Dirt on Exterior Surfaces of the Building Envelope

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1. INTRODUCTION

After a period of time the exterior surface of buildings like roofs and facades will become dirty, uneven discoloration will appear, often in patterns revealing how rain washes off the surfaces. Depending on the kind of dirt and the risk of deterioration of the surface by the dirt, the building owner after some time might choose to clean the surface. Cleaning, however, can be expensive and introduce other problems to the surface. This paper describes different kinds of dirt and their possible effects on surfaces, and methods to prevent dirt layers on exterior surfaces are indicated.

To some extent architects may desire discoloration as patina, giving the building its unique expression. But discoloration due to dirt will continue and after some time, patina of this kind is undesirable. Dirt on surfaces will in this paper therefore be considered as undesirable.

2. DIRT

The term dirt has been used to describe different kinds of layers, which in time occur on exterior surfaces; the origin of these layers can be very different. Basically dirt can be divided into two groups: Particles from the environment settling on surfaces and biological growth. The two groups seldom appear simultaneously.

2.1 Environmental Particles

Particles are transported by air to surfaces, where they settle as a layer. The rain will wash off some of the particles in unprotected areas, while areas under protective items like sills or coverings will not be cleaned by the rain. This results in darker areas under protective items.

The composition of the dirt layer depends on the environment. Soil and dust can be dominant in rural areas whereas soot and oil dominate in urban areas. Important factors for the forming and composition of a dirt layer are:

- Particle origin
- Particle size
- Weather conditions and deposition

The factors interact; the particle size depends on the origin and smaller particles are carried further by wind than larger and heavier particles. Figure 1 gives a schematic overview of environmental particles floated in the air, combining origin, size and depositing.

2.1.1 Particle Origin. Particles origin from different sources. Spindler (2001) describes that some particles probably form from CO_2 emission, e.g. seen as blue haze over large woods. More acknowledged is that particles arise from fossil fuel burning, industrial processes or are mechanically generated.

Many of these processes involve carbon; the content of carbon and soot is therefore often very high in environmental particles. The smaller the particles from urban areas are, the higher the

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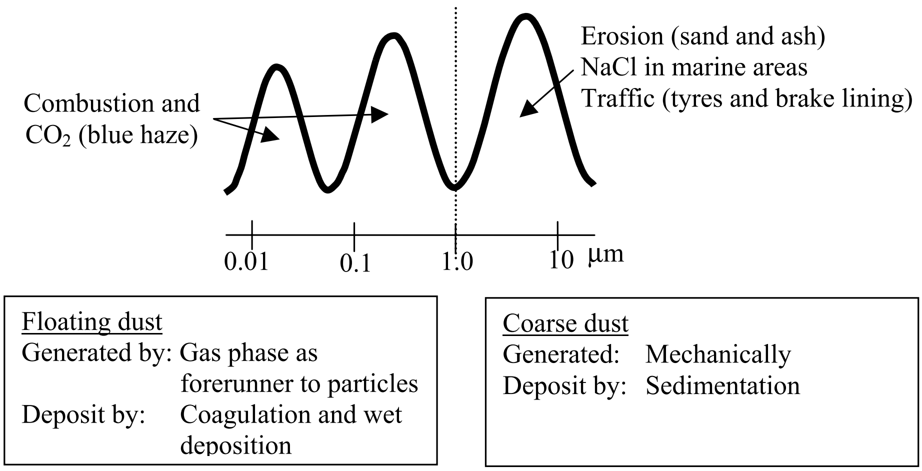

Figure 1 Schematic overview of environmental (non biological) particle size distribution by volume, origin and deposition on surfaces. (Spindler 2001 and Bagda 2001)

carbon content, revealing that the sources are fossil fuel burning and diesel soot. Figure 2 demonstrates how particles from different sources through emission react with water in the air and later deposit on surfaces.

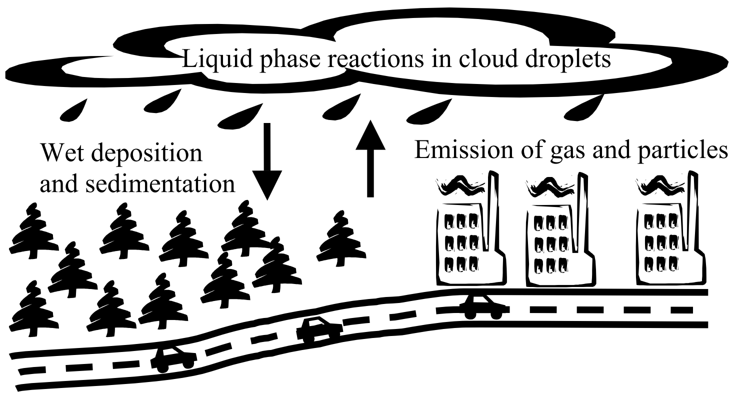

Figure 2 Particles of different origin react in gas phase, but mainly with water in liquid phase. In the clouds particles absorb water, leading to droplets, which finally will return as raindrops, depositing particles on surfaces. (Spindler, 2001)

