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Dusting Losses in Daylight Transmission for Glass Surfaces

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Abstract: Thanks to the radiation coming from the sun to the Earth, there is no need for artificial light indoors and energy savings are achieved. In recent years, the most common pattern of daylight entering interior spaces is the use of glass surfaces instead of roofs and building walls. An important variable that prevents daylight from entering the interior of the building is dust on glass surfaces. Over time, dust in the air sticks to the glass surface or covers the glass surface with various factors, reducing the amount of sunlight/radiation entering the interior. Decreasing daylight negatively affects indoor light level values. Pollution or dust varies depending on climate, humidity, wind regime, soil structure, and vegetation. In this study, daylight efficiency was investigated on glass surfaces used in buildings due to dust pollution in Diyarbakır province. This research is about the inclination angle of glass surfaces and dusting of glass surfaces. The daylight performance of glass surfaces was monitored when glass surfaces of equal and certain sizes were exposed to 5, 10, 15, 20, and 25 g of dust. In addition, daylight performance was analyzed on glass surfaces inclined at 55-65-75-85-95 degrees. This mechanism, simulated in Matlab Simulink, was compared with the physically prepared mechanism. As a result, it has been determined that the sunlight entering the interior area decreases due to the effects of dust and pollution on glass surfaces. In a typical glass-surfaced roof, losses occur in the penetration of daylight into the interior area due to dust.

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1.Introduction

Powder is small solid particles formed as a result of an object being exposed to situations such as breaking, crushing, chemical change, and disintegration. These small solid particles have a structure that bears the characteristics of the original state of the object and varies in size between 0.5 and 100 pm. According to another definition (ISO 4225:2020), small solid particles with a diameter of less than 75 microns, which can remain suspended in the air but collapse after a while due to their weight, are called dust (Mavruk, 2005). Powders have the fluidity to fill containers or voids and can be compressed like gases. Nowadays, the dust cycle has become an important part of the earth system on a global scale (Tegen et al. 2004). Dust originates from places where vegetation is sparse, in other words from arid regions, due to wind erosion. Pits are the dominant sources of atmospheric desert dust because these areas are places where water carries soil and are highly susceptible to wind erosion (Prospero et al. 2002). Types of powder are examined under three main headings. These are powders according to their source, powders according to their chemical origin, and powders according to their biological effects (Modanlıoğlu, 2013).

According to their source, dusts are classified as human-derived dusts and natural-derived dusts.

• Dust of human origin; Dust occurs due to reasons such as processing and transportation of materials, dust from cooling towers, vehicle traffic on asphalt or unpaved roads, and agriculture.

• Powders of natural origin; They are dust formed by the combination of solid or non-solid substances spread due to situations such as avalanches, hot springs, landslides, rock slides, waterfalls, and volcanoes (Countes, 2006).

According to their chemical origin, dusts are classified as dusts of human origin and dusts of natural origin.

Organic powders; are powders of plant origin such as flour dust, cotton powder, straw dust, wood dust, animal dust such as hair and feathers, and powders with synthetic components such as trinitrotoluene (TNT) and Dichloro Diphenyl Trichloroethane (DDT).

Inorganic powders; Metallic powders such as copper, iron, and zinc powder, non-metallic powders such as coal powder and sulfur powder, powders with chemical compounds such as manganese oxide and zinc oxide, powders consisting of natural compounds such as ores, minerals, and clays.

Dusts in terms of biological effects; are classified as fibrogenic dusts, toxic dusts, carcinogenic dusts, radioactive dusts, allergenic dusts, and inert dusts (Peker, 1993).

Dusting, which occurs as a result of the accumulation of dust or other pollutants on glass surfaces, causes a thin layer to form on the glass, and due to this thin layer, the amount of light coming from the sun decreases. The decrease in radiation is caused by the dust accumulated on the glass absorbing and scattering the sunlight received by the panel (Qasem, 2014). Mekhilef and his colleagues conducted a study on the amount of dust accumulated on the glass surface. They found that dust accumulated on the glass surface reduced daylight efficiency by around 10-20% (Mekhilef et al. 2012). Figure 1 shows panels with dirty and clean glass surfaces.

Figure 1: Panels with dirty and clean glass surfaces

2. Dust Accumulation Rate and Daylight Transmission on Glass Surfaces

Dust accumulated on glass surfaces is one of the important environmental factors affecting the performance of light passing through glass. The dust factor is effective in many different ways, depending on the amount of sunlight passing through the glass surface. Therefore, the factors affecting the dust accumulation rate on the glass surface are; It consists of parameters such as the angle of inclination of the glass surface, wind speed, humidity, precipitation, seasonal effect, and snowfall. Inclination angle of glass surfaces; It is known that if the angle of inclination of glass surfaces with the horizontal plane is greater than 15°, rain will be effective in cleaning the dust accumulated on the glass surface (Detrick et al. 2005). Figure 2 shows a low-slope glass roof suitable for dust collection.

