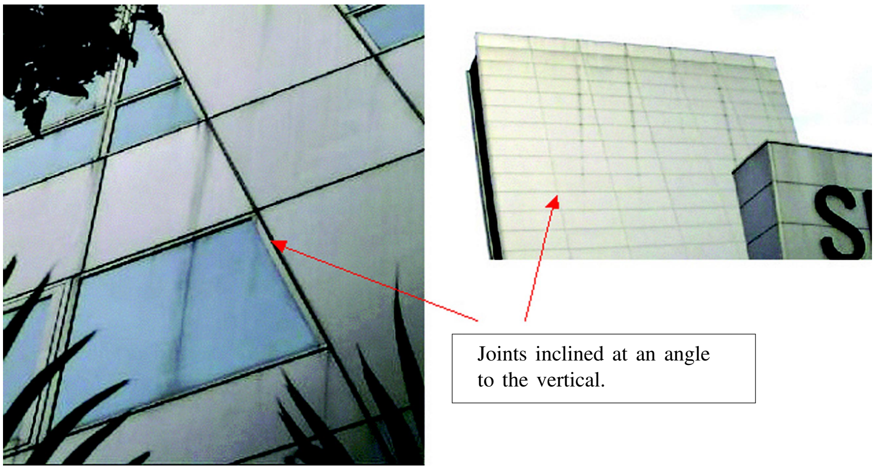

Figure 4.25. Joints inclined at an angle to the vertical.

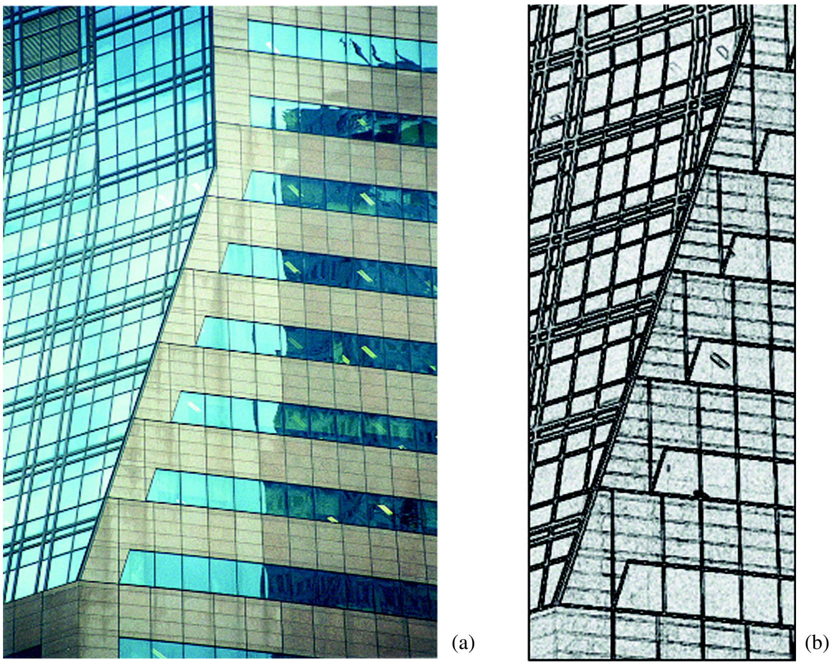

Figure 4.26. (a) Joints misalignment on the facade of the building interrupts the even flow of runoff and results in staining. (b) Drawing shows the clear misalignment of joints.

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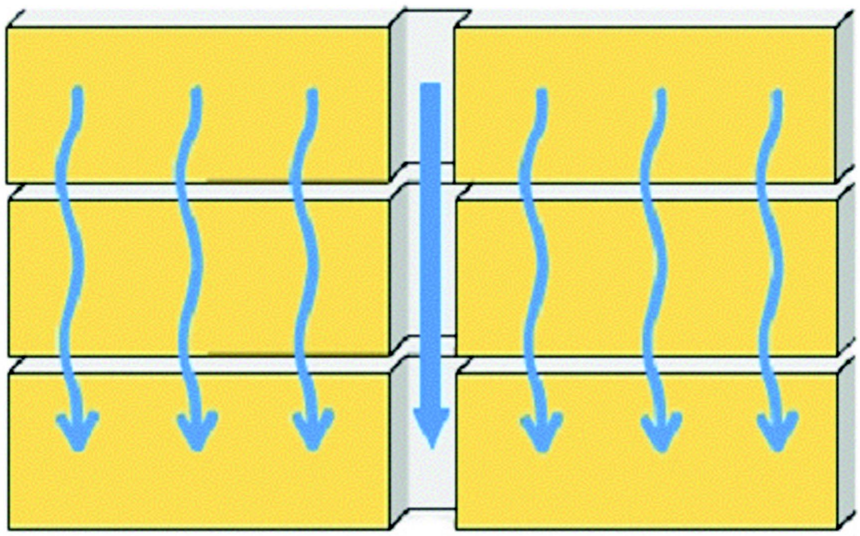


Figure 4.27. Runoff should be allowed to flow unobstructed along vertical joints.

can then be controlled to flow from the top of the facade to the bottom, and subsequently be drained off the facade as shown in Fig. 4.27.

Attention must also be paid to workmanship during the construction of these joints to ensure that they are in line. Poor workmanship can sometimes result in joints being misaligned, causing flow to be affected and bringing about long streaks of stains beneath where the misalignment occurs (Fig. 4.28). This may happen on tiled facades where on-site installation is heavy and misalignment resulting from poor workmanship may occur. Encouraging prefabrication and using facade systems that require little on-site installation may rectify such a problem [11].

4.4 Protruding fixtures

Any installation of signboards, logos, letterings, external lightings, speakers and other small fixtures onto the facade, done independently from the facade installation can be grouped as protruding fixtures.