2.1.2 Particle Size. Particles smaller than 0.01 µm are not stabile in the atmosphere; they will either react with oxygen or coagulate to larger particles. Emission of gases and particles by industry and cars generate particles up to 1 µm. Coarser dust, with particles larger than 1 µm, is generally generated by abrasion. The particle size distribution varies with the environment, but generally the bulk of the particles are < 1 µm, both measured on mass, volume and on numbers. (Spindler 2001).

2.1.3 Weather Conditions and Deposition. While larger particles sediment quite soon, because of their weight, smaller particles < 1 µm are floated in the air for days or weeks, during thattime, they can be transported over 1000 km before they deposit. The particles are washed out in clouds or rain, a high content of water-soluble salts, especially in "urban" particles, lead to wet deposition.

Large particles sediment on horizontal surfaces (e.g. sills or on horizontal parts of a rugged facade). To some extent the rain can clean unprotected parts of these surfaces, but often leaving a trace of dirt. Small particles do not sediment in the same way. Bagda (2001) claim that gravity is not the main reason why particles < 1 µm end on surfaces, instead the particles are drawn by forces of adsorption and electrostatics. According to his theory the chemical composition of a surface determines whether small particles deposit or not, while only the physical appearance is significant for the sediment of larger particles.

2.1.4 Standardized Environmental Particles? One of the goals in this field of research is to be able to predict how a surface will smudge. Standardized tests instead of time-consuming field tests would be helpful when developing new surface treatments. There is a variety of standardized durability tests, but for the time being only few standardized accelerated field tests or laboratory tests on smudging. Furthermore, the correlation between the test results and practical results is under discussion (Born, 2001).

To be able to do standardized tests on how surfaces get dirty, some kind of standardized dirt with a given composition and size distribution would be necessary, but results obtained with one kind of dust may not apply to other kinds. Results from tests with standardized dirt (applied by a standardized method) must be worked up to apply for other environments. Different approaches are possible; methods from structural design or service life estimations, where results are multiplied by a factor depending on the environment compared to the standard environment could be one way. Another method would be using different dusts to resemble e.g. rural or urban environment. A combination of the two methods could give a hint on how susceptible different surfaces are to dirt, but probably not an effective method to predict how a given surface in a particular environment will smudge.

An extra difficulty in predicting how surfaces smudge in nature is that the environment varies over time. The particle composition varies over the year, because of the heating in winter. But there are also changes over a longer period of time. The traffic amount might rise, but new filters are installed, heating systems change from individual heating systems to larger plants with effective filters. Even if standardized dirt and applying methods were available, environmental changes could change the picture entirely.

2.2 Biological Growth

A fast indication of whether discoloration is caused by biological growth or environmental particles can be obtained by observing the smudging pattern. Environmental particles are transported by water and to some extent also washed away by rain, leaving exposed surfaces cleaner than other parts. Biological growth, on the other hand, is typically seen on exposed surfaces that for some reasons are moist. Through a microscope the difference is often clear, because of the spores and mycelium in for instance moulds. However, sometimes it can be useful to apply the unknown dirt layer to agar plates, especially when deciding whether the matter is alive. This method is also useful in identifying the genius of the biological matter.

Biological growth on surfaces can be moss, lichen, algae or moulds. These are hardy species; nutritious matter can be found everywhere in nature, and if only the right moisture and heat conditions occur often enough, and the environment is not toxic, biological growth will appear. Biological growth is often seen near leaking downpipes or gutters, where the moisture content of the material is very high, but also on surfaces without unusual water supply, biological growth is seen. Figure 3 shows an example of this.

Figure 3 The southeast corner of a 2-year-old building with extensive mould growth of Cladisporium herbarum, a common outdoor mould. The building has exterior insulation with rendering. The growth appears on all 4 sides of the house.