Figure 2: Low-slope glass roof suitable for dust collection

Increasing the angle of inclination causes the dust accumulated on the panel to decrease. This is because when the angle of inclination is high, the dust cannot adhere to the glass surface and slides off it (Tanesab, 2018). Figure 3 shows a high-slope glass roof that is not suitable for dusting.

Figure 3: A high-slope glass roof that is not suitable for dust collection

Wind speed; Dust suspended in the atmosphere adheres to glass surfaces, covers the surface, and reduces daylight efficiency (Piliougine et al. 2008;Cengiz, 2016). Although it is thought that the wind has the effect of cleaning the dust accumulated on the glass surface, it is more common for dust flying in the air to accumulate on the glass surface. This reduces sunlight passing through the glass surface onto the roof.

Moisture; In areas with high humidity, dust accumulated on the glass will stick to the surface due to the effect of humidity. This prevents dust from spontaneously rising from the glass surface, reducing efficiency. On the other hand, since the wind's dust transport speed is low in humid regions, an advantageous situation arises that prevents the wind from accumulating dust on glass surfaces. In addition, the perspiration effect of moisture on the glass surface negatively affects the efficiency of the glass surface by causing the incoming sunlight to refract.

Precipitation; Studies on the effects of dust on glass surfaces have found that efficiency losses are higher than normal in regions with low rainfall (Piliougine et al. 2008). Glass surfaces need to be cleaned regularly to reduce efficiency loss.

Seasonal effect; Studies in the literature have concluded that air pollution, which varies according to seasons, causes panel performance efficiency to change. The research determined that air pollution is at its highest level in the winter months and therefore this pollution reduces daylight efficiency. It was determined that air pollution decreased regularly in windy weather in autumn and the amount of sunlight reaching the glass surface was higher than in the winter months. It has been observed that the highest efficiency from daylight is obtained as the angle of inclination on glass surfaces increases, as the rainy weather in the spring months washes away the dirt. It has been observed that the efficiency of the system is highest at an inclination angle of 23° in the summer months. (Akalp et al., 2021;Cengiz and Mamiş, 2015;Cengiz and Cengiz, 2018). Figure 4 shows A building with dirty glass surfaces.

Figure 4: A building with dirty glass surfaces

Snowfall; Due to the accumulation of snow on the surface, a layer will form on the glass surface and thus the amount of sunlight passing into the interior area will decrease. The effect of snowfall on efficiency loss rates is around 2% in roof systems (Efe and Varhan, 2020;Cengiz et al. 2015). In another study, it was observed that dust generally accumulated more on spherical glass surfaces. Figure 5 shows a sphere-shaped glass roof suitable for dust accumulation.

Figure 5: Spherical glass roof suitable for dust accumulation

3. Material and Method

The main environmental conditions affecting the light transmittance of glass surfaces are; These are variables such as the economic life of the glass surface (whether the glass surface is new or old), shadow effect depending on the location, the angle of the sun hitting the glass, and dust pollution of the glass surface.

Glass surface efficiency is determined by losses in light transmittance. Losses may arise from environmental conditions, design, quality of materials used, workmanship, or glass surface contamination (Yuci et al. 2016). Glass surfaces transmit light at the maximum rate if the environmental conditions are favorable and the glass surface is clean. This light transmittance decreases over time due to the adhesion of dust, dirt, pollen, bird feces, and various particles that form on the glass surfaces. On glass surfaces that are installed in a dirty and dusty environment and are constantly left open, there is a loss of efficiency in daylight transmittance due to external influences. The main causes of glass surface pollution are;

• Meteorological dust transport, dry and wet dust precipitation,

• Waste, soot, and soot collapses for industrial or heating purposes,
• Adhesion of pollen and pollen to glass surfaces
• Effect of stabilized road dust, exhaust gases, and railway lines,
• Lime residues formed during washing with tap water,
• Effects of leaves, seeds, and resin falling from nearby trees,
• Agricultural pesticide dust transport,
• Dirt formed due to high humidity and high temperature,
• It can be listed as insect remains and bird droppings.