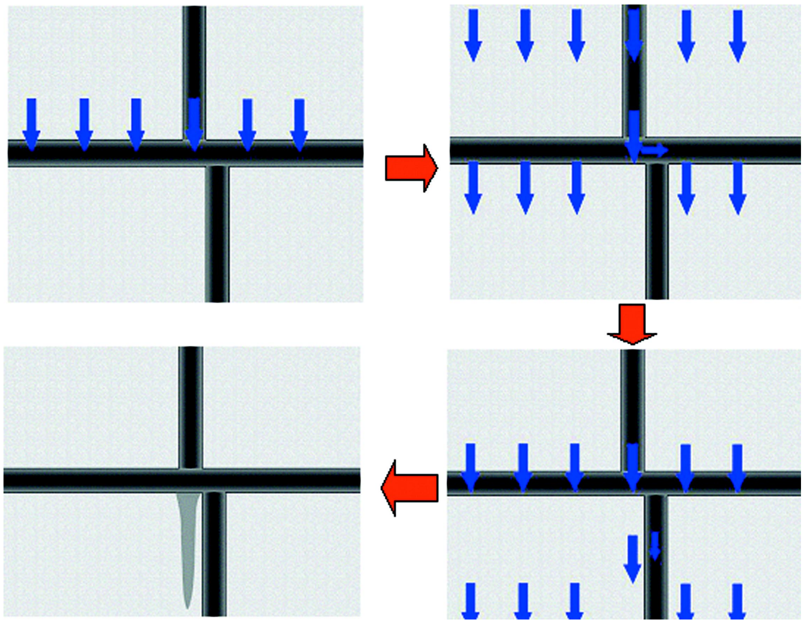


Figure 4.28. Sequence of runoff flow pattern and the resultant staining pattern when panels are slightly out of alignment.

Many building owners give identity to their buildings by installing their company logos or names on the front facade of the building. However such minor projections from the facade could disrupt the flow of water and redistribute it, washing off dirt at some areas and depositing dirt at others, causing an unsightly effect [1].

4.4.1. Factors Causing Staining at Protruding Fixtures

Designing and installing fixtures on a facade without considering the effects that they will have on the facade may yield adverse results (Fig. 4.29). When these fixtures are installed to protrude on a facade, dirt will settle on its horizontal surfaces. The degree of stain formation due to protruding fixtures will depend on the width of protrusion of the fixture and the presence of corners created between the fixture and the facade.

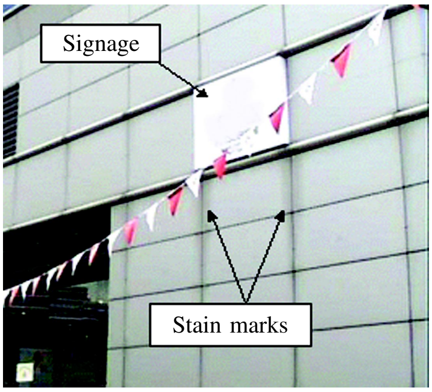


Figure 4.29. Protruding fixtures on building facade.

The more the fixture protrudes from the facade, the larger the horizontal surface area for dirt to settle. When runoff flows over the protrusion, the dirt will be washed off from the fixture and redeposited on the facade as stains. The protruding fixture causes staining in a very similar way as that of a ledge.

The method by which the fixture is attached to the facade has a large effect on the intensity of staining. Fixtures such as lightings and signage can be attached to the facade with clearance in between the two or be fixed directly to the facade without clearance. In the former, disruption of even and regular runoff flow on the facade will be minimised and dirt that gathers on the protrusion cannot be washed onto the facade. However, the clearance between the fixture and the facade must be wide enough to prevent debris and dirt particles from collecting in the clearance gap.

4.4.2. Mechanism of Staining at Protruding Fixtures

The basis of staining due to protruding fixtures can be reinforced with the observations obtained from subjecting a typical tightly installed light fixture to the rain runoff simulation experiment. The resulting staining pattern can be seen from Fig. 4.30 and similar staining patterns can be observed from Fig. 4.31.

The mechanism by which stain marks form around signage is very much similar to that of stains formed around protruding fixtures. This is illustrated in Fig. 4.32.

The horizontal and sloping surfaces present on the letterings are areas where more dirt can be retained to be later washed away to form stains on the facade. Stain streaks can originate either from the extreme vertical sides of the lettering or from behind the lettering. This is because of the different methods of attachment. The former case occurs when the

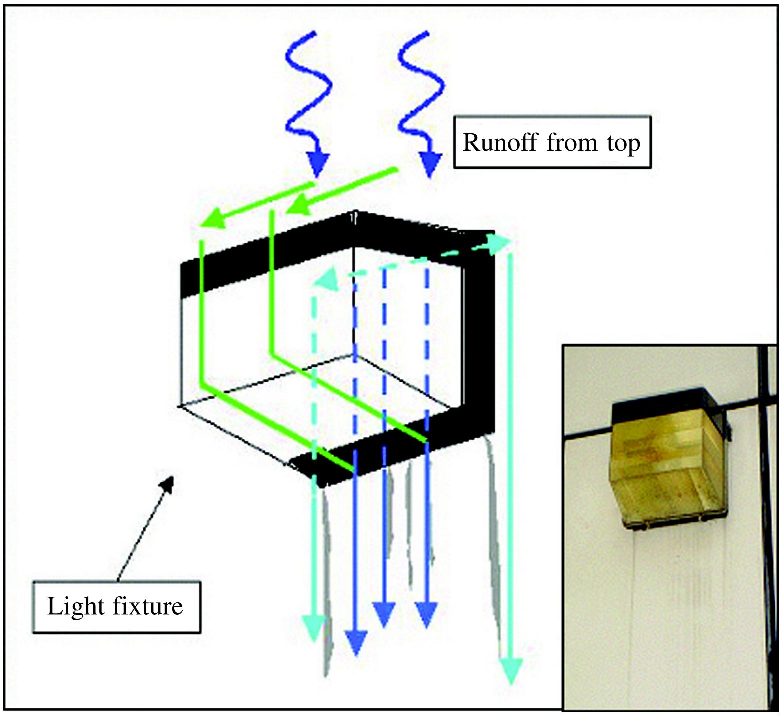


Figure 4.30. Mechanism of staining around a protruding fixture. (1) Runoff drips down vertically along the sides of the fixture. Long streaks of stains will be formed at both sides of the protrusion ("Moustache" staining) (Flow represented by →). (2) A few drips of runoff may flow behind the fixture and emerge below it if the attachment is not completely tight. This will cause a few long streaks to form at the area immediately below the protrusion (Flow represented by →). (3) Most of the runoff will trickle along the profile of the fixture, either dripping off its face or continuing to trickle back to the facade (Flow represented by →).

