Building and Construction Authority

SINGAPORE INSTITUTE OF ARCHITECTS

GOOD PRACTICE GUIDE

FOR WIND-DRIVEN RAIN IN HIGH-RISE RESIDENTIAL DEVELOPMENTS

VERSION 1.0 [MAR 2025]

The “Good Practice Guide for Wind-driven Rain in High-rise Residential Developments” provides information on building design for wind-driven rain.

The information in this guide is derived from a joint taskforce led by Building and Construction Authority (BCA) and Singapore Institute of Architects (SIA), along with Housing & Development Board (HDB), Singapore Civil Defence Force (SCDF), Urban Redevelopment Authority (URA), Association of Consulting Engineers Singapore (ACES) and Real Estate Developers' Association of Singapore (REDAS).

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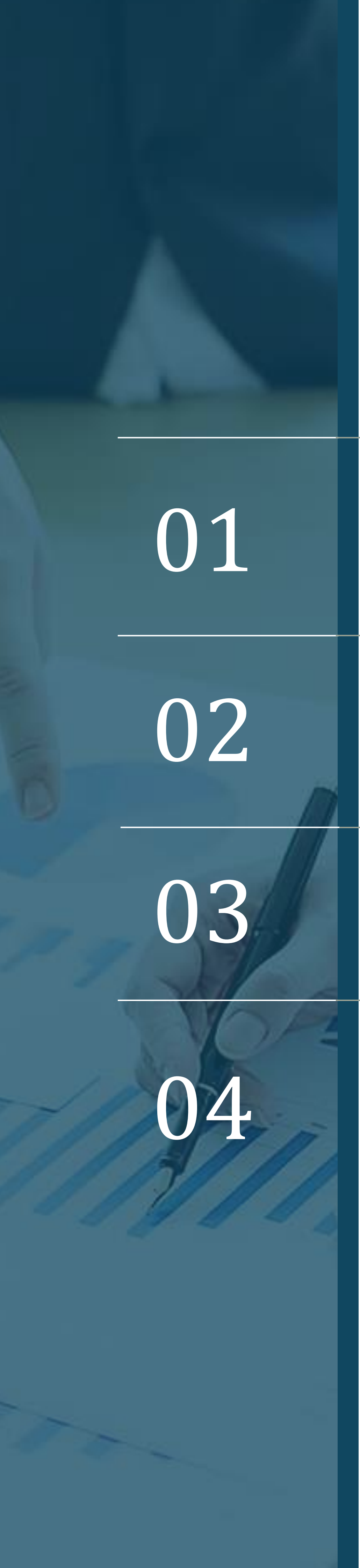

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ACKNOWLEDGEMENT

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We wish to thank all members of the taskforce for their valuable contributions.

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01

INTRODUCTION

CHAPTER 01

INTRODUCTION

1.1 PURPOSE OF THIS GUIDE

The Good Practice Guide for Wind-driven Rain in High-rise Residential Developments is primarily for building designers, but will be of interest to building developers, builders and other stakeholders involved in the design decision making process.

While building designers are to ensure that their designs comply with building regulations, the information in this Guide also seeks to provide more perspective to wind-driven rain in high-rise residential developments with a set of practicable passive design strategies to minimise its impact on residential developments.

The considerations should be made early in the upfront planning and design stages to minimise the need for ad-hoc downstream reactive interventions that could instead be more costly and ineffective.

It should be noted that the recommendations in this Guide seek to minimise rather than fully eliminate the effects of wind-driven rain, which is inherent in high-rise living. Readers should apply the relevant strategies and calibrate its implementation to meet the needs of each unique site context. Actual design outcomes are dependent on, and not limited to factors such as site-specific conditions, project requirements, safety, security, sustainability and regulations by competent authorities.

1.2 TROPICAL LIVING, CLIMATE CHANGE AND WIND-DRIVEN RAIN IN SINGAPORE

Our local climate is warm, humid, and experiences the seasons of Northeast monsoon (December to March) and Southwest monsoon (June to September).

Singapore's weather is typically classified into 4 periods according to average prevailing wind directions:

a) Northeast monsoon season (December to early March)
b) Inter-monsoon Period (late March to May)
c) Southwest monsoon season (June to September)
d) Inter-monsoon Period (October to November)

On a day-to-day basis, the patterns may have large deviations from the average rain and windfall behaviour. Singapore is also beginning to experience the effects of climate change with erratic and sudden changes in weather condition, from higher surface air temperatures to increased occurrences of lightning and intense rainfall.

When coupled with strong winds, wind-driven rain can become a common occurrence. For high-rise living where natural ventilation is a predominant means of providing fresh air, common spaces are consequently susceptible to ingress of wind-driven rain.

Notwithstanding the adoption of design strategies to mitigate wind-driven rain, homeowners and MCSTs continue to play important roles in regular maintenance and housekeeping of the property, facilities and estates.

1.3 IMPACT OF WIND-DRIVEN RAIN

In high-rise residential developments, good wind flow is an indication of well-ventilated spaces. While residents enjoy the benefits of breezy indoor living and common spaces, it is important to understand that ingress of wind-driven rain is a natural by-product. Generally, the stronger the wind flow, the greater the volume and deeper the penetration of water ingress is to be expected.

Notwithstanding the above, extreme wind-driven rain occurrences has resulted in unintended impact to buildings in aspects not limited to the following:

- ponding in corridors;
- inadequate rainwater discharge through drainage system;
- slippery wet floor surfaces;
- rainwater seepage into lift shafts;
- deterioration of entrance door surface material;
- malfunctioning entrance lockset mechanism; and
- rainwater seepage into units.

Figure 1: Examples of deterioration to door material and ponding along the corridor

The following chapters provide considerations to be taken note of in the design of naturally ventilated spaces that may help reduce and mitigate the extent of wind-driven rain impact.

02

BUILDING DESIGN

CHAPTER 02

BUILDING DESIGN

2.1 ACCEPTANCE CRITERIA

While rainwater ingress from wind-driven rain cannot be completely avoided, it is important to ensure wind-driven rain does not disrupt users' access into their residential units or penetrate spaces within the residential unit.

The following is a recommended set of acceptance criteria during wet weather to demonstrate what should be expected in safeguarding usability of spaces in residential developments. Users are also expected to have taken reasonable measures to keep the spaces shielded from rain e.g. closed windows.

Type of space	**Acceptance criteria**	**Considerations**
Common areas E.g. Sky gardens	Splashing of rain	Amenities generally for non-wet weather activities
Corridor spaces	Some splashing of rain, water flowing in right direction towards outlet	Transient zone between units and vertical circulation towards other amenities
Lift entrance	No direct splashing of rain	To minimise residents' exposure to rain when entering and exiting the lift
Unit entrance	No direct splashing of rain, some wetness, no ponding	Ensure residents can manoeuvre, unlock their doors and access their units with minimal disruption
Unit living spaces	No wetness	Not to disrupt daily living
Unit balconies	Some splashing of rain	Naturally ventilated semi-outdoor transition zone between internal unit living space and outdoors

2.2 DESIGN REQUIREMENTS

Building designers take on the task of planning, designing, and supervising the works while executing their statutory responsibilities. Below is a brief overview of the main regulatory parameters influencing design of residential developments, especially its naturally ventilated common areas.

2.2.1 PLANNING AND LAYOUT

Project teams should adopt a balanced approach between the designing of a meaningful building layout that mitigates the effects of wind-driven rain and the developer's desire to optimise efficiency of floor area. This is because as the development progresses into more advanced stages, building designers often encounter difficulties in making ad-hoc design adjustments at the downstream stage.

Hence, stakeholders in the project teams should at the upfront stage, design the building layout taking into consideration and responding to the development's unique site conditions, especially for areas vulnerable to wind-driven rain impact.

To safeguard inclusivity and liveability in residential developments, there are also spatial requirements that apply to common spaces such as corridors, as stipulated in the Code on Accessibility in the Built Environment. The key requirements include:

- At least 1500mm clear width for accessible route;
- No more than 50mm level difference between the unit entrance and the level abutting the common area; and
- Minimum manoeuvring space of 300mm adjacent to the leading edge of the door at the unit entrance.

These requirements are imperative to ensure that users, including elderly and persons with disabilities can access their homes easily and safely and that any retrofitting if required, is made feasible and less challenging.

