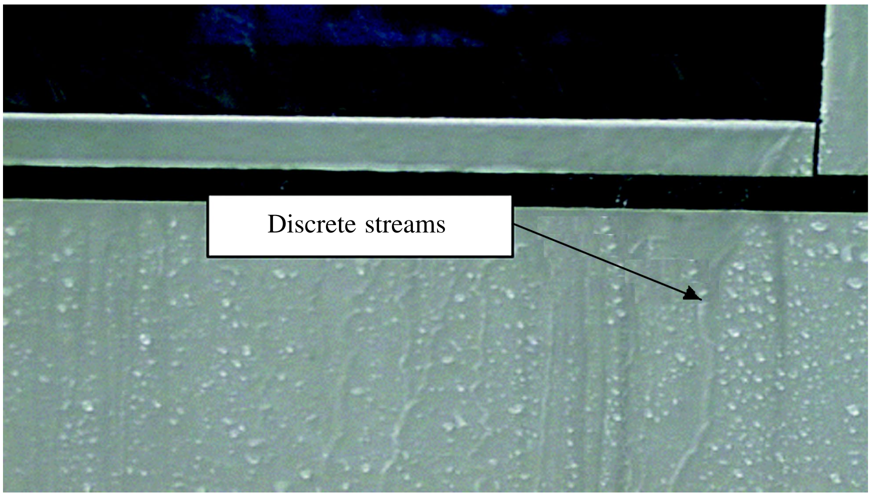


Figure 3.31. Hydrophobic nature of aluminum results in discrete streams.

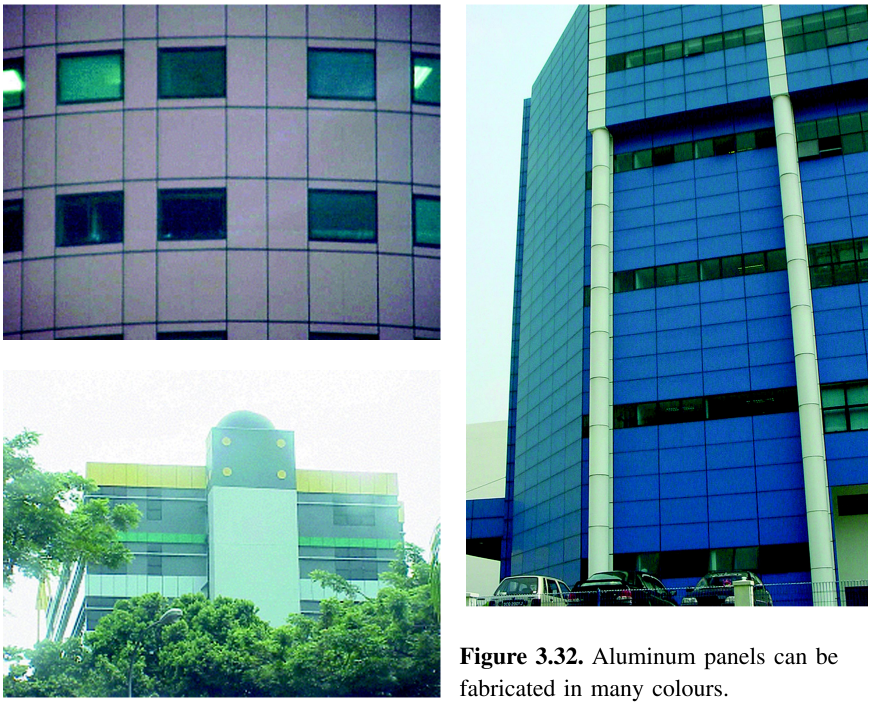


Figure 3.32. Aluminum panels can be fabricated in many colours.

The main characteristics of metal cladding are:

- High strength but light-weight.
- Non-combustible.
- Weather resistant.
- Ductile.
- Offers a wide variety of trapezoidal profiles and coloured finishes.

Stainless steel, bronze and copper have also been widely used as cladding materials in other countries [19]. Aluminum cladding has overtaken steel in terms of popularity due to its strong, light, stable and adaptive qualities. With the right finish, aluminum will retain its appearance for many years even with little maintenance. Aluminum can be finished by a number of methods. Due to the Singapore's tropical environment, aluminum is usually finished with hardwearing fluorocarbon coat (PVDF). Anodising — a process whereby a hard patina that prevents further deterioration of the surface is produced — can also be used.