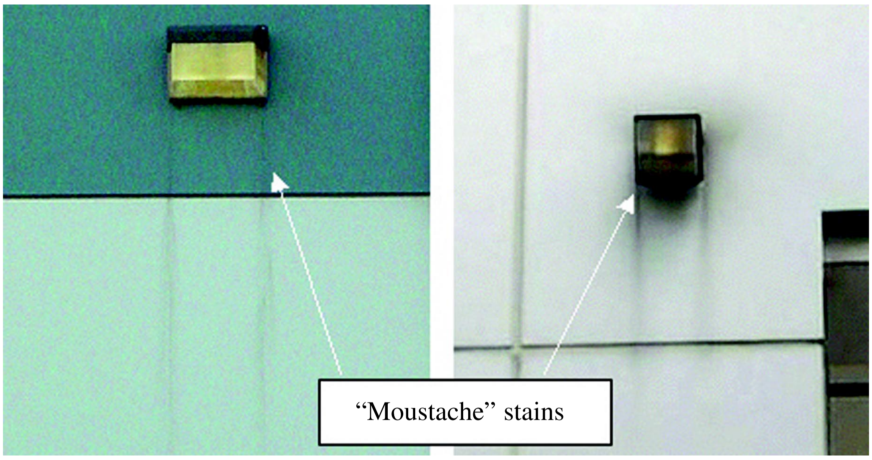


Figure 4.31. "Moustache" staining originating at the light fixture.

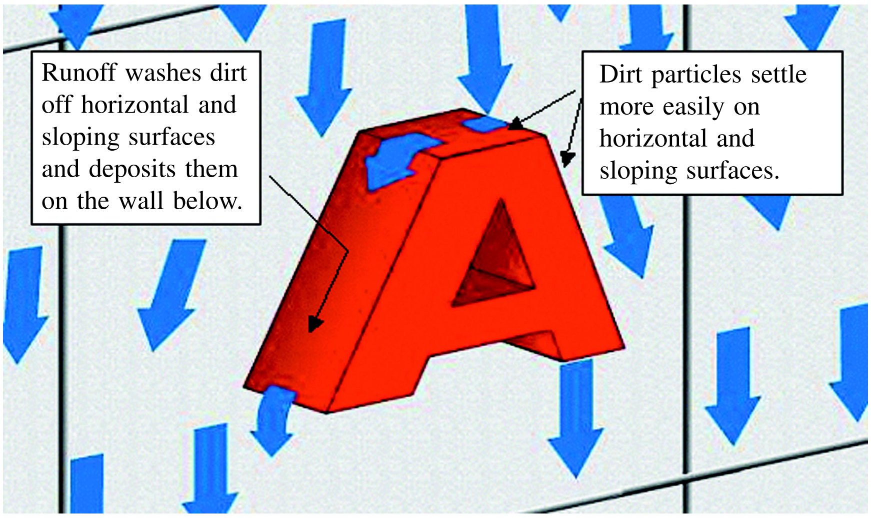


Figure 4.32. Runoff flow pattern over a signage to cause the resulting staining pattern.

letterings are fixed directly to the facade without clearance between the facade and the letterings, thus, dirt gathered on the lettering is washed onto the facade (Fig. 4.32). In the latter case, the letterings are not in direct contact with the facade and stains begin at the attachment points

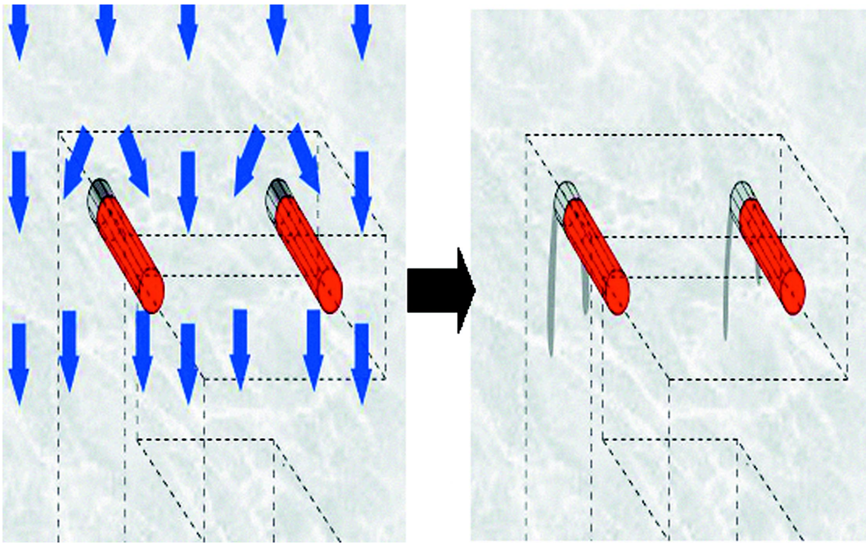


Figure 4.33. Staining originating from attachment points.

with no dirt from the lettering being washed onto the facade (Fig. 4.33). Staining in the latter case would thus be less intense as shown in Fig. 4.34.

4.4.3. Design Considerations

Protruding fixtures such as signage and external electrical installations are common protrusions that may cause staining to facades. Instead of fixing the letterings and signage tightly to the wall, they may be fixed by means of small-dimension bolts with a clearance between the facade and the fixture (Fig. 4.35). In this way, disruption of runoff flow would be significantly minimised. The attachment points would also gather minimal dirt.