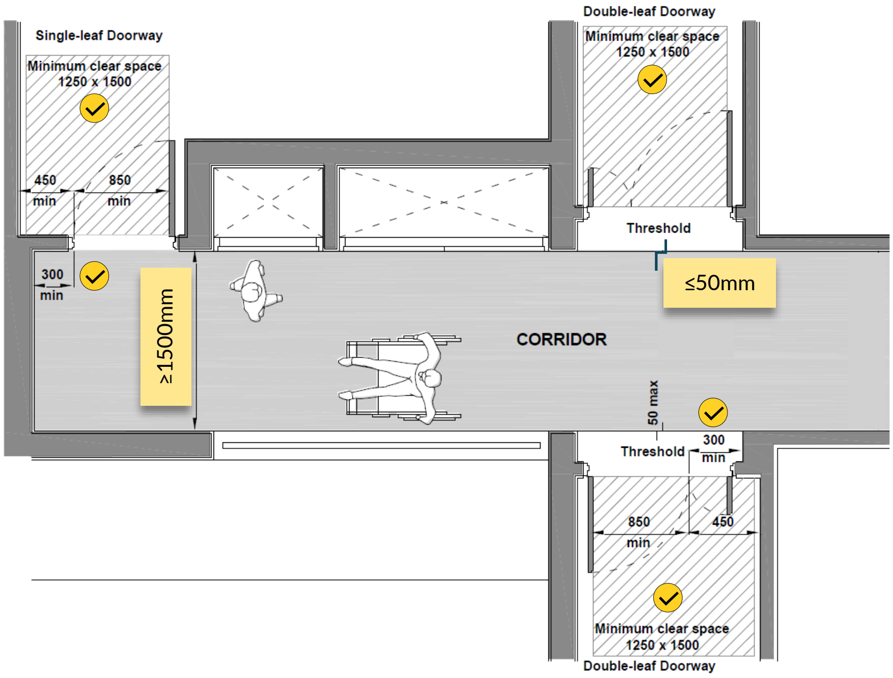


Figure 2: BCA Code on Accessibility Requirements for Residential Common Corridors

2.2.2 VENTILATION

The provision of natural ventilation in residential developments is a fail-safe means of providing fresh air to occupants, as compared to relying on mechanical ventilation systems. It also helps to promote the conservation of energy by eliminating the need for active mechanical ventilation systems.

Under the Building Control Regulations, ventilation requirements that apply to residential developments include:

- Provision of natural ventilation by means of openings with an aggregate area of not less than 5% of the space to be ventilated;
- No part of the space designed for natural ventilation shall be located more than 12m from any opening that is used to ventilate the space;

Building designers may also utilise Computational Fluid Dynamics (CFD) simulations and other alternative solutions to ensure that the prescribed objectives and performance requirements for ventilation are complied with.

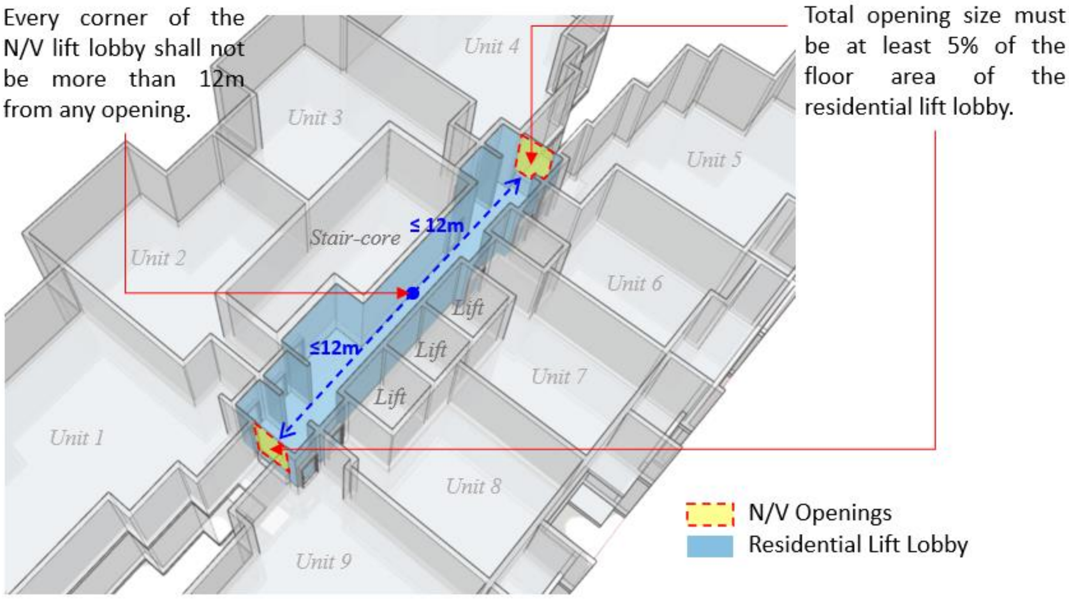


Figure 3: Provision of Natural Ventilation for Residential Lift Lobby

In terms of fire safety, ventilation openings are essential to facilitate smoke dispersal, reduce the likelihood of the corridor being smoke logged, as well as minimise smoke entry into the exit staircase when used by evacuees and emergency responders during fire emergencies.

Depending on the building height and layout, the development shall comply with the requirements stipulated in the Code of Practice for Fire Precautions in Buildings.

2.3 SITE AND FORM

In the early stages of project development, it is imperative for designers and the project team to understand the site conditions to better design against vulnerabilities.

There have been many recorded severe wind-driven rain incidents in high-rise residential developments across the island since 2017. The frequency of incidents has increased over the years.

A study was done to identify recurring similarities across majority of the recorded cases to establish probable site conditions that are conducive for high wind velocity in the development's micro-climate and consequently at higher risk to severe wind-driven rain occurrences.

Designers should assess if the proposed development possess the following pre-conditions and should consider running wind-driven rain simulations to evaluate the severity and required mitigating measures.

2.3.1 MICRO-CLIMATE

➜ <u>**Site location and context**</u> **–** Based on the incidents recorded, non-landed residential developments can experience high velocity horizontal trajectory of wind-driven rain droplets into façade openings with the following conditions:

- adjacent open spaces such as open fields;
- adjacent water bodies; and
- low-lying surrounding developments

Figure 4: Diagrammatic study of typical site conditions leading to wind-driven rain

- **Topography and building height** – With reference to wind velocity profile, buildings located on higher topography and higher levels of the block generally experience higher wind velocities. Moreover, due to the surface roughness caused by uneven terrain and adjacent low-lying buildings, the disruption to wind profile can cause turbulence at the ground level. For residential developments that adopt a slab block profile, this means ingress of wind-driven rain can affect lower levels, while topmost levels are most susceptible to severe penetration of wind-driven rain.

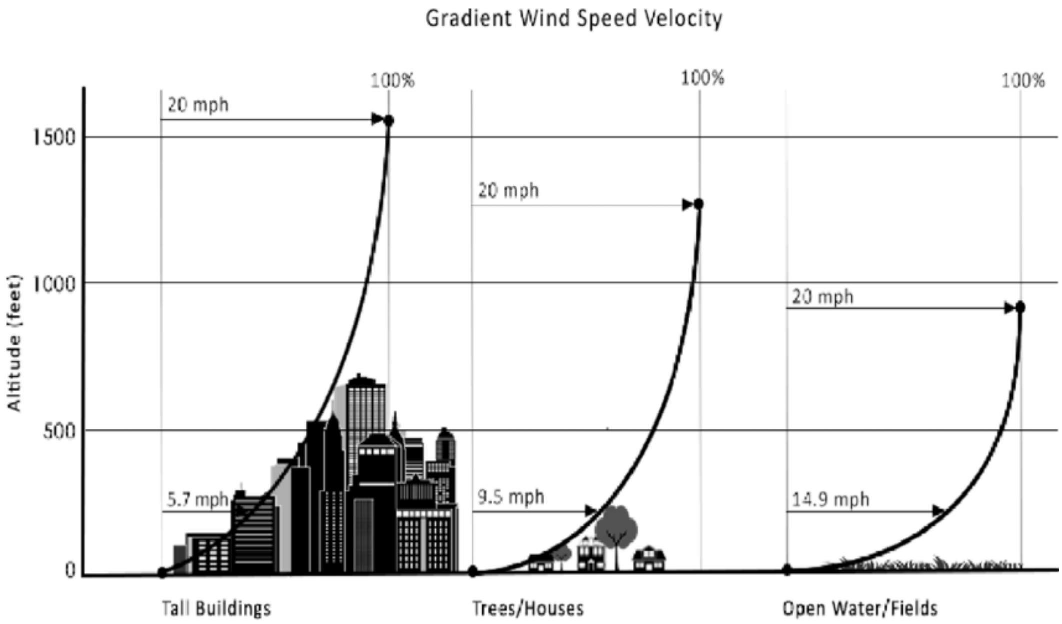


Figure 5: Variation of mean wind velocity profile with surface roughness
(Extracted from Research Gate - Gherbi, Aboubakar & Belgasmia, Mourad. (2018)