During heavy rainfalls, rainwater that impacts on the facade will generate runoff to bring about an efficient washing effect. However, the washing effect during a light rainfall is weak and may result in localised staining arising from dirt absorption, erosion and deposition. The degree of staining depends on the facade design and wetability of the facade material. Aluminum has an absorption coefficient of almost zero.

Figure 3.33 shows the vertical streaks of stains below the whole length of a ledge. This is due to airborne dirt accumulating on the

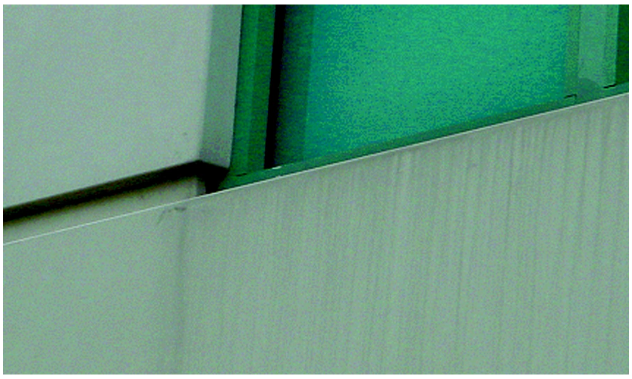


Figure 3.33. Stain streaks originating from a window ledge.

horizontal window ledge and later washed down by the runoff. These streaks are more visible against the light coloured panels. Figure 3.34 shows more severe dirt staining problems on fluorocarbon coated aluminum cladding. Long-term exposure to polluted air and chemical rain coupled with little or no maintenance has allowed the stains to build up. Chemical attack from cleaning solutions or abrasions from the use of wrong cleaning agents and equipment may also cause deterioration of the surface.

Figures 3.35 and 3.36 show staining associated with recessed or protruding joints, detailing faults and other factors. Chemical rain brought about by highly polluted air in urban and industralised areas is one of the causes of staining. Erosion of the facade over time due to chemical rain has degraded the facade and weakened the coating's resistance to chemical attacks, thus making it easier to attract dirt. Deterioration of sealant between metal panels can also cause staining (Fig. 3.37).

Biological growth such as algae and moss may also stain metallic facades. Algaes thrive on the thin film of moisture on the panels. Their growth may be supported by the presence of organic particles in the

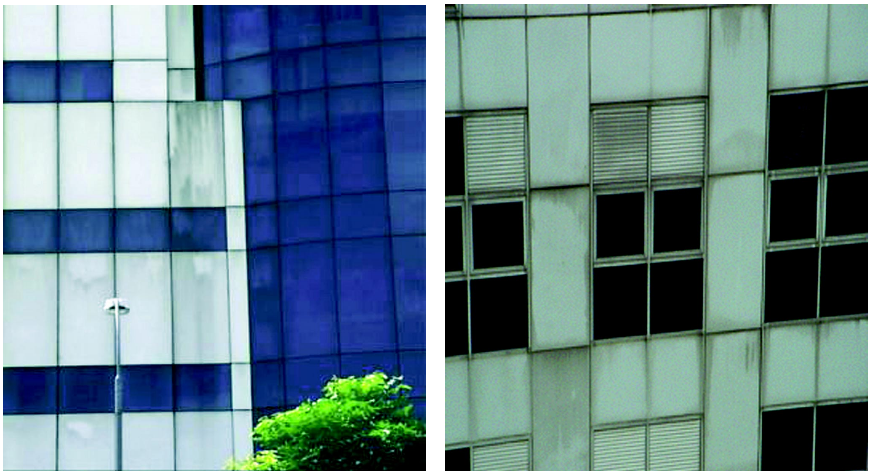


Figure 3.34. Dirt stains on light coloured aluminum panels show off even more.

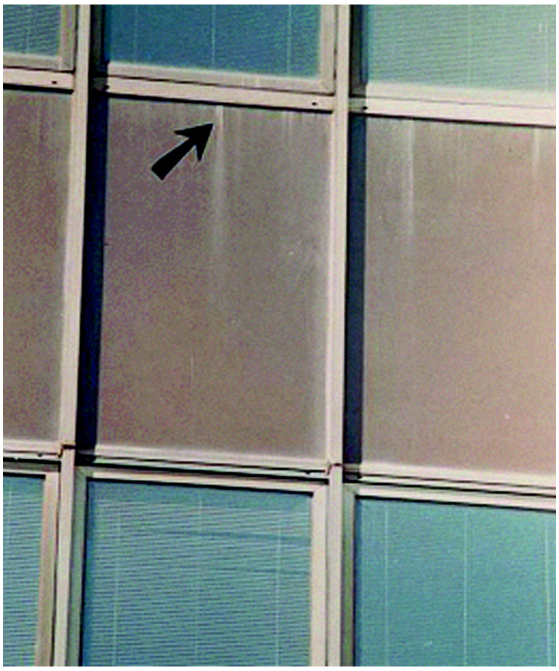


Figure 3.35. Staining on enamel steel

Figure 3.36. Staining on enamel steel resulting in corrosion of panels.