In Denmark biological growth on surfaces has not been systematically registered, but among professionals in the building trade there seem to be a general feeling that the problem with biological growth on surfaces has increased during the lastest years. Different theories on why the conditions for biological growth might have improved are numerous:

- After the energy crises in the '70s, the insulation in the buildings has increased, in new building by thicker layers and in old building by adding extra insulation. This means that the temperature of the material on the cold side of the insulation decreases. An example: A ventilated roof construction; in clear nights heat radiation results in lower exterior surface temperature than outdoor temperature, causing condensation on the roof. The roof will be more susceptible to biological growth.
- External insulation with a thin cover of rendering is a relatively cheap way to enhance the insulation in older buildings, but the rendering has only a small heat capacity compared to the traditional Danish brickwork. The risk of condensation at night is therefore larger at walls with external insulation. (Künzel et al. 2001).
- The nitrate content in the air is increasing. Although only small amounts of nutritious matter are enough to support biological growth, large amounts seem to enhance the growth. Large pig farms are typical examples of this, the roofs and walls are rapidly covered with a green layer of biological growth.
- Biological growth is sensitive to the pH-value, and after the acid rain is no longer as acidic as 10 years ago, the conditions have improved.
- Increasing environment awareness means that less toxic materials and chemicals are used in surface treatments and cleaning methods.
- The latest 5 winters in Denmark have been relatively warm and wet, improving the conditions for biological growth.

If biological growth is an increasing problem, the reason might be among these theories or in combination of these. At the moment a research project (Project "Cleaner Technology for avoiding biological growth on brickwork, tile and concrete roofs") financed by the Danish Environmental Protection Agency (Miljøstyrelsen) look into biological growth on surfaces, classifying what species grow on different surfaces and under what conditions. When this is known, it might be possible to validate the theories above.

3. POSSIBLE EFFECTS OF DIRT

Dirt on surfaces is generally not seen as a major problem because it does not involve any safety consequences unless it covers signs of deterioration. But the dirt is visible, and it is therefore natural to ask what effect the dirt has on the building.

3.1 Aesthetics

Aside from some romantic ideas on how old houses should look, a too visible dirt layer on a building is an aesthetical failure, regardless of its origin. This kind of aesthetical problem is to some building owners unacceptable, as it can be seen as neglect and ignorance. This may cause an image problem or even accelerate; if nobody seem to care how a building look, the risk of graffiti increases, the area becomes less attractive and finally the crime rate increases. Dirt on surfaces can probably not cause this alone, but is an important factor in the course.

In the case shown in Figure 3 biological growth is unacceptable, the building is new, placed in walking distance from the old town of Stockholm with a view over the archipelago. Although there is probably no other damage than aesthetical, the reason for the growth must be determined and the facades will have to be cleaned. Also in old houses the reasons for refurbishment is often other than severe damage like deterioration. A Finnish study (Aikivuori, 1999) of the town Oulu has shown that only 17% of refurbishment in the private sector has failure due to deterioration as primary cause, while 44% has subjective features of the decision maker as primary cause. Cleaning of surfaces is probably one of these reasons.

3.2 Deterioration

Deteriorated areas are often covered with biological growth, but this does not mean that the biological growth has caused the deterioration; it is more likely that the cause is water damage. It is likely that heavy biological growth may enhance deterioration; biological growth keeps the surface moist, increasing the risk of frost damage, as illustrated in Figure 4.

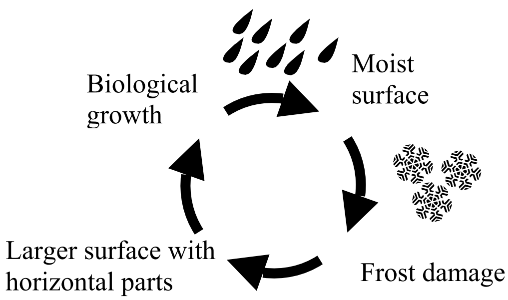

Figure 4 A vicious circle of deterioration with biological growth. Rain on biological growth, does not dry out as fast as on a clean surface, the risk of frost damage increases. When frost damage occurs, the surface will be larger with horizontal parts, where water and new biological growth have even better conditions.

Depending on the surface and the composition of environmental particles, a dirt layer can prevent the surface from deteriorating or react with the surface in an irreversible way, e.g. limestone and concrete can react with sulphate, forming a gypsum layer, which will appear as a crust, sometimes just visible to the naked eye as a discoloration.

4. CLEANING AND PREVENTION

Graffiti is a special kind of smudging of surfaces; it is a sudden solvent-based smudging in a well-defined area, quite different from “natural” smudging. A typical precaution against graffiti is an anti-graffiti treatment, which will ease the cleaning. The treatment must therefore not only be water and oil repellent but also have easy-to-clean properties (Weißenbach et al 2001). The wide field of anti-graffiti treatments will not be treated further in this paper.