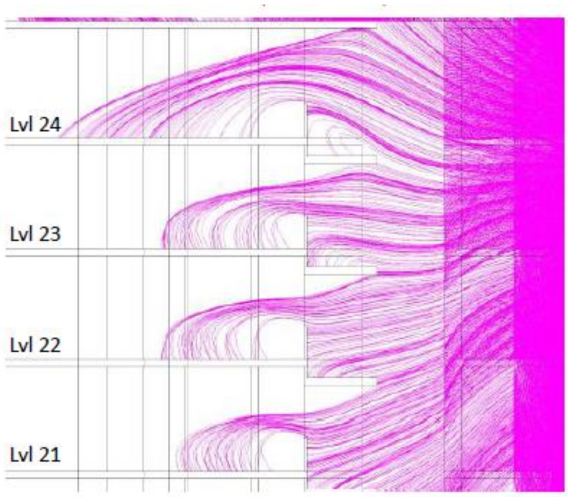


Figure 6: Wind-driven rain simulation showing more severe rainwater penetration at higher levels

- **<u>Wind tunnel effect</u>** –While it is common for residential buildings to orientate buildings to optimise wind-flow and avoid thermal transmission into living spaces, care should also be taken where the openings of linear cross-ventilated corridors front oncoming wind. This is likely to result in wind-tunnelling effect, where high wind speed will exacerbate the penetration of rainwater ingress through the length of the corridor. The intensity of wind-driven rain is expected to be greater for units located nearer to the openings.

2.4 BUILDING DESIGN CONSIDERATIONS

The following describes design considerations mitigating rainwater ingress at areas prone to wind-driven rain. Building designers should be discerning in the adoption of such strategies to strike an appropriate balance between mitigating water ingress and achieving the design intent.

2.4.1 VENTILATION OPENINGS

Ventilation openings are designed to meet an aggregate area of opening sufficient to meet daylight, natural ventilation and fire safety requirements. Corridors designed to be compact and linear with cross-ventilation are conducive for wind tunnel effect that drives deeper penetration of wind-driven rain.

As a first line of defence, the ventilation façade openings should be designed to mitigate direct exposure to wind-driven rain. For example, solid barriers such as parapet walls would <u>better shield the direct trajectory of wind-driven rain</u> at façade openings, as compared to more porous railings or perforated panels.

Figure 7: Railing as safety barriers resulting in extensive wind-driven rain into corridor

Designers should plan for a configuration with an aggregate area of façade opening beyond minimum requirement to allow for the inclusion of features such as perforated panels or louvers where necessary.

Types of façade treatment:

- Vertical louvres/fins
- Horizontal overhangs/fins
- Perforated screen

Generally, due to the horizontal trajectory of raindrops from wind-driven rain, vertical elements such as vertical louvers/ fins and perforated screen perform better at mitigating wind-driven rain compared to horizontal elements, which are more effective in reducing upward trajectory of wind-driven rain.

Designers may consider adopting a hybrid of both horizontal and vertical façade elements, optimising horizontal overhang as well as vertical drop-down panels/fins, subject to compliance with the ventilation requirements in the Fire Code e.g. for a cross-ventilated corridor situation, no part of the corridor shall be at a distance of more than 12m from the outermost edge of any overhang above ventilation openings and the vertical drop down panels shall not reduce the ventilation openings below the required size.

In instances where the above cannot be complied with, performance-based studies and other Computational Fluid Dynamics (CFD) simulations can be carried out to address adequacy of the ventilation design.

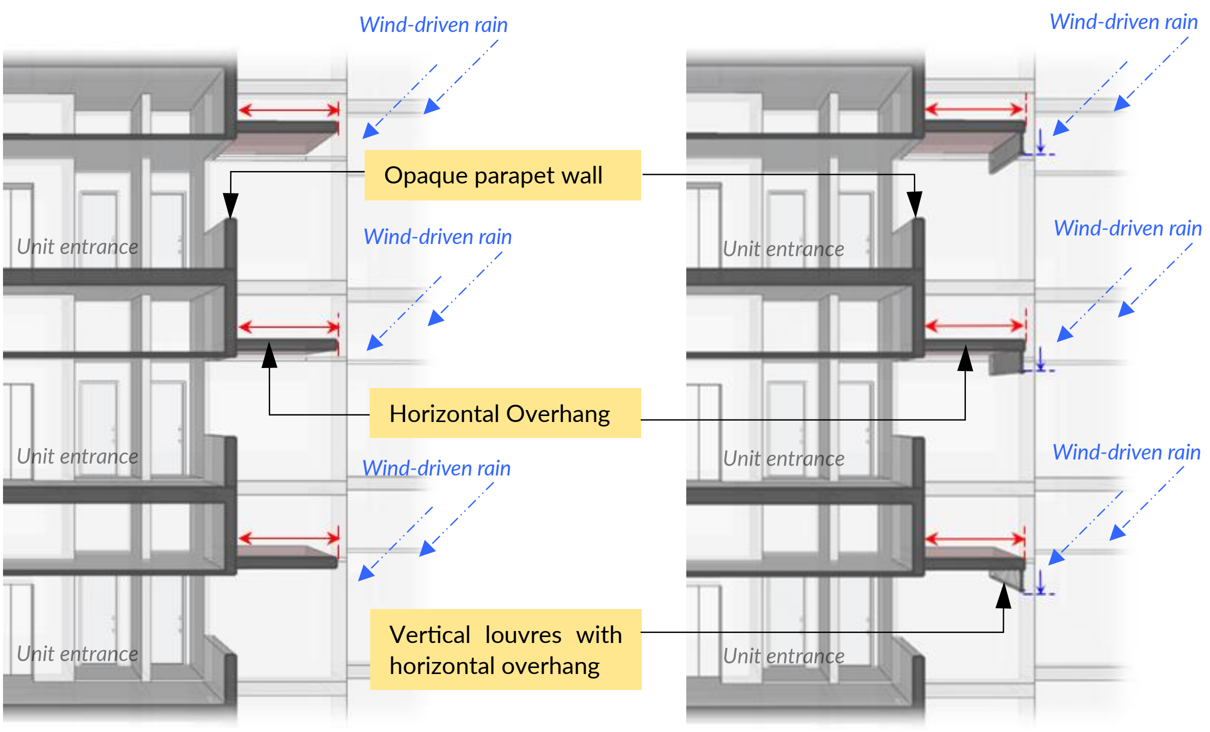


Figure 8: Provision of horizontal overhang and drop-down vertical louvres along corridors