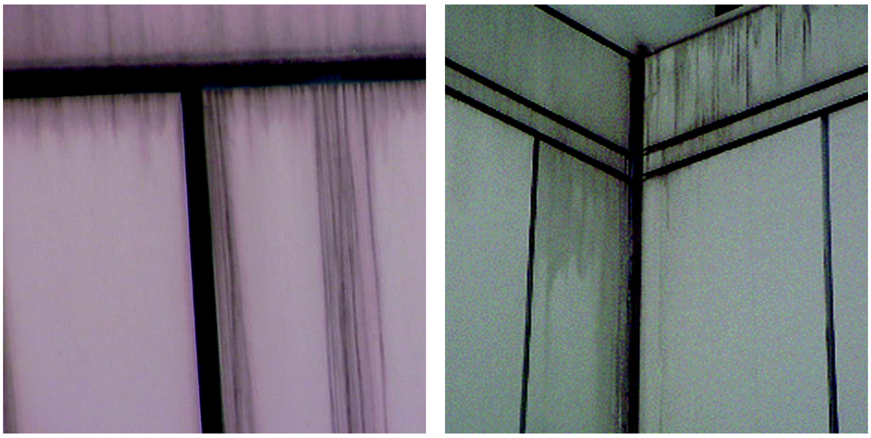


Figure 3.37. Sealant failure resulting in black stains.

Figure 3.38. Biological growth on facade at ground level and in proximity to vegetation.

atmosphere or by the organic substances present in the fluorocarbon coated metal panels (Figs. 3.38 and 3.39).

Figure 3.39. Biological growth on facade panels at 4th storey and in proximity to trees.

3.7 Glazing

The use of large glazing panels on facades has become widespread due to improvements in technologies which enable glass to span many floors but yet withstand high wind loadings, and also due to building owners becoming more willing to spend lavishly for higher aesthetical qualities for their buildings (Fig. 3.40). Glass is usually used at vision areas as infill materials for curtain wall systems.

The material properties of glass with respect to staining problems are summarised in Table 3.7.

Figure 3.43 shows dark streaks below the joints. The open joints coupled with glass's hydrophilic nature trap dirt. When rainwater runoff flows over the joints, the dirt is washed out to stain the glass. Like metal, glass has an absorption coefficient of zero. Hence, during heavy rainfall, impacting rainwater and its runoff is able to effectively wash off general dirt stains from glazed surfaces. This allows glass to have a "self-cleansing effect". However, when the rainfall is light and intermittent, the runoff generated flows in discrete streams and does not provide an efficient washing effect. This results in dirt streaks forming almost immediately. Over time, the aesthetic quality of the glazed facade is affected. Intermediate roofs or projections without adequate drainage system or features to "throw out" the rain water, will result in accumulated dirt on the roof surface, and this will be washed down onto the facade surface, resulting in obvious streaking (Fig. 3.44). The pattern of the streaking is determined by the rain flow pattern, which in turn, is determined by the design profile, material, wind, etc. (see Chapter 4).

In cases where sealant is used between glass panels, its chemical make-up and electrostatic nature may attract and retain dirt. When rain water runs over the sealants, loosely held dirt particles will be dislodged and carried downwards to form stain streaks that originates from the

Figure 3.40. Buildings clad entirely in glass exude modernity.

Table 3.7. Characteristics relating to the staining problems of glazed facades.

Glass / Properties	Glass
Porosity (%) (volume of pores/total vol. of whole material)	Not applicable.
Water Absorption [(saturation wt.- dry wt.) /dry wt. of material]	~ 0. All of the rainwater forms runoff. Hydrophobic property results in discrete streams and prevents even washing. May result in non-uniformly stained walls on wall areas directly below glazed areas (Fig 3.41). Walls below glazing should be materials with colour or texture which can mask the stain streaks [1].
Surface Texture	Very smooth. Microscopic cracks exist on surface. Hydophilic nature causes a thin moisture to form on glass.
Colour	Can be coated. Usually gray, bronze or green. Coating should be balanced with daylight transmission and views to outside. Dark coats can mask stains (Fig. 3.42).
Resistance to Chemical Attacks	Affected by lime, caustic soda, ammonia and strong acids usually from cleaning solutions. Airborne acids, alkali and solvents from industrial sources may damage the coating of glass [20].
Resistance to Biological Growth	Inert to attacks. But film of moisture may promote growth.
Relevant Standards	BS 952 –1:1995, BS 4254:1983, BS 5516:1991, BS 6262:1982, BS 5889:1989, ASTM C719-98, ASTMC603-97, ASTM C510-90, ASTM C792-98, ASTM C793-02, ASTM C1087-00, ASTM C1193-00.