The decrease in light transmittance caused by glass surface contamination depends on the type of contamination, the time since the last rainfall, and the routine cleaning period. It has been observed that rain is effective in cleaning dust if the glass surface inclination angle in the horizontal plane is greater than 15°, and at this angle, the efficiency loss due to dusting is around 0.5% (Gedik, 2015, Kaynaklı et al. 2018). If the glass surface angle is less than 15°, or the rainfall is low-infrequent, and the area is exposed to special dustiness and industrial pollution, the loss of efficiency in daylight transmittance increases. However, apart from special experimental studies, research also shows that losses caused by glass surface pollution levels are important in daylight transmittance (Kymakis, et al. 2009).

In the experiment carried out to observe the negative effect of the pollution level on the glass surface, a glass surface with a width of 78 cm-67 cm was left in the dust environment at an angle of 15° on the horizontal plane. The powder mixture was prepared using waste ash from burned coal and chimney soot. The energy produced from the photovoltaic panels under this glass surface was compared according to the amount of dust. Although it is known that less energy will be produced because the sunlight passing through the highly dusty glass surface will be less, it is not known to what extent the efficiency loss occurs. For this purpose, the amount of energy produced according to the amount of sunlight passing between the clean glass surface and the contaminated dusty glass surface was analyzed.

The power change of the glass surface exposed to 5, 10, 15, 20, and 25 g of powder is shown in Figure 6. Accordingly, it is seen that as the dustiness rate increases, the efficiency decreases from 2.94% to 12.14%.

As glass surfaces become dusty, the difference in energy production between the clean glass surface and the dusty glass surface increases. Glass surfaces located side by side under equal conditions benefit from solar radiation according to the dust level and illuminate the area behind the glass surface as much as daylight passes. When the dirty glass surface is exposed to 5 g/m^2 of dust, the clean glass surface transmits enough sunlight to produce 5.1 W energy, while the less dusty glass surface produces 4.95 W energy. Only 2.94% less energy was produced due to less light transmission between the clean glass surface and the glass surface exposed to 5 g/m^2 dust.

When the contaminated glass surface is exposed to 10 g/m^2 dust within the scope of the study, the clean glass surface transmits enough sunlight to produce 5.1 W energy, while the less dusty glass surface produces 4.92 W energy. Even between the clean glass surface and the glass surface exposed to 10 g/m2 dust, 3.47% less energy was produced due to less light transmission.

When the contaminated glass surface is exposed to 15 g/m^2 dust within the scope of the study, the clean glass surface transmits enough sunlight to produce 5.1 W energy, while the dusty glass surface produces 4.77 W energy. Even between the clean glass surface and the glass surface exposed to 15 g/m^2 dust, 6.31% less energy was produced due to less light transmission.

When the contaminated glass surface is exposed to 20 g/m^2 dust within the scope of the study, the clean glass surface transmits enough sunlight to produce 5.1 W energy, while the dusty glass surface produces 4.63 W energy. Even between the clean glass surface and the glass surface exposed to 20 g/m^2 dust, 9.09% less energy was produced due to less light transmission.

Finally, when the contaminated glass surface is exposed to 25 g/m^2 dust within the scope of the study, the clean glass surface transmits enough sunlight to produce 5.1 W energy, while the dusty glass surface produces 4.48 W energy. Even between the clean glass surface and the glass surface exposed to 25 g/m^2 dust, 12.14% less energy was produced due to less light transmission.

Accordingly, as dusting increases, the sunlight passing through the glass surfaces will decrease. Systems that produce energy depending on light produce less energy accordingly. In other words, as dust and pollution of the exterior will reduce light transmittance, the use of artificial light for interior lighting will increase. Figure 6 shows the dust formation on the glass surface and the proportional change of the generated power.

