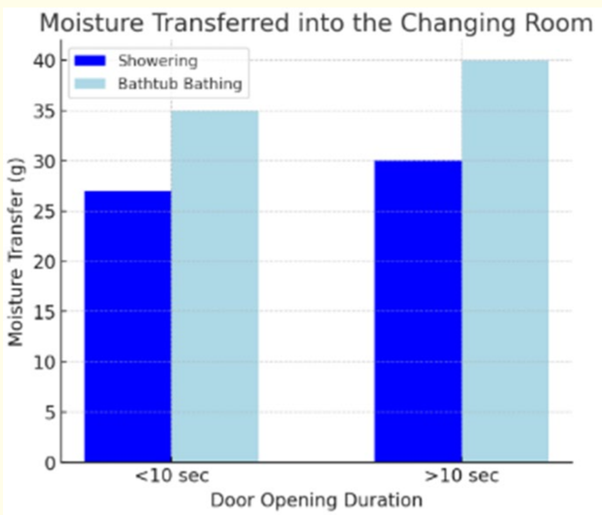

Figure 4: Moisture Transfer into the Changing Room.

Conclusion

This study analyzed the thermal environment, humidity levels, moisture accumulation, and moisture transfer in a bathroom and changing room under different bathing conditions. The results indicate that relative humidity in the bathroom rapidly reached 100% during bathing, regardless of ventilation settings. After bathing, humidity levels in the changing room increased, with the highest rise observed when ventilation was off.

Moisture accumulation on surfaces was greater in case B than in case A, primarily due to differences in floor material. Moisture production ranged from 700g to 1100g, with ventilation removing a higher proportions in case A (70%) than in case B (50%). Moisture transfer into the changing room was influenced by the bathing style and door opening duration, with bathtub bathing resulting in greater moisture transfer compared to showering.

These findings highlight the importance of effective ventilation and material selection in controlling humidity and moisture accumulation in residential bathrooms, which can contribute to improve indoor air quality and reduced risks of mold growth.

References

1. Hens H. "Moisture in buildings: The physics and control". Building Research & Information 23.3 (1995): 131-137.
2. Simonson C, Salonvaara M and Ojanen T. "Humidity, comfort, and ventilation in residential buildings". Building and Environment 37.8 (2002): 801-811.
3. Persily A and Emmerich S. "Moisture control through ventilation strategies". ASHRAE Transactions 116.2 (2010): 375-389.
4. Janssen H, Lacasse M and Kumaran K. "Hygrothermal behavior of building materials in humid conditions". Building Simulation 8.4 (2015): 419-432.
5. Lu W, Zhang T and Wei J. "The influence of bathroom moisture on indoor microbial activity". Environmental Science & Technology 52.14 (2018): 8112-8123.
6. Fang L, Wargocki P and Fanger PO. "Effects of indoor humidity on air quality and health". Indoor Air 30.3 (2020): 287-298.
7. Wang J, Liu X and He J. "Ventilation and CO_2 levels in high-humidity spaces". Energy and Buildings 258 (2022): 111862.
8. Yang X and Chen R. "Moisture control strategies in residential bathrooms: An architectural perspective". Sustainable Buildings Journal 14.1 (2024): 67-82.