Figure 3.41. Staining of stone walls due to water running off from glass.

Figure 3.42. Glazed facade with different tints and reflectivity.

Figure 3.43. Staining on glass originating from open joints.

sealant joint. Disintegration of sealants worsens the staining problem (Fig. 3.45). Exposure to heat and moist conditions in the form of rain, dew and high humidity has caused many sealants to fail prematurely. The hydrolysis of the polymer chemically produces hydroxyl radicals in the presence of sunlight. This product is detrimental to the structure of sealants and may result in leaching of plasticisers and stabilisers [14]. This may result in the upward migration of plasticisers and stabilisers in the sealant as shown in Fig. 3.46. Figure 3.47 shows staining on glazed surfaces due to the deterioration of sealant.

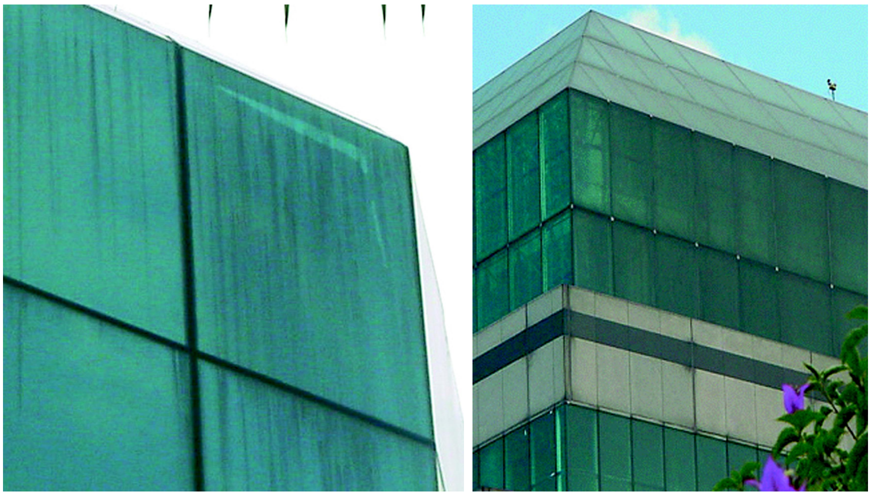


Figure 3.44. Accumulation and washing off of dirt from the sloping roof causes staining on the glass facade.

Figure 3.45. Sealant between the glass panels retains dirt and causes staining to be more severe.

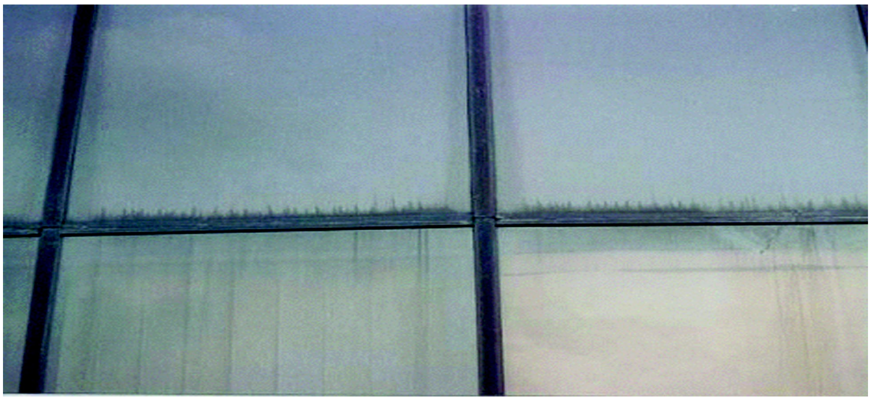


Figure 3.46. Upward migration of plasticisers and stabilisers in the sealant causes the stains shown.

Figure 3.47. Staining of glass due to corrosion of sealant.