By comparing the two methods of attaching fixtures to the facade as shown in Figs. 4.32 and 4.35, it is evident that by allowing a clearance between the facade and the fixture, runoff would be able to flow with minimal disturbance and staining below the protrusion would be minimised. When selecting the material for the attachment, more

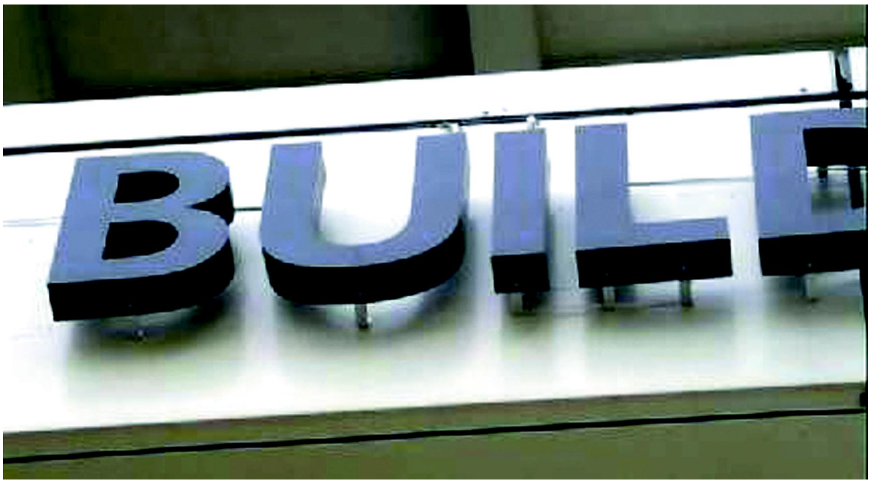


Figure 4.34. The intensity of staining is much reduced when there is a clearance between the signage and the facade.

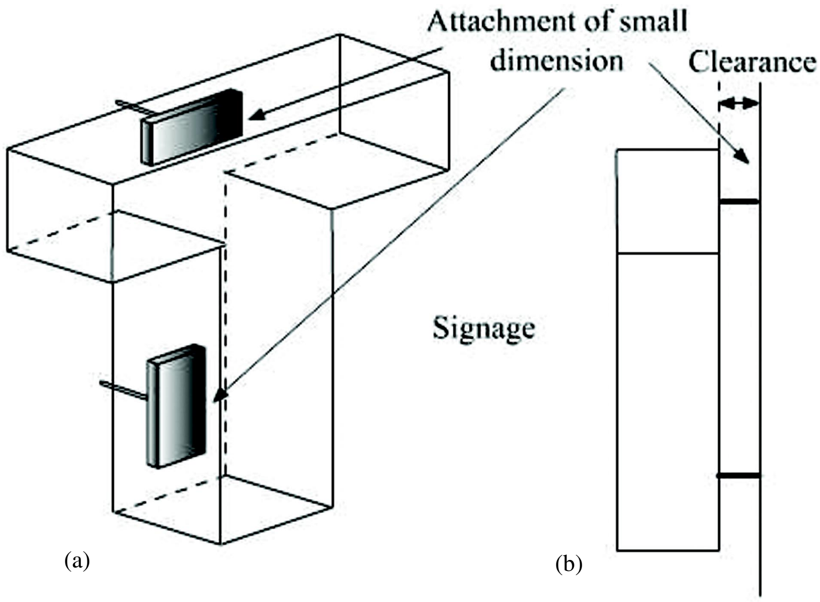


Figure 4.35. Proposed method of fixing attachments to facade so that runoff flow would not be disrupted. (a) Elevation view of signage been attached to the facade. Attachment used must be of small dimension. (b) Section view of signage being attached to the wall.

attention should be paid to its durability. Some contractor teams may overlook such considerations. Consequently, staining may be a result of the attachment material corroding, rather than due to dirt accumulation and redeposition [9–11].

4.5 Louver Units

Louver units provide visual texture to a building facade and at the same time serve as a functional component to provide ventilation or to expel air from the building. Needed mostly for circulation purposes, they have exacted a price in terms of visual deterioration and routine maintenance costs. They can be in the form of louver doors or windows. Louver units may also be designed as part of the facade solely for aesthetic purposes. The exhausted air from a louver unit usually contains a high concentration of dirt that is retained and accumulated at the top face of each louver pane. When runoff flows over the louver panes, the dirt particles are carried along and redeposited as stain marks. For this reason, areas below louver units are often stained. The staining effects of louver units are thus an important design consideration when designing facades.

4.5.1. Factors Causing Staining around Louver Units

The intensity of staining derived from louver units on the facade is dependant on a few factors:

- Surface area and angle of inclination of louver panes,
- Location of building and orientation of facade,
- Location of louver unit on the facade,
- Functional purpose of louver unit.
- Effective facade area where runoff can flow over after running over the louver unit.

The louver panes within a louver unit constitute a large surface area for dirt to settle. Since louver units are mostly used for ventilation

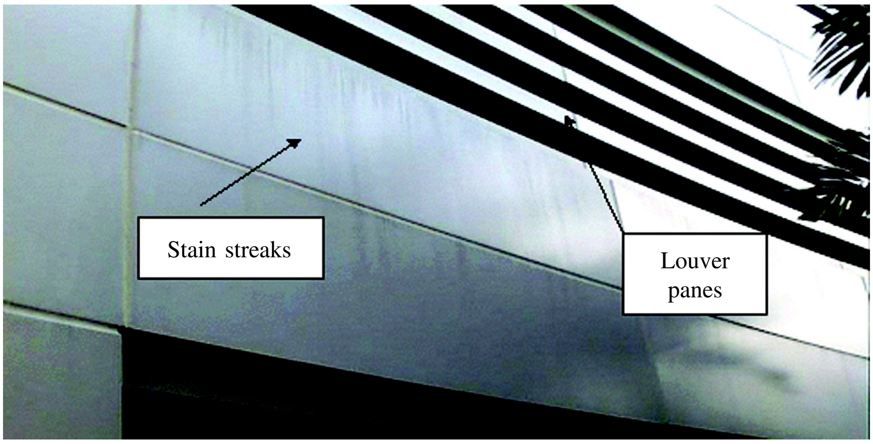


Figure 4.36. Louver units with horizontal louver panes.