4.1 Cleaning

After years of exposure to the outdoor environment, cleaning the surface may be necessary to restore the original expression of the building. There are numerous ways to clean a surface; from abrasive techniques like sandblasting to laser cleaning and water spraying. The cleaning method must always be adjusted to the surface and the layer to be removed, and even in a given case the possibilities are numerous, e.g. Marie-Victoire et al. (1999) describe ten different techniques tested to clean ancient concrete with a black crust. A thorough description of the different cleaning techniques is beyond the scope of this paper, just some of the factors to be considered shall be mentioned:

- *Possible damage by cleaning*. Aggressive methods may increase the surface and roughen it in a way that in the future the surface is more susceptible to new smudging. Even a mild method like letting water run down the surface for a longer period, may be damaging by leaking water into the interior of the building.
- *Costs*. Cleaning is often very work intensive, especially when the surface is decorated, most mild methods must be completed by hand brushing if no traces of dirt are acceptable. Both method and cleaning level are therefore important cost parameters.
- *Environmental aspects*. Removing biological growth can be made easier by the use of fungicides, and different solvents can help removing environmental particles. But for environmental reasons chemicals like these should be avoided.

Before a building owner decides to clean the building, the aesthetical expression has probably been poor for some time, and as stated above cleaning surfaces imply a risk of damage to the building, it is costly and may create pollution. Instead of cleaning surfaces, preventing the forming of a dirt layer must be preferable.

4.2 Prevention of Smudging

The market for dirt repellent or self cleaning surfaces is huge, and not only buildings but also windows, cars and other things exposed to outdoor environment could benefit from such a technique. Preventing environmental particles from depositing on surfaces does not seem possible, but using the falling rain to wash off the dirt is the idea of at least to different techniques used in commercial products.

4.2.1. Hydrophilic Surface. The glass Pilkington Activ has a thin transparent coating, making the surface photocatalytic and hydrophilic. UV-radiation from daylight reacts with dirt and organic deposits, oxidises them and breaks their adherence to the surface. Due to the hydrophilic surface raindrops spread as a film on the surface, ensuring that the loosened particles are washed from the surface during normal rainy weather. (Pilkington, 2001).

4.2.2 Hydrophobic Surface. The opposite of hydrophilic is hydrophobic or water repellent; on a hydrophobic surface the water does not form a film, but stays in droplets. The Lotus-effect uses this phenomenon, combining it with a rough structure. Barthlott et al. (1997) describes how a hydrophobic surface with protrusions becomes “superhydrophobic” ensuring even lower wettability of the surface.

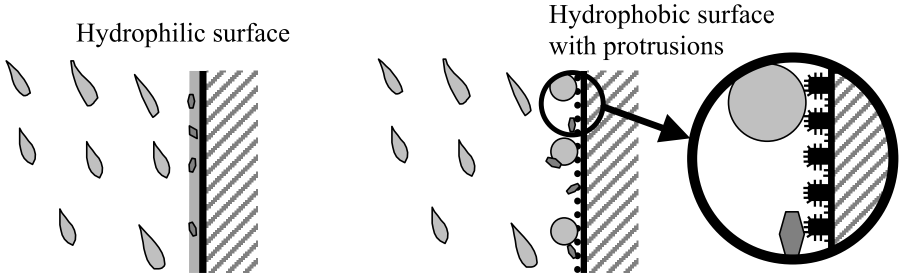

Figure 5 Two ways to create self-cleaning surfaces. Left: Rain forms a film when meeting a hydrophilic surface, because of a photocatalytic effect the particles are loose and are washed off by the water film. Right: Protrusions enhances the hydrophobic effect, particles are carried away as the droplets run off.

As shown in the enlargement of Figure 5, protrusions at a hydrophobic surface means that the drops and larger particles have very little surface contact; the droplets catch the particles as they run off. The protrusions are 10-50 µm high and with a spacing of 10-100 µm, this means most environmental would not even be visible on Figure 5. When droplets run off on top of the protrusions, it is difficult to imagine how particles situated between the protrusions can be removed, but tests on plants with a similar structure (Bartlott et al. 1997) show that also small particles (0,5-3,5 µm) are removed by falling rain. According to EP 0 772 514 B1 (1996) the explanation is that falling drops, because of their kinetic energy, for a short time are pressed between the protrusions, the particles are torn out and washed away with the drops.