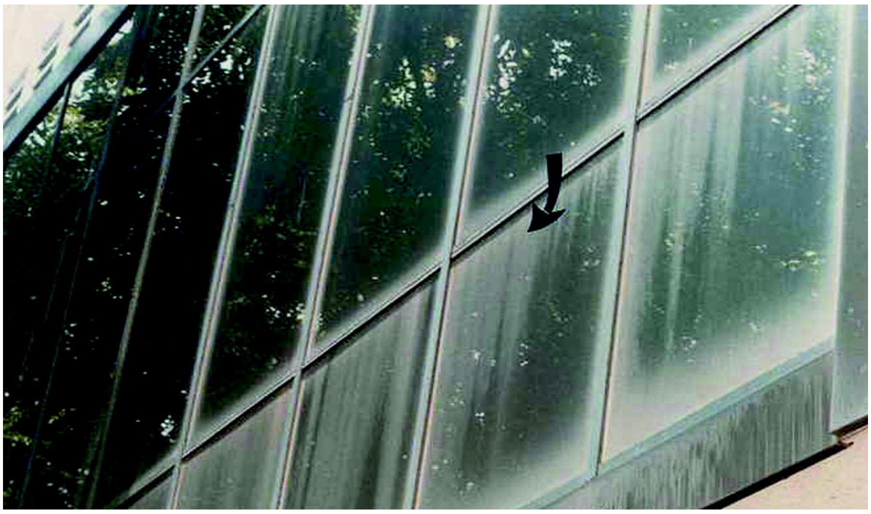


Figure 3.48. Staining of glass due to corrosion of transoms and mullions

In some cases, corrosion of other components that make up the facade may cause staining to glass (Figs. 3.48 and 3.49). When cementitious adhesives are used in a glass facade, rainwater hitting the facade may carry the soluble salts in the adhesive to the surface, which will form efflorescence on drying.

Facades that are exposed to direct sunlight, prolonged rainfalls and in close proximity to vegetation may be prone to algae attack (Fig. 3.50).

3.8 Plaster and Paint Surface Coatings

Two common surface coatings used in the region are plaster and paint. The characteristics of plaster and paint are summarised in Tables 3.8 and 3.9 respectively. Plaster and paint coatings serve as decorative, functional and protective coverings which upon spreading over a surface, will dry into a continuous solid film. Plaster and paint can come in different colours and textures. Table 3.10 shows some examples of various types of finishes, smooth or textured, that is available with plaster.

Figure 3.49. Staining from weepholes results in a regular staining pattern throughout the facade.

Figure 3.50. Algae growth on glass.

Table 3.8. Characteristics relating to the staining problems of exposed plaster facades.

Exposed Plaster / Properties	Textured Finish	Plain Finish
Porosity (%) (volume of pores/total vol. of whole material)	Depends on size and proportion of aggregates.	
Water Absorption [(saturation wt.-dry wt.) /dry wt. of material]	Determined by the water/plaster ratio of the mixes [21]. If plaster is made denser, the water absorption level will reduce.	
	Flow of rainwater over the surface is distributed. Staining is thus more distributed.	Flow of rainwater over surface is concentrated. Staining is thus more concentrated.
Surface Texture	Traps and retains dirt easily. Textured and rough surface may mask stains.	Stain streaks may show easily.
Colour	Different colours can be obtained by adding colour pigment to mix. Light colour shows off stains.	
	Uniform appearance for paints can be easily achieved.	Uniform appearance for paint may be difficult to achieve.
Resistance to Chemical Attacks	Prone to chemical attacks due to aggregates used. Gypsum plaster may suffer attacks from Portland cement due to formation of calcium salts [22].	
Resistance to Biological Growth	Water may get trapped in the plaster layer and accelerate biological growth. Organic material present in the plaster mix may encourage biological growth.	Prone to biological attacks, but less than textured surfaces. Constituents in plaster mix may encourage biological growth.
Relevant Standards	BS 8000-10:1995, BS 5262:1991, BS 1191-2:1973, BS EN1015-19:1999, BS 00/106850 DC prEN 13914-1, BS 00/103730 DC prEN 998-1, ASTM C897-00, ASTM C932-98a	

Although many coatings are able to "breathe" out any moisture trapped beneath the coating, the rate of evaporation may not be fast enough and this provides a breeding ground for algae and fungi. When the colour of plaster or paint is light, staining would be readily visible.

Figures 3.51 and 3.52 show dark stains on plaster-and-paint surfaces arising from dirt deposition. The textured surfaces of plastered walls are capable of trapping and retaining dirt particles. When runoff flows over

Table 3.9. Characteristics relating to the staining problems of painted facades.