purposes, it is expected that dirt-laden air will be forced out between the louver panes. The larger the surface area of panes, the greater the amount of dirt particles that will be retained. The angle of inclination of the panes would also affect the rate of settlement of dirt. Panes that are horizontal (Fig. 4.36) will be less prone to retaining dirt as compared to inclined panes since a portion of the inclined panes are shielded from the direct outflow of air (Figs. 4.37 and 4.38).

The rate at which dirt settles on the louver panes is higher than normal settlement on the other areas of the facade. Thus, louver units that are sited away from impacting rain or are recessed into the facade such that runoff or driving rain will not be able to reach the dirt retained on the louver will not cause staining. This allows dirt to build up evenly on the louver panes without disturbance from runoff flow.

Louver units may be used on a facade to break its monotony. It could also be utilised to ventilate spaces within the building. When used for ventilation purposes, air such as that from air-conditioning exhaust ducts will contain a higher concentration of dirt particles and thus the rate of accumulation of dirt on the panes would be higher.

When the louver unit is located on the ground floor or when it is located such that the runoff after flowing over the louver panes will drain off the facade immediately, staining may also be minimised.

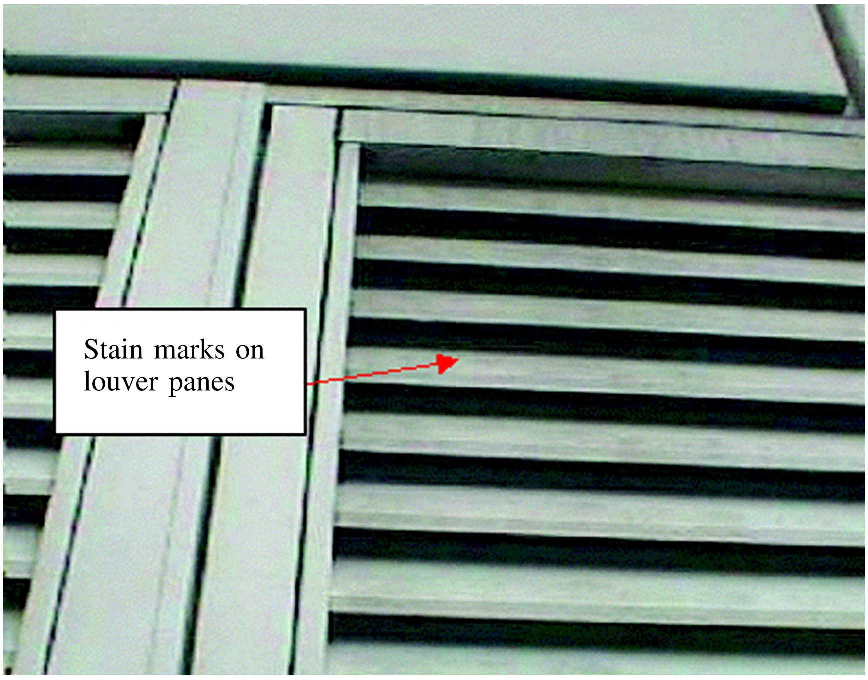


Figure 4.37. Stain marks on the louver panes of a louver door unit.

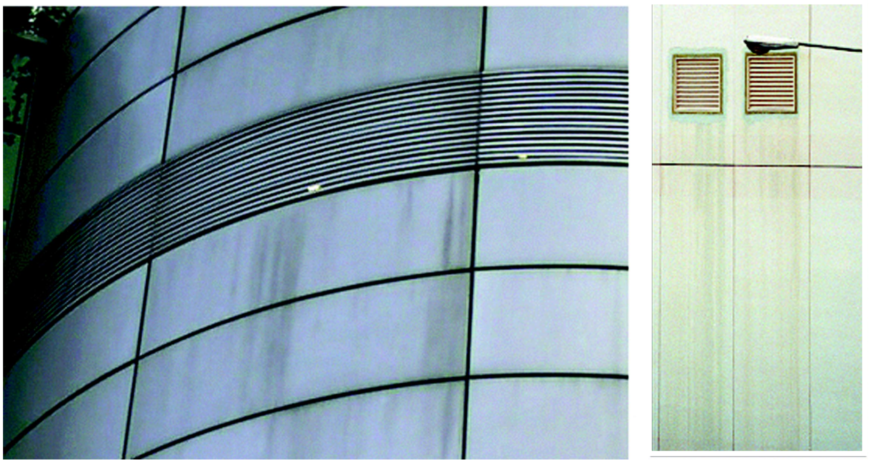
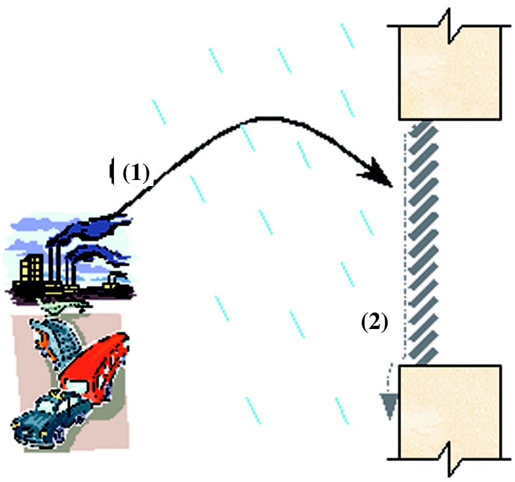


Figure 4.38. Serious staining on the facade due to louver units.