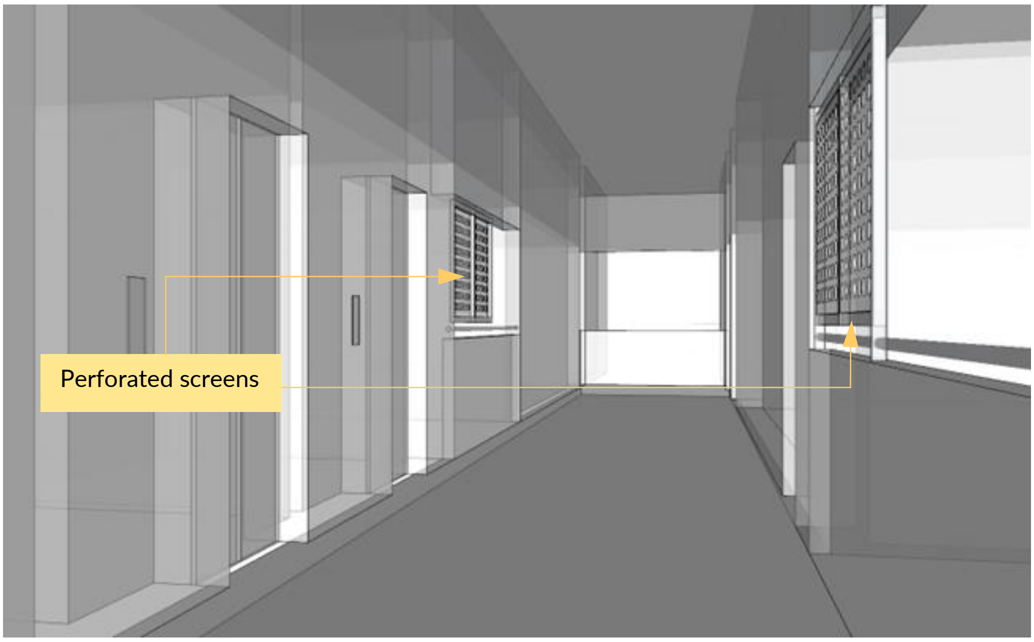


Figure 9: Provision of perforated panels along long cross-ventilated corridors

2.4.2 LIFT LOBBIES

While lifts are typically located in the central zone of a common corridor to serve the occupants of the dwelling units, good cross-ventilation often result in wind-driven rain penetrating deep into the corridors near the lifts. To protect the lift installation and avoid rain from seeping into the lift pit through the lift door gap, and into the lift shaft, building designers could consider providing a gentle upslope at the threshold between the lift car and the corridor.

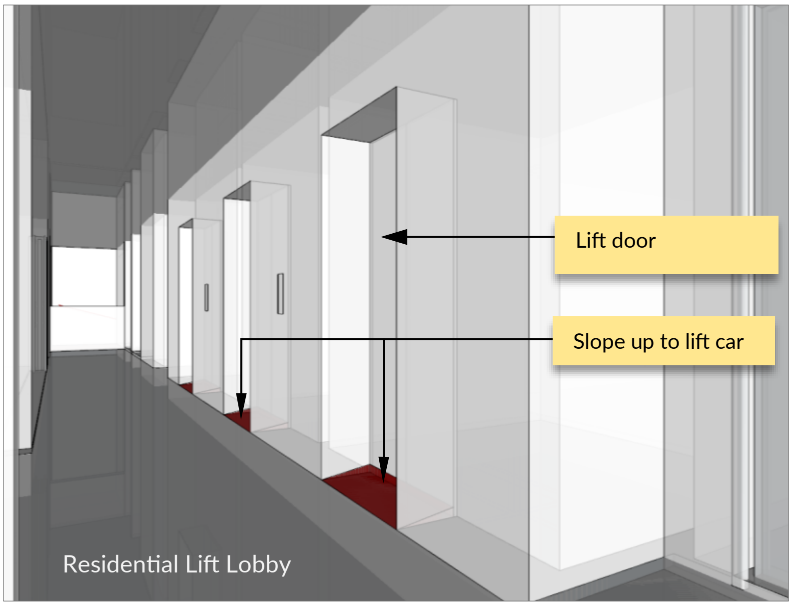


Figure 10: Residential Lift Lobby with Sloped Design to Prevent Rainwater Seepage

2.4.3 MATERIALS

As common corridors are expected to have some wetness, to safeguard residents against the risks of slip and fall as they traverse between the lift and their units, designers should take into account the traction of the floor finishes especially in wet weather conditions. SS485 Specification for slip resistance classification of pedestrian surface materials provides recommendations for pedestrian surface materials in some specific typical locations such as covered public accessible area/ corridor/ walkway/ porch/ lift lobby that is exposed to weather on side(s) as well as entry area/ foyer where they may be prone to being wet.

2.4.4 UNIT ENTRANCES

There are several areas of concern for unit entrances:

- Location of unit entrance
- Orientation of door
- Material
- Ironmongery and locksets
- Door seal
- Recess spaces
- Gates

Location: To achieve high efficiency of floor area and to optimise the number of dwelling units within a development, it is common to see corner unit entrances being located right next to corridor openings, especially for cross-ventilated corridors. Due to the proximity to the openings, these units' entrances are most prone to the impact of wind-driven rain.

Orientation: To avoid doors and lockset mechanisms from direct exposure to wind-driven rain, designers should orientate and setback the unit entrance from corridor openings, especially for corner units.

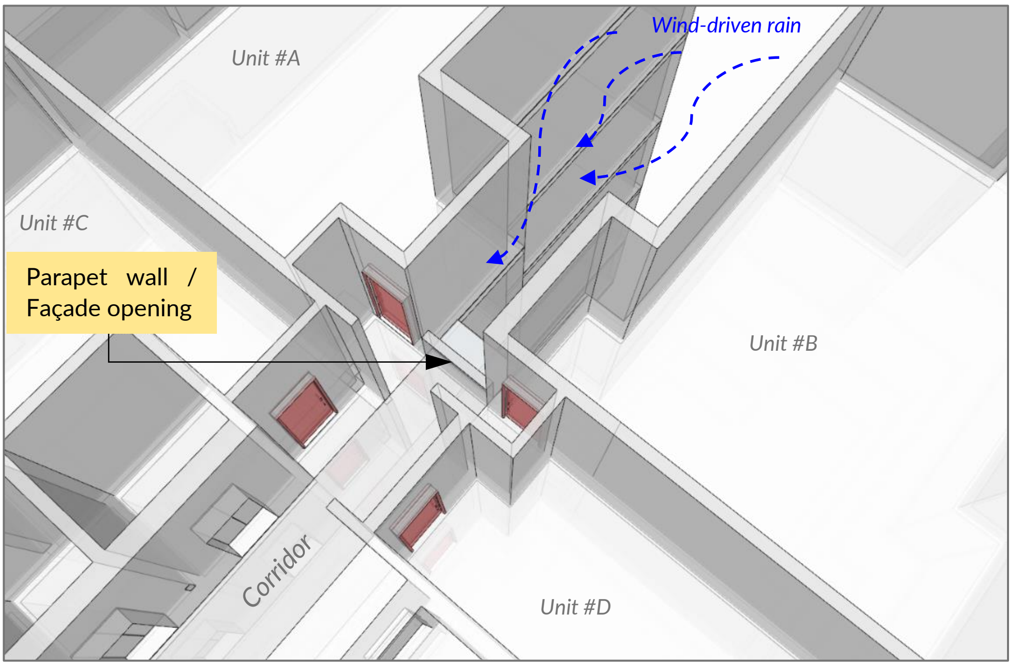


Figure 11: Diagram showing unit entrances (#A &#B) oriented away from façade opening

Material: Designers should consider more weather-resistant and less porous surfaces for entrance door material to avoid moisture from seeping into the material, causing wear and tear.

Ironmongery and locksets: Digital locksets are commonly used at entrance doors to provide greater convenience to users but are prone to damage of the circuitry caused by wind-driven rain seeping into the lockset mechanism. Project teams may consider integrating or providing protective covers for the lockset

Door seal: It was observed that during severe wind-driven rain conditions, rainwater ingress from the common corridor may seep through the gap under the entrance door into the unit. Project teams should consider the provision of door seals or doors with integrated door seals to prevent seepage into the units and into key living spaces.

Recess spaces: As residents are expected to pause for a short while at their entrance to operate their doors to gain access into the units, designers can provide shelter for users and avoid direct exposure of their doors and locksets to wind-driven rain through having deeper thresholds with recess spaces.