Paint Systems on Plastered, Concrete or Brick Walls / Properties	Acrylic Co-Polymer Emulsion	Veova (Modified Acrylic) Emulsion	Epoxy	Acrylic Emulsion	Solvent-Based Acrylic	High Performance Acrylic Emulsion	2-Pack Poly-Urethane	Texture Coating Water-Based Acrylic Topcoat	Texture Coating Poly-Urethane Topcoat
Porosity (%) (volume of pores/total vol. of whole material)	Depends on overall system.								
Water absorption [(saturation wt.-dry wt.) /dry wt. of material]	Depends on overall system.								
Surface Texture	Textured.	Luxurious sheen emulsion that gives a smooth and silky appearance.	Textured.	Decorative, high build, textured, non-gloss.	Satin finish.	Smooth.	Various textures may be created with different types of brushes.	Textured.	Textured.
Colour	Matt.	Sheen.	Low gloss/ gloss.	Matt.	Semi-gloss.	Low sheen.	Good gloss retention.	Semi-gloss.	Gloss.
Resistance to Chemical Attacks	Good.	Very good.	Excellent.	Good.	Very good. Good durability to weather.	Very good.	Excellent. Good weathering resistance.	Very good.	Excellent.
Resistance to Biological Growth	Good.	Good.	Excellent.	Good.	Very good.	Excellent.	Excellent.	Very good.	Excellent.
Relevant Standards	SS CP 22:1981, SS 5, SS 7:1998, SS 34:1998, SS 150:1998, SS 345:1990, Good Industry Practices- Painting (BCA)								

Figure 3.51. Dirt staining of Shanghai plaster.

Figure 3.52. Dirt staining on a smooth plaster-and-paint wall.

the surface, it flows along depressions and crevices of the rough surface. Any dirt that is picked up along its path is redeposited. The flow pattern causes the resultant dirt stains to be distributed. On smooth plaster surfaces, staining may also occur but the staining pattern is likely to be less concentrated as dirt particles are washed along in more even and

Table 3.10. Types of plaster finish.

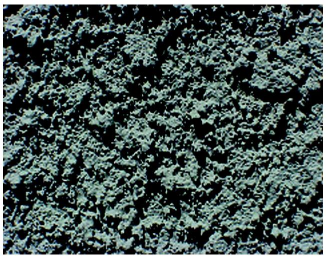
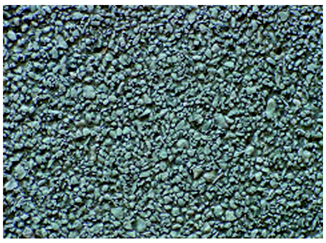
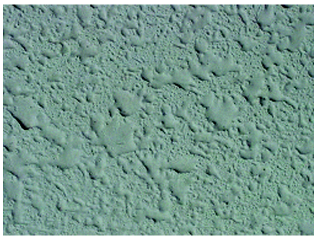
1) Smooth 	The final coat is finished with wooden trowel or steel trowel and is made rather flat and smooth. In Singapore, most of plain finishes are painted.
2) Textured 	Apply scraping or rubbing on 2nd coat when it is still not completely hardened by using hand tools or trowels.
3) Rough cast/pebble dash 	Consists of 2 coats. The final coat is applied by throwing small pebbles or other coarse aggregates onto the 1st coat and left untrowelled. The coarseness of the texture depends upon the size and shape of the coarse aggregate used.
4) Shanghai plaster 	Coarse aggregates of small pebbles are added to the mix of the final coat to achieve a rough textured finish. Before the surface hardens, it is scrubbed with fibre brushes to expose the aggregates and then rinsed off with water.

Table 3.10. (*Continued*)

5) Scraped finish

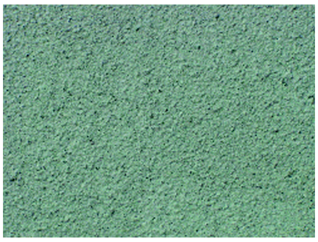
Scraped finish is a textured finish. The final coat of mortar is allowed to harden for several hours and the surface is then scraped with a suitable tool to remove the outer surface and some of the coarser particles.

6) Spattered finish



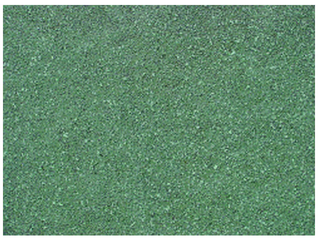
The spattered finish is produced by a hand-operated machine which flicks droplets of a workable mortar onto the wall where they set and harden.

7) Machine sprayed finish



Power-operated machine can be used to apply the plaster.