4.5.2. Mechanism of Staining at Louver Units

Staining at louver units occur due to runoff or driving rain carrying away and re-depositing the dirt particles that settle on louver panes. The sequence of staining is stepwise and begins with runoff flowing from facade areas above the louver unit onto the louver panes (Fig. 4.38). Driving rain may also impact on the louver panes to form runoff that carries off the dirt particles. From the topmost pane, runoff will continue to flow downwards to the last pane in no definite pattern of flow. This irregular flow causes washing off in some areas while promoting staining at others. When louver panes are inclined, only the outside portion of the panes experience wetting while the rest of the pane will be sheltered by the pane above it. The washing away of dirt from the outside portion of each louver pane results in the dirt being deposited on areas of the facade below the louver unit.

A rain simulation experiment conducted on a typical louver unit also demonstrated similar runoff flow pattern (Fig. 4.40). It was shown that the dripping of runoff down the louver unit was random and unpredictable and there was no defined location where drips were more concentrated.



Louvers have a large effective horizontal surface area that can double as a dust fall collector from urban activities (1). The dust collected on louver panes would be washed off from the louvers and deposited as stains streaks on the immediate facade surface below (2).

Figure 4.39. Large louvers are able to collect more dust and result in stains more easily.

Figure 4.40. Random runoff flow pattern from louver pane to pane. Experimental setup.

However, there would be areas of flow concentration if any of the abovementioned design features (i.e. ledges, misaligned joints and protruding fixtures) were sited above the louver unit. These have the effect of disrupting the even flow of runoff so that flow becomes concentrated in streams before it runs over the louver panes. Runoff would then flow in defined flow paths over the panes to yield stain streaks at particular areas. The sequence of stain formation for a rounded louver unit is similar and is shown in Fig. 4.41.

4.5.3. Design Recommendations

Louvers are incorporated usually for the functional purpose of exhausting air in the building to outside the building. If they are necessary as part of the facade, they should ideally be located near to ground level or where there is no wide expanse of facade beneath it (Fig. 4.42). By doing so, there would not be sufficient area for the runoff to reach its limit of flow and thus dirt would not be deposited. This may involve re-evaluating the location of machine rooms and other service rooms.

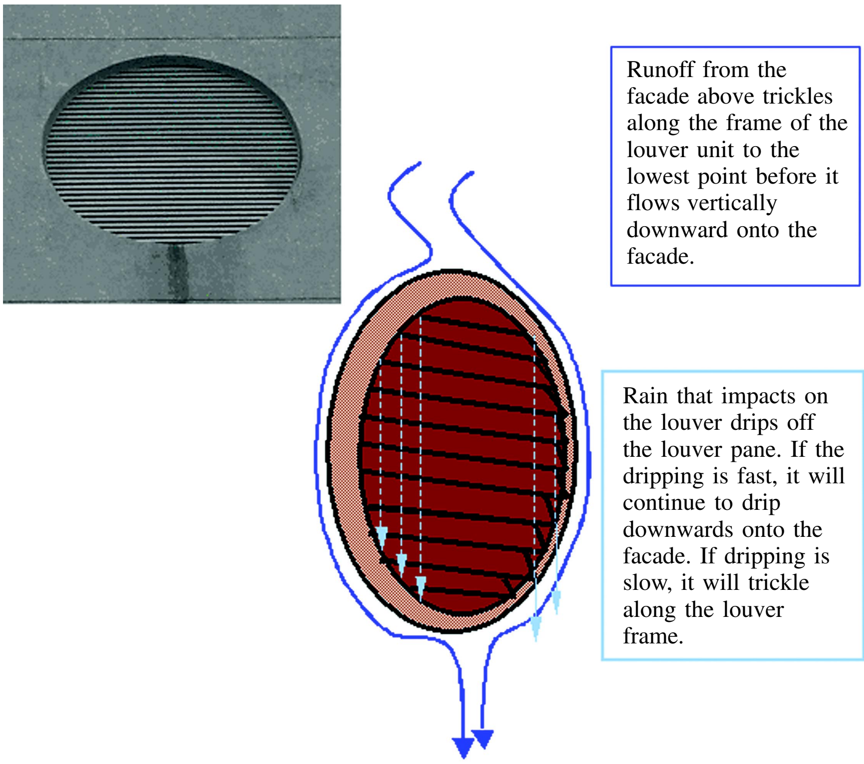


Figure 4.41. Sequence of stain formation at the lowest point of a round louver unit.

Louver units could also be recessed deep into the facade so that runoff flowing down from above will not run over the louvers and driving rain could not impact on the louver unit (Fig. 4.43). An up-stand can also be created at the horizontal recess so that run-off will not flow back onto the facade (Figure 4.44). Small louver units could be sheltered in this manner but for large louver units, the depth of recession may be too large and thus might not be feasible.

In the next section, an overview of the experimental setup designed to investigate the relationship between runoff flow and the pattern of staining would be given. The staining mechanism for ledges, joints misalignment, protruding fixtures and louver units will be investigated based on case studies and supported with experimental simulations.