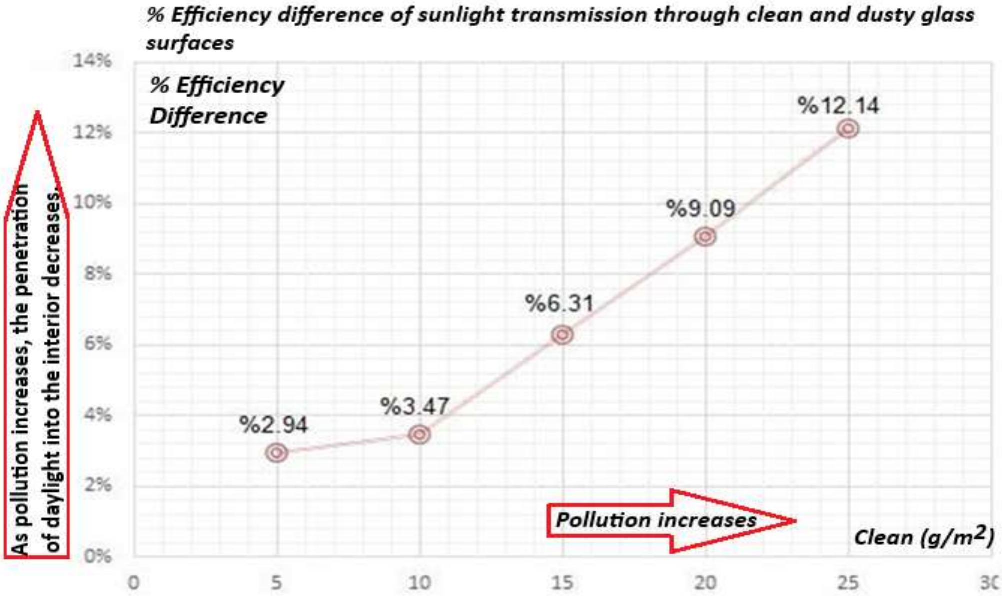

Figure 6: Dust formation on the glass surface and proportional change in the power produced

Another important parameter affecting the efficiency of glass surfaces is the glass surface inclination angles. For this purpose, dust-related energy-efficiency relationship analysis was carried out for different angles of the glass surface in simulation and real environments. In this study, first of all, the inclination angle of the glass surface was controlled with the simulation created in Matlab-simulink. Then, the power production of a glass surface at different angles in the physical environment was observed and the simulation and real power production were compared. Figure 7 shows the glass surface model created in Simulink.

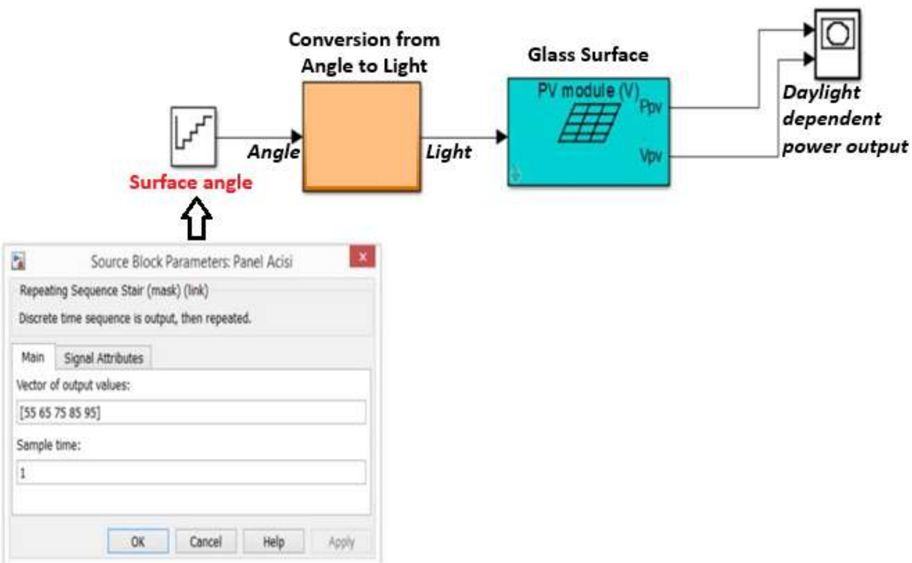

Figure 7: Power output model according to glass surface angle created in Matlab-Simulink

The power outputs obtained from glass surfaces with a slope of 55°, 65°, 75°, 85°, and 95° in the simulation environment are 8.18 W, 6.67 W, 5.32 W, 3.81, and 1.9 W, respectively. According to the simulation in Figure 8, since the effect of daylight differs for different angles, the output powers are also different. Figure 8 shows Power outputs depending on sunlight penetration at different angles.