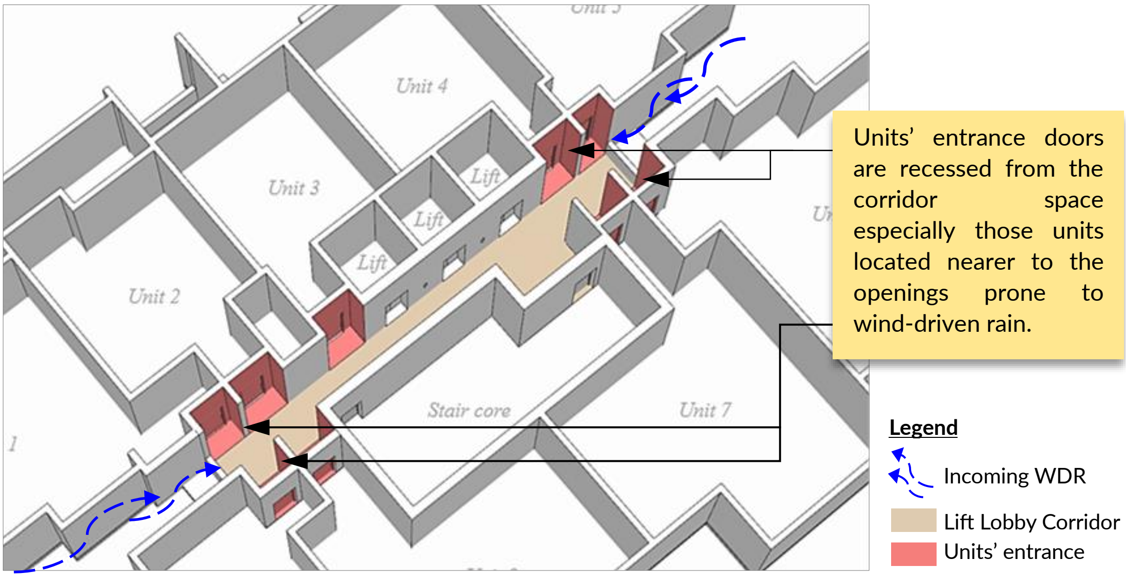


Figure 12: Diagram of Residential Corridor with Recessed Unit Entrances

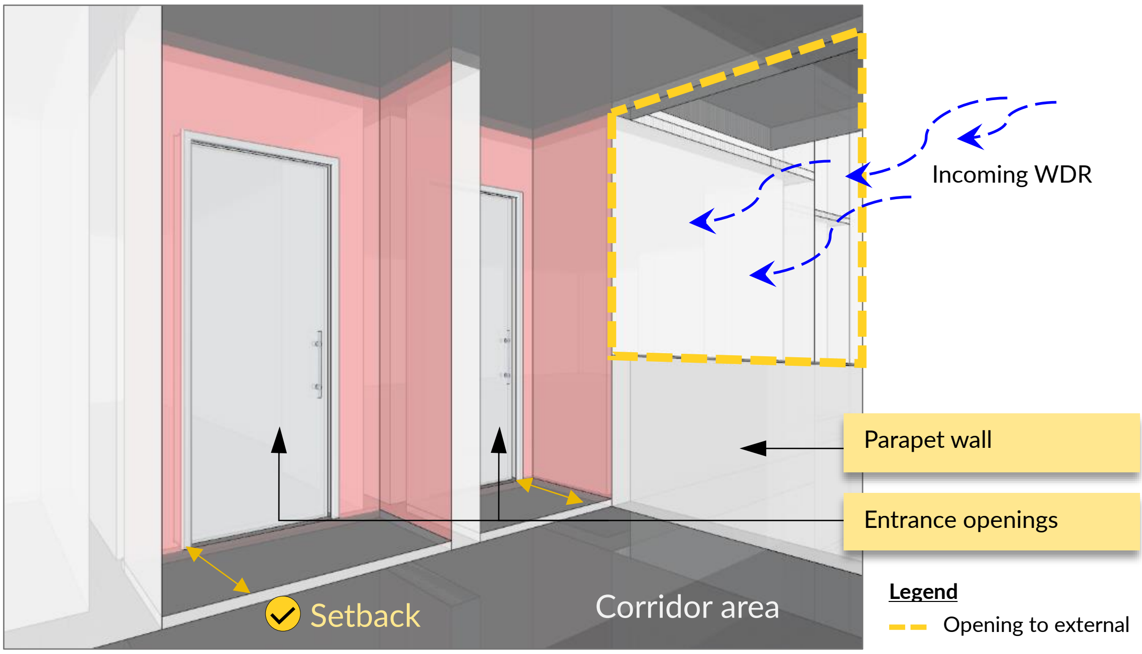


Figure 13: Residential Corridors with Recessed Unit Entrances Near Openings

Door gates: Gates if any, should be designed with appropriate porosity in response to the expected rain ingress at the unit entrances.

Figure 14: Gates with Low Porosity to Minimize Incoming Rain

2.4.5 INTERNAL UNIT LAYOUT

Placement of entrances and ventilation openings should consider the cross-ventilation and wind flows within unit layouts.

Seepage into units: It is common for designers to situate balconies directly across the entrance door as it optimises daylight penetration into the entrance foyer. This is also conducive for good cross-ventilation of the living area.

During wet weather however, it was observed in some cases when balcony doors are not completely shut, rainwater ingress from the common corridor may seep through the gap under the entrance door into the unit, presumably due to the lower wind pressure within the unit.

To mitigate this phenomenon, provision of door seals is recommended.

Given that balconies are semi-outdoor transition spaces that are still largely exposed to weather conditions, rainwater ingress is to be expected. It is good practice for developers and project teams to advise homeowners through the relevant handover guides or information kits to consider placing weather compatible furniture in balconies to avoid undue damage to property. Similarly, advice could be provided to homeowners that where additional balcony blinds are installed, care should be taken not to obstruct the scupper drain or the rainwater downpipe outlet.

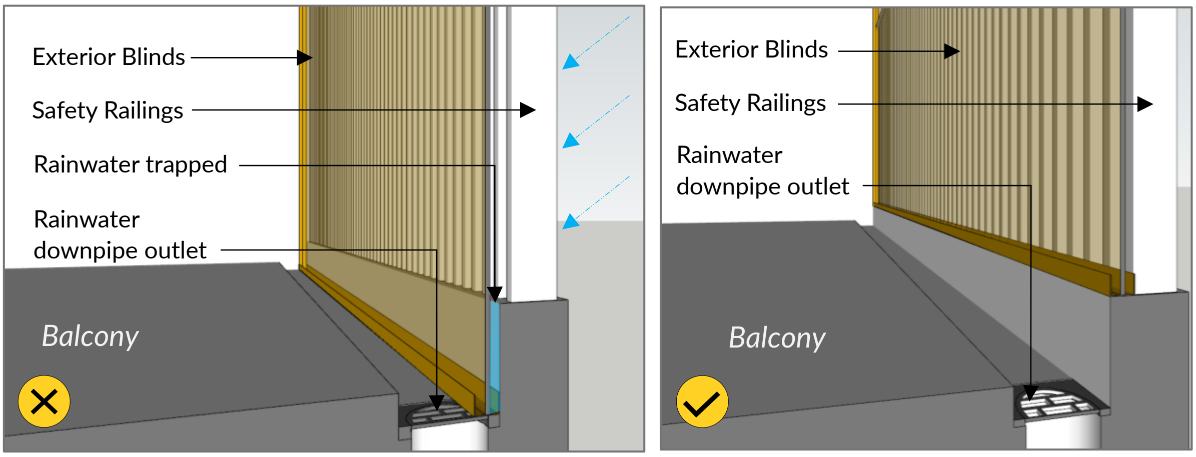


Figure 15: Cross-sectional view of exterior blind installations
Left: Exterior blinds mounted in the scupper drain, blocking the floor trap and impeding proper rainwater flow
Right: Exterior blinds fitted without obstructing the balcony's drainage system