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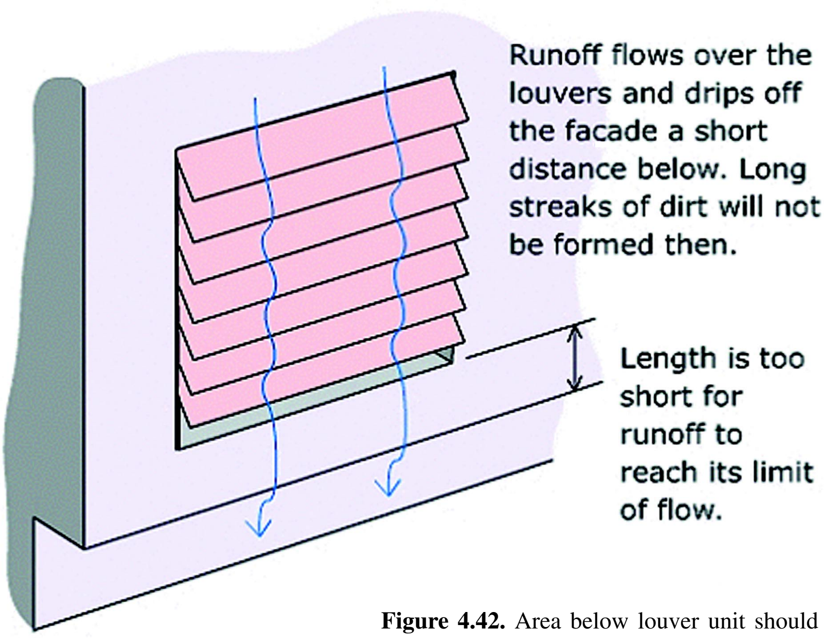


Figure 4.42. Area below louver unit should be kept small so that runoff could be drained away before it reaches its limit of flow.

4.6 Experimental Methodology

To verify the pattern of staining around a design feature caused by runoff flowing over it, an experimental setup capable of reproducing impacting rainfall is devised as shown in Fig. 4.45. The setup was devised based on experimentally sound models used to study wind-driven rain patterns over a building facade [17–22]. The subsequent runoff flow pattern generated over a typical facade feature can then be investigated [23].

A nozzle was used to produce a full-cone spray pattern completely filled with spray droplets (Fig. 4.46 and 4.47). This nozzle is able to provide a round coverage. By using a combination of a few such nozzles, impacting rain can be realistically simulated with overlapping areas representing areas receiving heavier rainfall. The feature under test can thus be subjected to similar on-site conditions of irregular rain volume

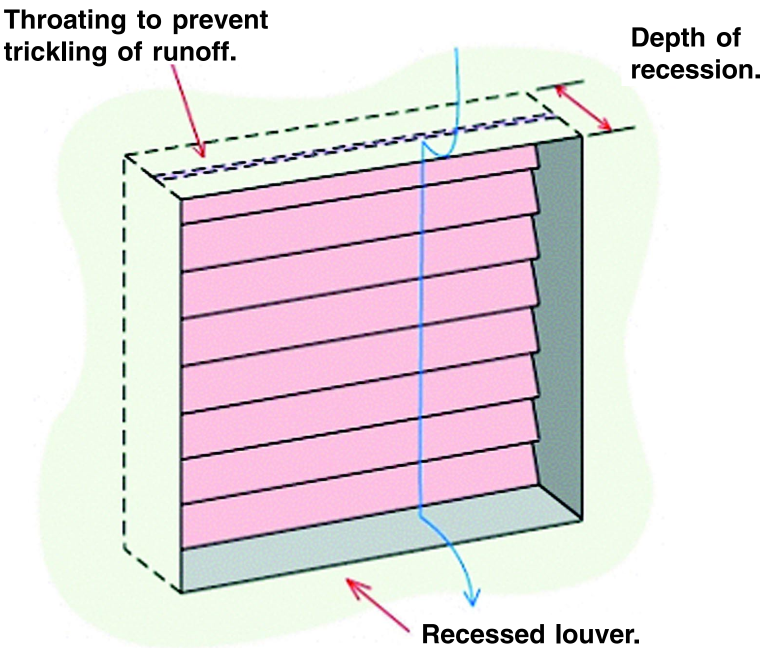


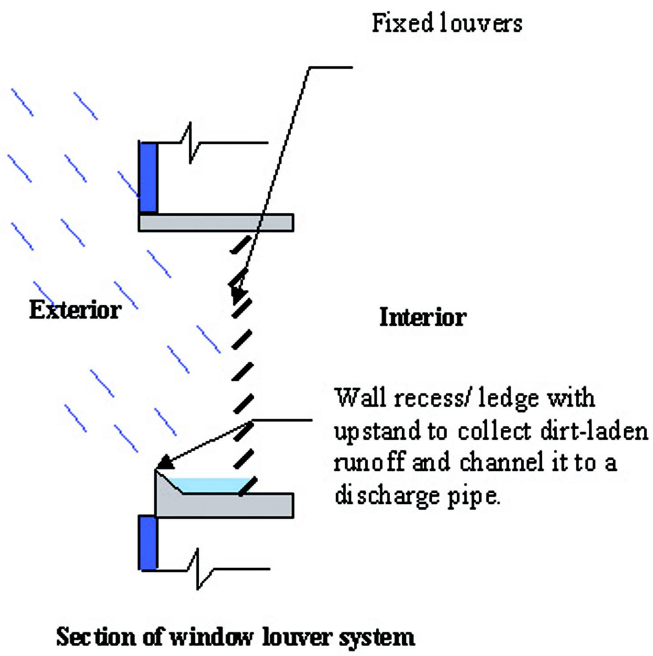
Figure 4.43. Runoff flow pattern after recessing the louver unit into the facade.

and flow rate. The subsequent flow pattern over the feature can thus be a combination of impacting sprays and runoff from above.

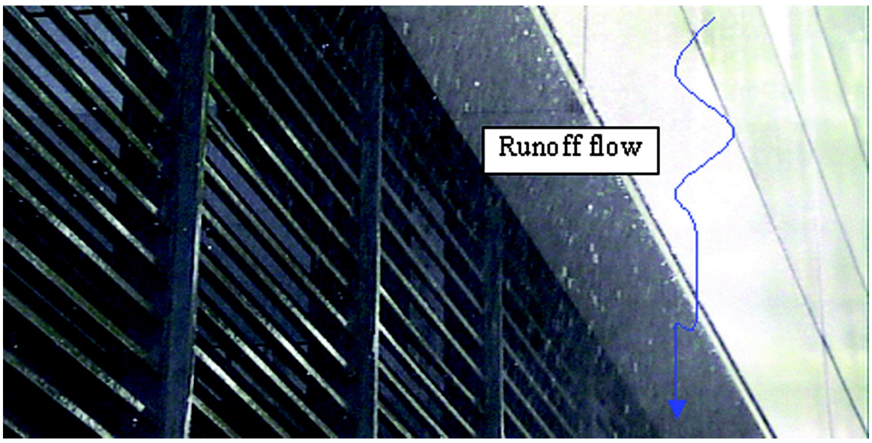
4.6.1. Methodology

With the experimental setup, facades that contain representations of the design features concerned were subjected to the rain simulation test. Observations were made on the runoff flow pattern 5 and 60 seconds after the water supply has been turned on, and 5 seconds and 15 minutes after the water supply has been turned off [23]:

- **5 seconds after water supply is turned on:** Synonymous with when the first few droplets of rain impact the facade and the initial runoff flows over a dry facade.