8) Rubbed machine sprayed finish



Some days after a plaster has been sprayed, it may be rubbed with a tool to produce a smooth flat outer surface with remaining texture.

concentrated flows. The washing effect on a smooth wall is greater and more effective in times of heavier rainfall.

Certain organic materials that support biological growth may be present in the aggregates that make up plaster. The use of such composition may result in biological staining (Figs. 3.53 and 3.54).

Painting is commonly done on plaster walls to enhance its aesthetic qualities. Paints are relatively permeable to liquids and gases. Depending on the type of paint system used, the water absorptivity and chemical resistance of the overall wall system can be improved. Table 3.9 shows the various characteristics of different paint systems with respect to staining [23, 24].

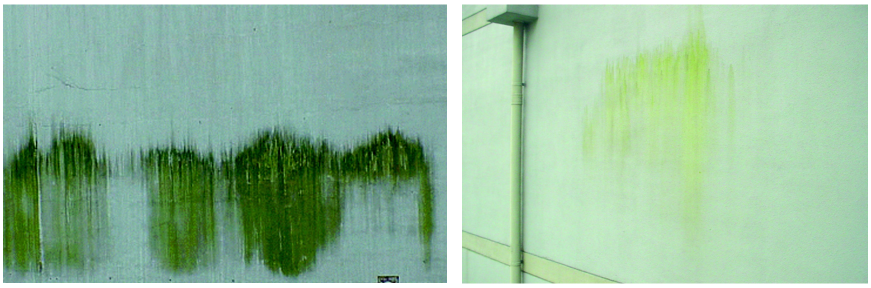


Figure 3.53. Biological staining on plaster walls.

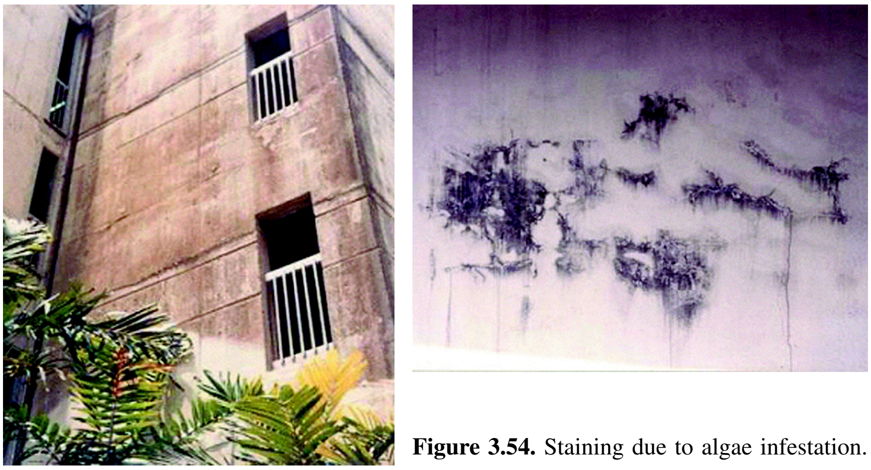


Figure 3.54. Staining due to algae infestation.

3.9 Material Interfaces

Facades are usually made up of more than one material either because different materials are required for their characteristic functions or a combination is neccesary to increase the aesthetic qualities of the facade. The use of different materials on a facade, whether necessary or not can lead to visual changes in the form of stains, if the materials are not chemically compatible. Therefore, besides understanding the characteristics properties of individual materials, it may also be important for the designer to know the effects due to the interaction of different materials when put together. Table 3.11 summarises the interactions between different materials when they are used in combination [6].

3.9.1. Bricks — Concrete / Plaster

Both concrete/plaster and brick mortar contains calcium hydroxide and alkaline salts. Calcium hydroxide efflorescence on the surface reacts with carbon dioxide to give insoluble calcium carbonate, which causes white encrustations on the adjacent material as well as on the material itself. Alkali salts found in cement also causes efflorescence. Bricks that exude sulphates should not be located against concrete or mortar which is susceptible to sulphate attack.

3.9.2. Bricks / Concrete / Plaster — Natural Stone

When large amounts of runoff flow over bricks, concrete or plastered surfaces, lime products from them or from their mortar joints may be deposited on the natural stone. Bricks contain certain salts, which may cause them to efflorescence but also discolour the natural stone.

3.9.3. Bricks / Concrete / Plaster — Glass

The surface of glass may be stained and damaged by the runoff carrying alkali silicates extracted when the runoff flows over brick mortar, fresh

Table 3.11. Material interfaces [6].