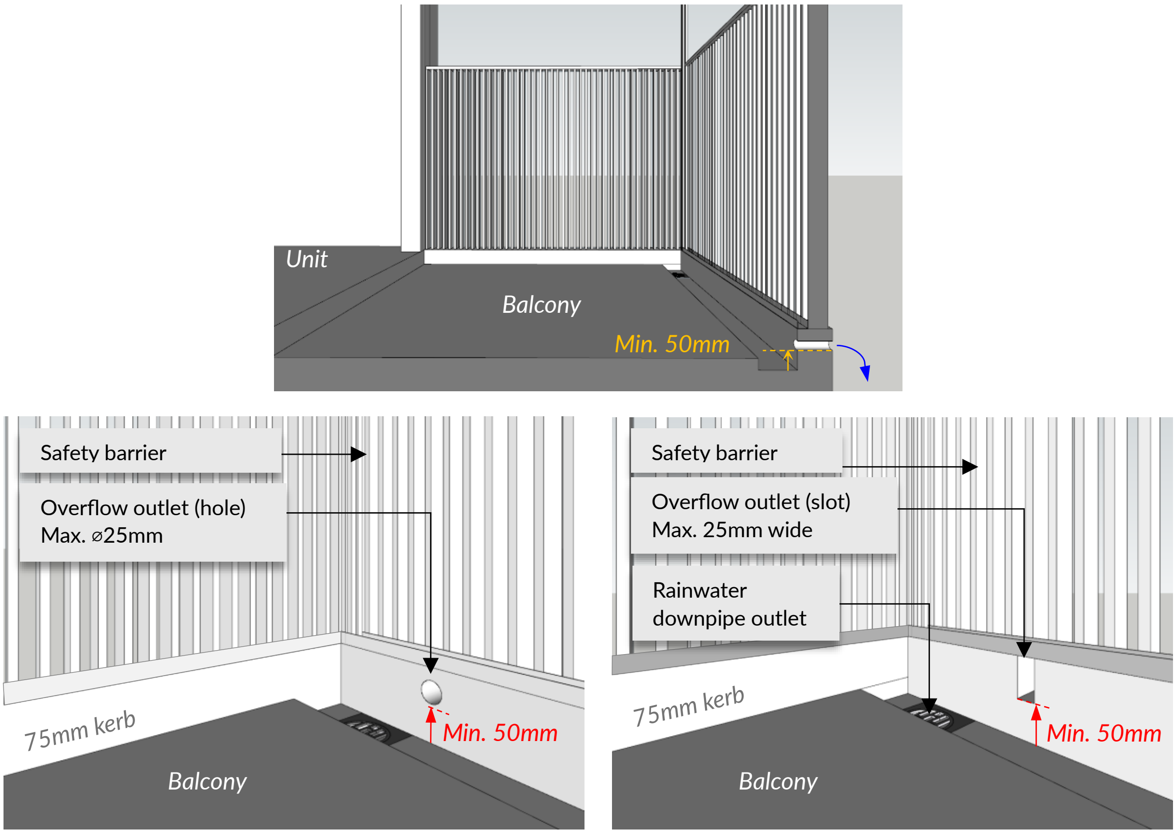


Figure 16: Balcony drainage system with overflow hole or slot as secondary measure to prevent flooding

During heavy rainfall, the existing drainage system may prove inadequate to manage the volume of water, resulting in significant ingress and ponding issues, particularly in balconies and corridors. This problem primarily arises from insufficient capacity in rainwater downpipes (RWDP) and a lack of properly sized or adequate number of rainwater outlets (RWO). Poor drainage system design may also contribute to the issue.

To mitigate these issues, secondary solutions could be implemented. One effective approach is to provide overflow pipes or slot holes. These additional drainage points can help manage excess water when the primary drainage system is overwhelmed. It is recommended to position these overflow holes at least 50mm above the level of the rainwater outlet.

Implementing these secondary measures and enhancing the overall drainage system design can significantly reduce the risk of water ingress and ponding. These improvements will help safeguard the building's structure and enhance occupant comfort.

2.4.6 DRAINAGE SYSTEMS

Due care and diligence should be taken in the design of drainage systems. In seeking to optimise or minimise the size and number of rainwater downpipes and outlets, careful calculations should be carried out with reference to the relevant standards. Where building projects establish specifications for the design and provision the development's drainage system, this should not be done in silo without clear coordination and understanding of the building catchment design. Early involvement of the specialist consultants where applicable and consideration of the drainage system design is important to ensure adequate space provisions for appropriate numbers and sizing of downpipes and outlets.

With more occurrences of sudden and adverse weather conditions, the design and provision of a robust drainage system is critical in the mitigation of wind-driven rain to ensure that the rapid ingress of excessive rainwater can be collected and discharged swiftly.

Building designers should strive to coordinate with the other relevant consultants and incorporate the provision of drainage systems as early as possible in the design phase.

The adoption of siphonic systems with compact piping and outlet sizes are specific to roof drainage systems. The same sizes should not be assumed to be effective when applied to weather exposed spaces in the intermediate levels of the development. Substandard drainage provisions may lead to backflow of water, causing severe ponding and can be very costly to rectify.

The drainage system should coordinate the following elements:

- **Location of rainwater outlets:** More provisions at areas exposed to direct wind-driven rain compared to deeper into corridor spaces with intermediate downpipes or outlets provided along extended corridors lengths.

- **Cross fall of the floor:** Floor to be designed with sufficient slope, which should be equal or gentler than 1:40, as a rule of thumb.

- **Provision of scupper drain:** Sufficient width and depth of scupper drains to be provisioned at areas exposed to direct wind-driven rain to collect and direct rainwater ingress to the outlets, keeping the rest of the floor dry.

- **Rainwater downpipe and outlet sizing:** An average diameter of 150mm or more.

- **Design of floor waste:** Avoid tile inserts as the effective drainage opening is reduced to the perimeter of the floor waste. A drainage outlet that has sufficient opening areas to release air while allowing ingress of water performs better than one with very small openings.

Floor wastes with tile inserts generally experience slower discharge rates

Figure 17: Recommended types of floor wastes for rainwater discharge

2.4.7 OTHER COMMON SPACES

Other common areas such as sky terraces, accessible roof gardens and void decks can experience more intense wind-driven rain effect as these spaces are usually designed with higher floor to ceiling height with more open sides.

However, compared to common corridors, users would avoid accessing these areas during wet weather. Nonetheless, measures should also be taken to adopt weather resistant materials to the common property, furniture and floorings etc.

Where the finished floor level of the sky garden is higher than the indoor finished level (E.g. retrofitted roof garden in an existing building), provide up-stand or cut-off drains with adequate capacity to minimize rainwater ingress.

03

SIMULATIONS AND TESTS

CHAPTER 03

SIMULATIONS AND TESTS

Conducting simulations and tests at early design phase can provide designers with greater awareness to introduce targeted mitigating measures in the building design. In addition, developers and designers are encouraged to conduct wind-driven rain simulation during the early design phase so that appropriate mitigating measures can be introduced in the building design.

3.1 WIND-DRIVEN RAIN SIMULATIONS

The simulation methodology and requirements are available in the Green Mark 2021 Residential Buildings Technical Guide.

3.3.1 ON-SITE INTERVENTIONS

In tandem with wind-driven rain simulations to identify potential wind-driven rain prone areas, building designers and their project teams can also conduct on-site observations during the construction phase and introduce additional mitigating measures where needed, for example, installing additional perforated panels. These interventions should be conducted upfront to avoid downstream feedback from users.

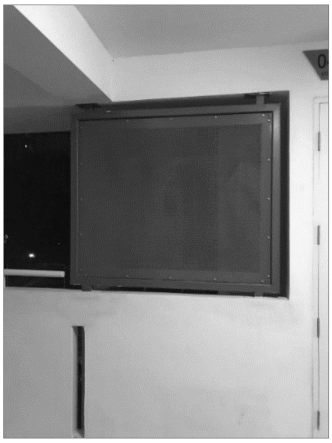


Figure 18: Example of an additional perforated panel installed along a HDB corridor

3.2 CONQUAS WATER FLOW TEST

CONQUAS (Construction Quality Assessment System) assesses the building project workmanship to assist developers and builders in ongoing efforts to enhance their construction quality. Design flaws are identified as major factor in wind-driven rain issues, which could be mitigated through improved design and construction quality. There has been recurring feedback regarding workmanship such as surface unevenness, improper slopes for drainage and the use of poor-quality materials, all of which contribute to water seepage in units and ponding in common areas of private residential buildings.

The CONQUAS banding system is designed to set benchmarks for private residential projects, with the goal of promoting a "do it right the first time" approach and ensuring high levels of construction workmanship quality to reduce defects. The scope of CONQUAS assessment includes a water flow test to verify the absence of water ponding issues along private residential unit corridors, lift lobbies, and external common areas. This requirement applies to private residential projects and mixed development projects with a residential component.

Areas to be assessed within the development:

AREA	SAMPLE DISTRIBUTION	LOCATION
Internal	70%	→ Unit Corridor → Lift Lobby
External	30%	→ Footpath → Walkway to carpark → Driveway in basement carpark → Basement carpark lot (not more than 3 lots)
NOTE: MAXIMUM 10M LENGTH PER SAMPLE If the project's Water flow Test consists of 10 samples: 7 samples will be from internal, and 3 samples will go to the external.		

Before conducting the water flow test, the assessor will choose the areas within the development that are exposed to weather or susceptible to ponding during rainfall. Each test will involve discharging 20 litres of water towards the direction of drainage using a bucket, or pail. The assessor will inspect the location 5-10 minutes after the water is discharged. The sample will be considered to have failed if it does not meet the criteria outlined below.