Hydrophobic treatments with protrusions are quite new, long-time tests are non-existing, and some manufacturers have questioned the effect. To test the effect a field experiment with roof tiles is currently being carried out at the Technical University of Denmark (start summer 2001) as part of a PhD project. The experiment consists of 4 set ups: 2 with different slopes (12º and 45º), and 2 with different orientations (north and south). Each set up consists of 3 rows of tiles with and without the treatment. The tiles will be exposed to weather for 2 years. During the experiment the surfaces of the tiles are regularly examined in electro microscope to determine how the tiles become dirty, and to see whether the treatment has any effect. Preliminary results and pictures will be presented at the conference.

4.2.3 Toxic Agents. Biological growth can be prevented by the use of fungicides in the material, however fungicides will wash out, releasing toxic chemicals to the environment and finally no longer be effective. For environmental reasons the use of fungicides should be avoided. Different metals may act as toxic agents; lead, copper and zinc all reduce biological growth. But the metals are only effective in areas wetted by water that has been in contact with the metal. Side effects like discoloration (copper) and accumulation of heavy metal (lead) may appear.

5. CONCLUSION

Dirt layer on exterior surfaces can either be of biological origin or caused by emission of gas and particles. The composition of the dirt layer varies highly with the environment. There seems to be an increase of biological growth, but the reasons are not clear.

Although a dirt layer does not involve any safety consequences, a dirt layer is a failure, at least from an aesthetical point of view, if the layer gets too visible. As a result the building owners might choose to clean the surface, with the risk of causing damage to the building or surface. Using self-cleaning surfaces might save the costs of cleaning exterior surfaces. Different techniques have recently been presented on the market, using rain to clean the surface, either by loosening particles by a photocatalytic effect and wetting the whole surface by making it hydrophilic, or the opposite, a hydrophobic surface with protrusions ensuring that neither the water nor the particles have large surface contact. Roof tiles with the latter properties are at the moment being tested at the Technical University of Denmark.

The test is a simple field experiment in real time, as effective standardized testing methods for smudging are not available. Creating a standardized test method would imply standardized dirt and application, as the “natural” dirt varies highly, and different ways to accelerate test results, like different slopes for surfaces, are still to be found.

6. REFERENCES

Aikivuori, A.M. 1999, Critical loss of performance–what fails before durability. Durability of Building Materials & Components 8. Vancouver, Canada (M. Lacasse and D. Vanier, editors)

Bagda, E. 2001. Zur Vergrauung von Fassaden. Zur Verschmutzung von Innen- und Außenflächen. Technische Akademie Esslingen, Ostfildern-Nellingen, Germany (E. Bagda, editor).

Barthlott, W. and C. Neinhuis. 1997, Purity of the sacred lotus, or escape from contamination in biological surfaces, *Planta* 202: 1-8, Springer, Germany.

Born, A. 2001. Zum Einflus der Oberflächenhydrophobie von Fassadenfarben auf ihr Verschmutzungsverhalten. Zur Verschmutzung von Innen- und Außenflächen. Technische Akademie Esslingen, Ostfildern-Nellingen, Germany (E. Bagda, editor).

EP 0 772 514 B1. 1996. Selbstreinigende Oberflächen von Gegenständen sowie Verfahren zur Herstellung derselben. *Europäische Patentschrift*. European Patent Office.

Künzel, H.M; M. Krus and K. Sedlbauer. 2001, Algen auf Außenwänden – Bauphysik als Ursache? Bauphysik als Lösung! -. 3. Dahlberg-Kolloquium: Mikroorganismen und Bauwerksinstandsetzung. Wismar, Germany.

Marie-Victoire, E. and A. Texier. 1999, Comparative study of cleaning techniques applied to ancient concrete. Durability of Building Materials & Components 8. Vancouver, Canada (M. Lacasse and D. Vanier, editors).

Pilkington, 2001, Pilkington Announces the World's First Self-Cleaning Glass, Press release, London, UK.

Spindler, G.; E. Brüggemann; T. Gnauk; K. Müller; C. Neusüß; A. Plewka and H. Herrmann. 2001. Partikel in der Troposphäre. Zur Verschmutzung von Innen- und Außenflächen. Technische Akademie Esslingen, Ostfildern-Nellingen, Germany (E. Bagda, editor).

Weißenbach, K and B. Standke. 2001. Anti-Graffiti and Easy-To-Clean Properties On Porous Mineral Surfaces are Achieved by Using Waterborne Fluoroalkylsilane Systems. Hydrophobe III, Third International Conference on Surface Technology with Water Repellent Agents, Hanover, Germany (K. Littmann and A.E. Charola, editors).