Facade material	Brick/Concrete/Plaster (above)	Natural Stone (above)	Glass (above)	Metals (above)	Paints (above)
Brick/Concrete /Plaster		No effect.	Runoff generated easily runs onto the bricks and causes bricks to remain damp for a long period of time. Implications for algae growth. Dirt streaks may form on bricks.	Runoff generated easily from metal surfaces runs over the bricks and results in clean strips on bricks below vertical member elements.	Chalk particles from paint chalking deposited on underlying materials are difficult to remove.
Natural Stone	Lime products from brick mortar can be deposited on natural stone. Brick contains salts which can cause efflorescence but also discolour the natural stone.		Runoff generated easily runs over natural stone and result in clean strips below vertical member elements.	Metals may produce fine oxidizing products which will be carried away by runoff and deposited on the natural stone.	Chalking of paint produces fine chalk particles which stain natural stone.
Glass	Glass can be stained by alkali silicates extracted by runoff from brick mortar. A deposit of silica forms on the glass and is hard to remove. Calcium and alkali-containing materials are easier to remove.	Alkaline solutions of limestone may form a deposit on glass. Can be cleaned off easily.		Streaking due to deposition of dirt onto glass surfaces. Rust (iron oxide) stains will be difficult to remove. Metal oxides produced due to weathering and allowed to accumulate is hard to remove.	Chalking of paint produces fine chalk particles which may decrease visibility of vision glass.
Metals	Lime products from brick mortar can show white streaks on dark coloured metal surfaces.	Alkaline solutions of limestone may attack and cause deterioration to aluminium.	Dirt running off glass surfaces can soil light-coloured metal panels.		Chalking of paint produces fine chalk particles which may stain dark coloured metal surfaces.
Paints	Calcium hydrate products react with paint pigments causing it to discolourize. Alkali salts could cause peeling of paint coatings.	No effect.	Increased washing effect on painted surface. May cause discoloration.	Increased washing effect on painted surface. May cause discoloration.	

concrete or plaster. A deposit of silica may be formed on the glass surface and may be hard to remove. Besides silica, calcium and alkali-containing materials may also be deposited, though these are easier to be removed. Silicone sealants used on such walls may also discolour glass surfaces. On the other hand, introduction of a glazed opening often has the effect of concentrating surface rainfall runoff and this may affect the durability of the materials in the vicinity. Runoff generated even from light rainfalls may run onto the brick, concrete or plaster wall, causing the wall to remain in damp conditions for longer periods of time. This will lead to algae growth and water seepage related stains.

3.9.4. Bricks / Concrete / Plaster — Metals

Alkali solutions leached out from mortar may react and cause metal to deteriorate. Aluminum in particular may dissolve when attacked by alkali. Conversely, when metal cladding is located above brick, concrete or plaster wall, runoff that is generated easily from metal surfaces will run over the wall and result in clean strips on the wall below vertical member elements. Such areas receive heavier runoff flows and is washed over more frequently.

3.9.5. Bricks / Concrete / Plaster — Paint

Calcium hydrates from mortar may react with certain pigments in paints to cause discolouration. Alkali salts running constantly over painted surfaces could cause peeling of the paint coatings. Products from the deterioration of paint such as fine chalk products from paint chalking may be deposited on underlying materials. These particles are very difficult to remove.

3.9.6. Natural Stone — Glass

Various forms of silicates are found in sandstone. Under certain circumstances, they are soluble in water and segregate on the surface in the form of coatings on glass, which are insoluble in water and acids. Due to high absorption of some stones, they should be treated with an oil/water repellent to minimise staining especially when runoff from glazed surfaces can run over it and redeposit dirt onto the natural stones.

3.9.7. Natural Stone — Metals

Natural stone does not stain adjacent metallic materials. However, alkaline solutions of limestone may attack and cause deterioration to aluminum. On the other hand, metals may produce fine oxidising products which will be carried away by runoff and deposited on the natural stones.

3.9.8. Natural Stone — Paint

Natural stone does not affect paint. However, when stones are sealed, runoff generated may increase. This may accelerate paint deterioration. The chalking of paint to produce fine chalk products can stain natural stone located beneath it.

3.9.9. Glass — Metals

Some metals such as steels release oxides over time. These metal oxides should not be allowed to build up over glass as it results in a layer of deposit that is difficult to remove. Otherwise, both glass and metals generate runoff almost immediately during rainfalls and do not affect each other visibly.

3.9.10. Glass — Paint

These materials do not affect each other visibly, except where there are horizontal ledges. Rainfall may carry dirt that had accumulated on the ledges and wash it down the painted surfaces. This could result in visible stains.

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