- Ponding should not be more than 3 mm
- Water falls in the right direction
- No pipe chokage

**The sample is deemed to have failed if any of the above criteria is not met.*

04

RESOURCES

CHAPTER 04

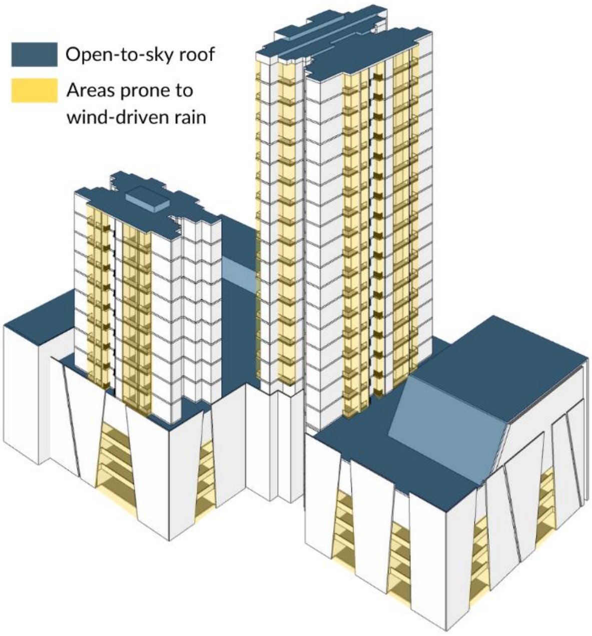
RESOURCES

4.1 GREEN MARK TECHNICAL GUIDE FOR WIND-DRIVEN RAIN SIMULATION

Conducting simulations at early design phase can provide designers with greater awareness to introduce targeted mitigating measures in the building design. In addition, developers and designers are encouraged to conduct wind-driven rain simulation during the early design phase so that appropriate mitigating measures can be introduced in the building design.

4.2 SS 525 CODE OF PRACTICE FOR DRAINAGE OF ROOFS

Singapore Standards SS525 provides guidelines for the design of drainage systems. It offers considerations for effective drainage of surface water from roofs, walls and spaces subject to wind-driven rain (WDR). The standard outlines recommended methods for the design and installation of gutters, downpipes, outlets and scuppers.



- Balconies
- Skybridges
- Recreational Areas
- Multi-storey car parks
- Lobbies
- Corridors / Linkways
- Canopies
- Staircases

Figure 19: Open-to-sky surfaces and areas prone to wind-driven rain

The number of scupper outlets needed for effective drainage in common areas will be determined by the surface area in contact with rainwater, the rainfall intensity, and the size of scupper drains provided. Designers must evaluate the flow rate (rate of run-off) in areas potentially exposed to wind-driven rain. This assessment is crucial for strategically placing outlets and scuppers, and for providing sufficiently sized pipes to ensure effective rainwater drainage.

4.2.1 RAINFALL INTENSITY

SS525 categorises the design risks based on rainfall records in Singapore. Different rates of rainfall would commensurate with different degrees of risk of overloading the drainage system. Designers should refer to SS525 in assessing the applicable rainfall intensity and design risk.

1) The design of flat surfaces where temporary ponding during and after intense storms is acceptable;

2) The design of sloping surfaces where ponding is generally undesirable. This design may occasionally overflow or cause ponding;

3) The design of surfaces where any overflowing or ponding is to be avoided (except for exceptionally rare storms where design is impracticable).

The risk must be assessed for adopting the same rainfall intensity as the roof for the internal WDR space.

4.2.2 WIND DRIVEN RAIN FACTOR

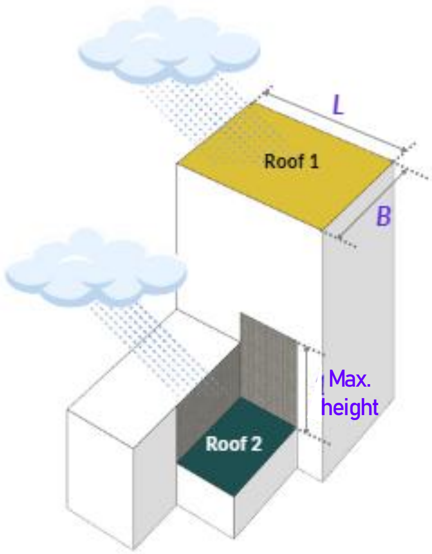
Compared to open to sky areas, the anticipated amount of water needed to be drained from Wind-driven Rain (WDR) areas includes water ingress from vertical openings. In determining rainfall rates for Wind-driven Rain (WDR) areas, SS525 applies a wind-driven rain factor (F_{WDR}) to elevation drainage for rain falling onto adjacent roof areas. Likewise, wind-driven rain factor can be employed for rain falling at an angle on areas exposed to wind-driven rain. The value of F_{WDR} increases where strong winds cause rain to fall at a steeper angles.

RATE OF RUN-OFF FOR OPEN TO SKY AREAS

Ae : Effective catchment area (m^2)
I : Design rainfall intensity (*mm/hr*)

$$Q\,(l/s) = \frac{Ae \times I}{3600}$$

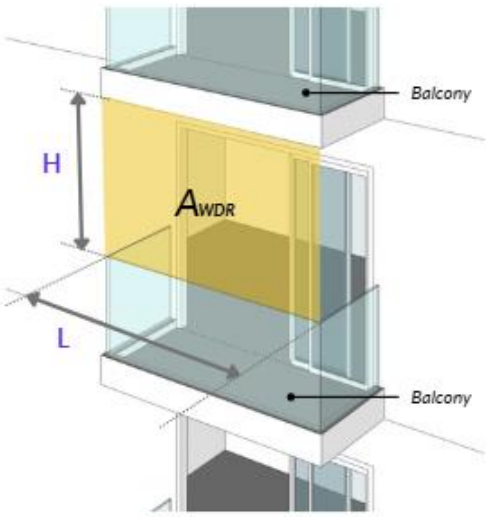
RATE OF RUN-OFF



RATE OF RUN-OFF FOR WDR AREAS

Q_{WDR} : Rate of run-off
Amount of water needed to be drained from the WDR space.

$$Q_{WDR} = \frac{F_{WDR} \times A_{WDR} \times I}{3600}$$



F_{WDR} = *WDR factor*
A_{WDR} = *Area of vertical openings exposed to wind-driven rain* (m^2)
I = Design rainfall intensity in (mm/hr)

Figure 20: Comparison of run-off rate calculations for open-to-sky areas vs. wind-driven rain

04 RESOURCES

4.2.3 CAPACITY OF RAINWATER OUTLET

The capacity of a rainwater outlet with grating is determined by the outlet size, the percentage of clear opening it provides, and is affected by the water depth around the outlet. The estimated capacity of grated circular outlets according to percentage of opening size are available for reference in SS525.