(a)



(b)

Figure 4.44. (a) Up-stand at horizontal recess (cross sectional view). (b) Louvers to be recessed into the facade to minimise surface flow of water over them.

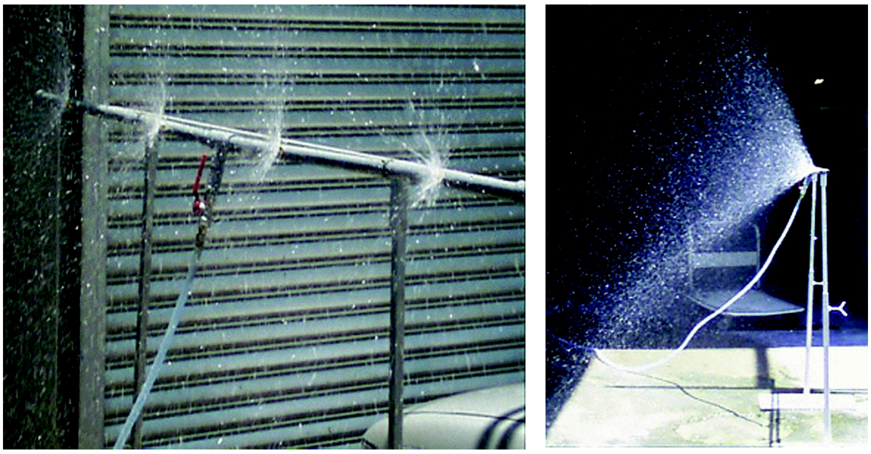


Figure 4.45. Experimental setup.

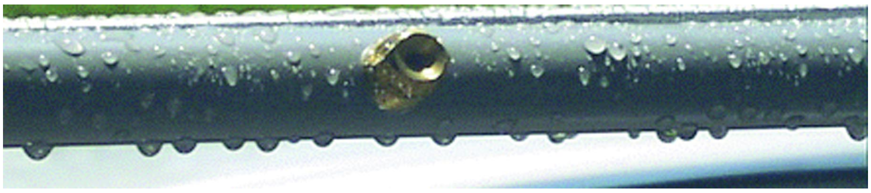


Figure 4.46. Nozzle used to simulate rainfall.

- **60 seconds after water supply is turned on:** Even wetting would have occurred and runoff flow would be regular and continuous. Synonymous with a heavy downpour at its heaviest intensity.
- **5 seconds after water supply is turned off:** Generation of runoff would have ceased; runoff flow would have slowed down and beginning to dry out. Synonymous with the period immediately after a light rain has stopped.
- **15 minutes after water supply is turned off:** The design feature would have nearly dried out and stain marks would have become more visible.

This simulation was used for the investigation of the various design features mentioned in the preceding sections.

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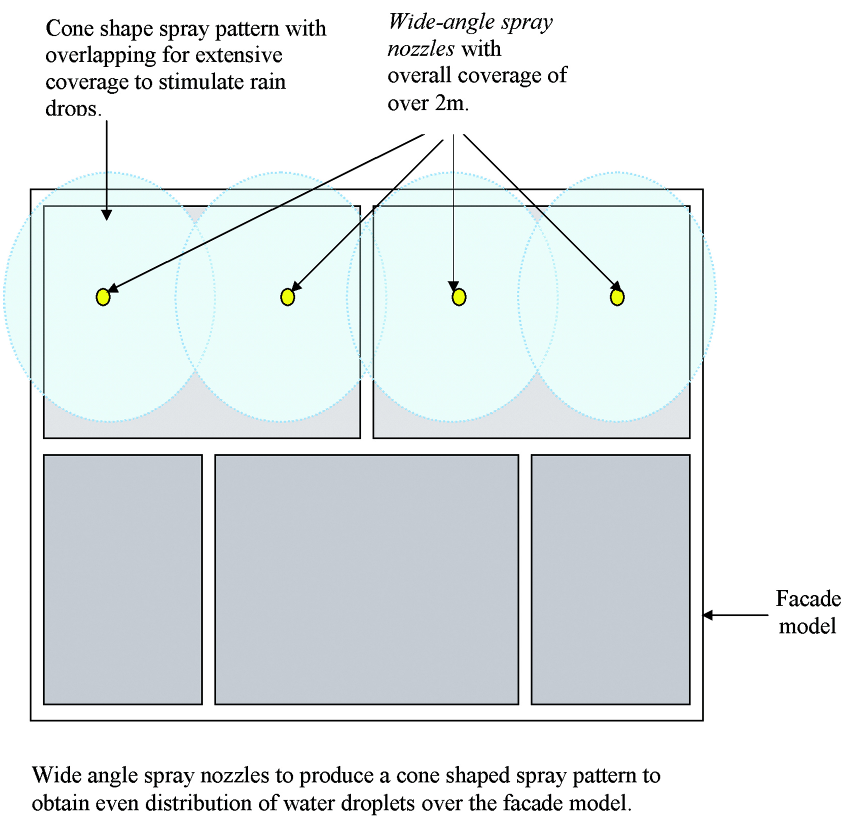

Figure 4.47. Spray pattern on facade using spray nozzles.

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