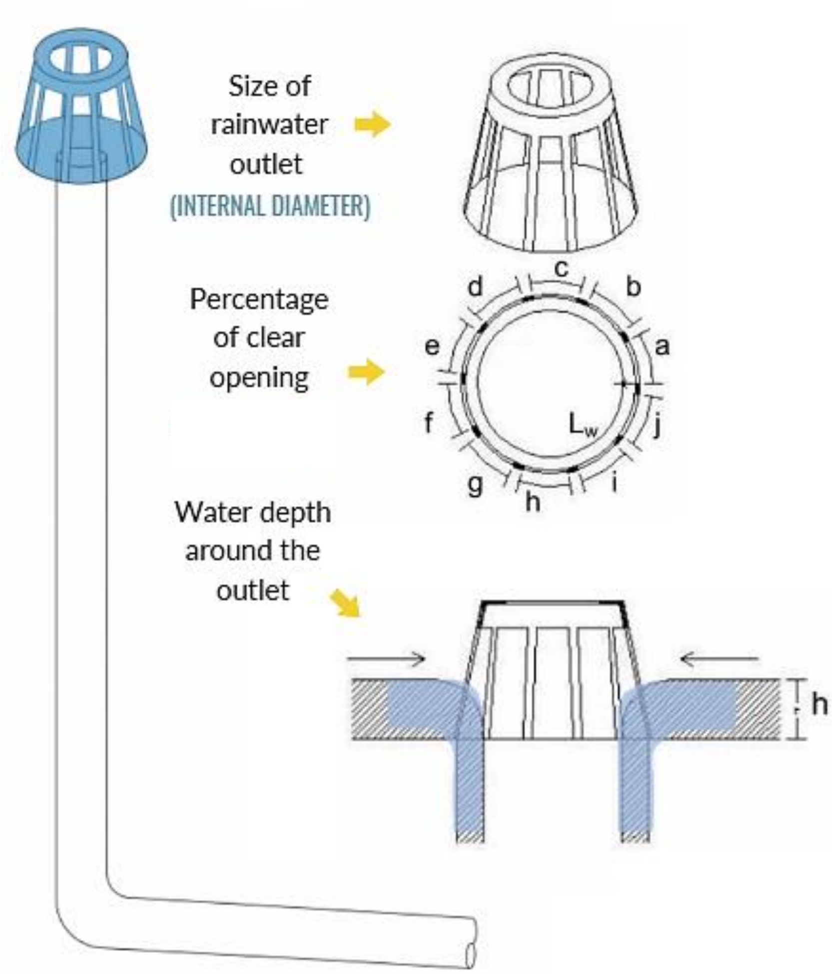


Figure 21: 3 Key Factors to Consider for the Rainwater Outlet Design

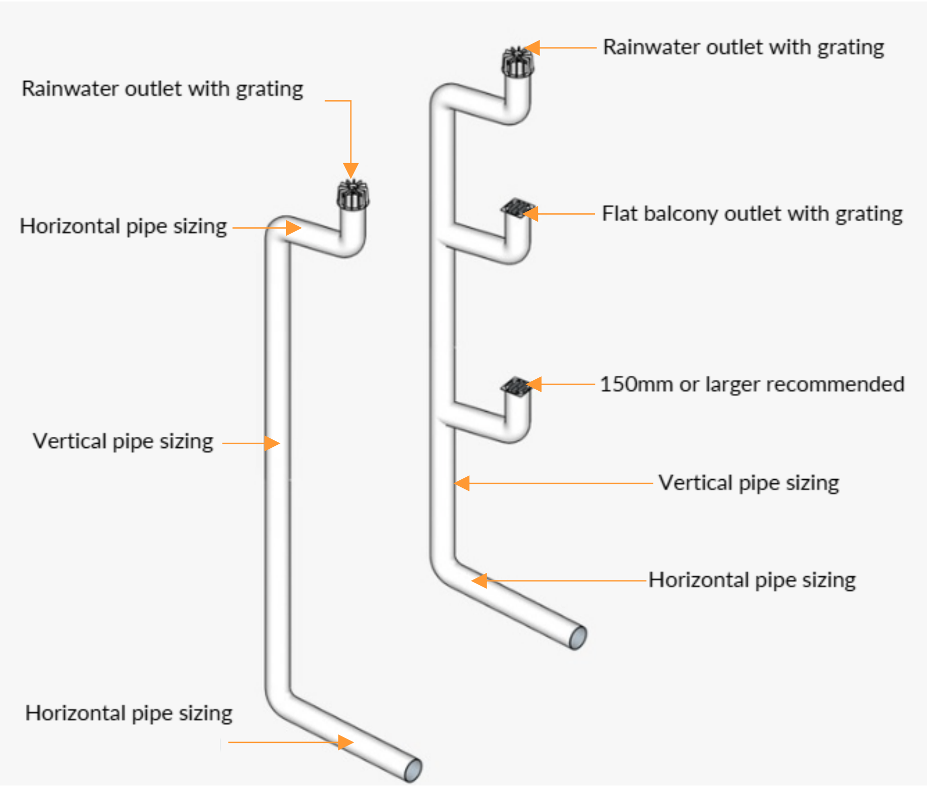


Figure 22: 3 Essential Components for Designing Effective Rainwater Drainage System

4.2.4 RISKS OF UNDER-DESIGN OF RAINWATER OUTLET AND PIPE

Effective balcony drainage design is essential in high-rise buildings with multiple balconies exposed to strong winds. Drainage systems at balconies and residential corridors typically involve a vertical drainage stack with multiple side branches and openings at various levels which differs from the conventional roof drainage systems. The conventional roof drainage systems are closed pipework without side branches or openings. The lower-level branches and side openings of a high-rise rainwater drainage stack face various risks.

Common causes of balcony drainage failures include:

- Backflow at branch outlets due to air pressure forcing water out.
- Backflow at branch outlets caused by internal pressure buildup in the pipework.
- Water unable to enter the drainage system because of air escaping from side branches.

To prevent under-designed rainwater outlets, designers should ensure:

- Sufficient rainwater outlet opening area.
- Proper distribution of the catchment area.

The diagram below illustrates two scenarios:

Diagram A: A well-designed system with adequately sized rainwater outlet and pipe, allowing adequate air flow.

Diagram B: An under-designed system with insufficient outlet opening size and pipe diameter, restricting air movement.

In **Diagram B**, restricted air movement and pressure fluctuations may cause water backflow, potentially overwhelming the gravity-based system and risking balcony flooding.

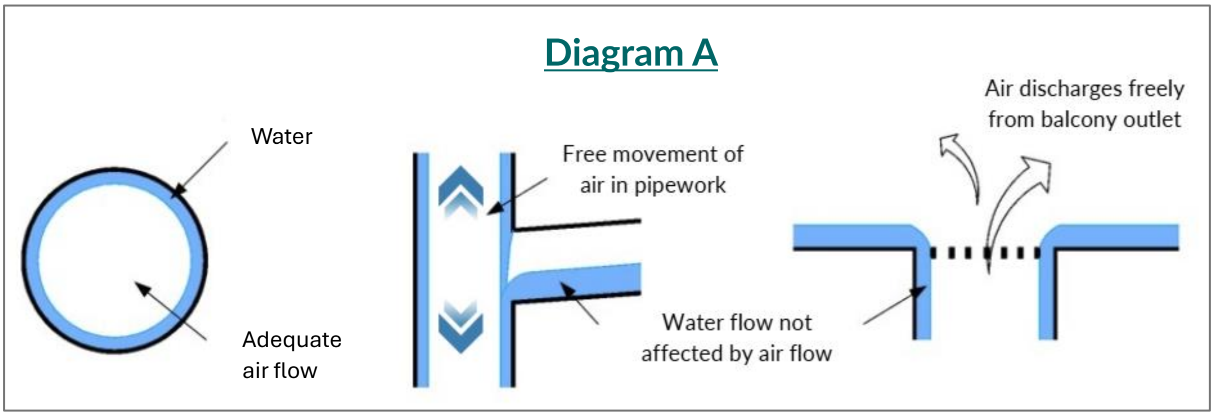


Figure 23: Correct Design of Balcony Drainage System

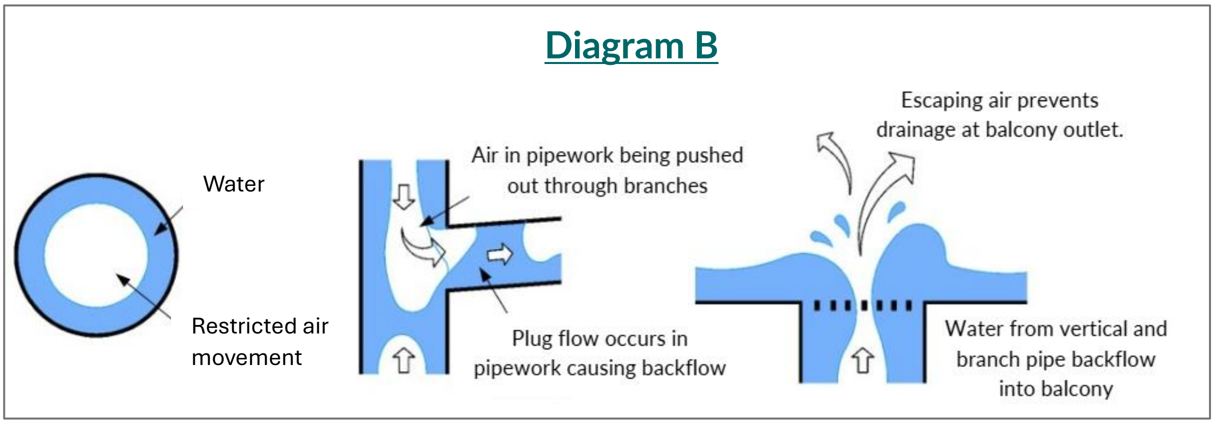


Figure 24: Under-Design of Balcony Drainage System causing Backflow