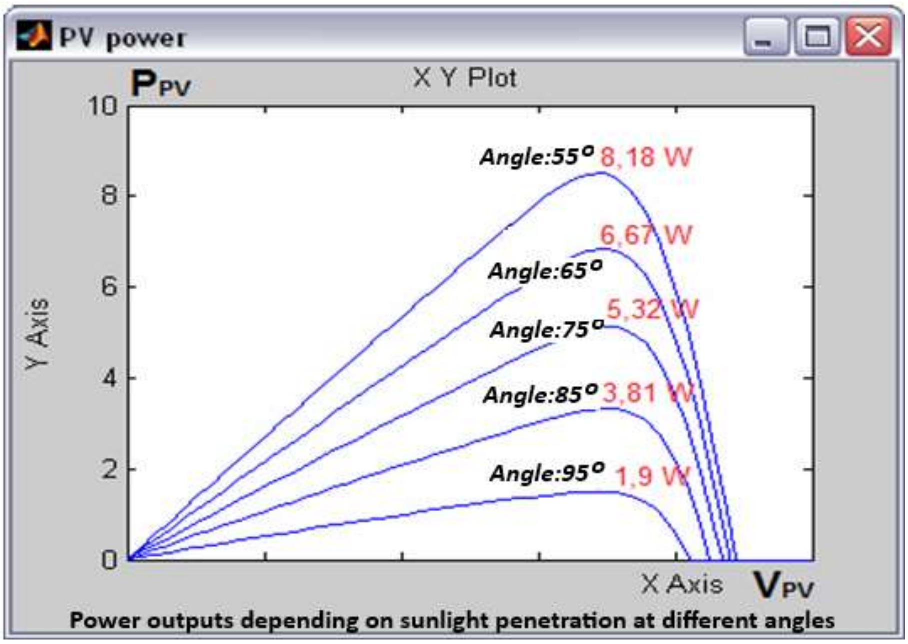

Figure 8: Power outputs depending on sunlight penetration at different angles

Accordingly, Figure 8 shows the output powers of the simulation and real glass surface depending on the daylight incident at different angles. When the output powers are examined according to the angle of incidence of daylight, it is seen that the output powers in the simulation environment are higher. The reason for this is that since the conditions in the simulation were ideal, any negative parameters that would reduce efficiency were not included in the calculation. As seen in Figure 9, it is seen that the real glass surface produces more power than the Simulation at a 95° angle. The reason for this is the additional power provided to the glass surface by the sun rays reflected from the surface. Figure 9 shows Power outputs depending on sunlight penetration from different angles, according to simulation and real results.

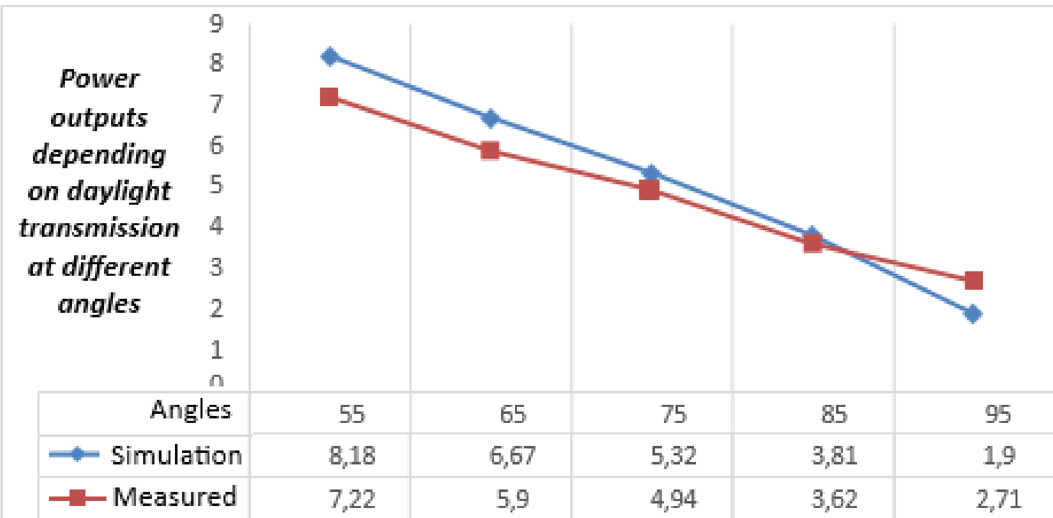

Figure 9: Power outputs depending on sunlight penetration from different angles, according to simulation and real results

4.Conclusion

Glass roof applications have become frequently preferred in recent years. In a glass-surfaced building, there is shading and dust loss in terms of daylight. It is very difficult to predict dust losses on glass surfaces due to its variable structure and amount. Parameters such as the soil structure of the region where glass-surfaced structures are installed, vegetation, humidity, temperature, and wind regimes, and the dust tendency of the glass surface are effective in the penetration of sunlight into the building. In this study, the effectiveness of urban dust accumulated on a glass surface structure exposed to dust in Diyarbakır, the transmission of daylight to the interior, and the effectiveness of glass surface pollution in terms of daylight in clayey, chalky and urban dust scenarios were investigated. The energy values produced by clean and dust-exposed glass surface panels were measured and the effect of dust on efficiency and therefore sunlight transmittance was measured.

The effect of this study on any glass-surfaced building element installed or planned to be installed in the city center or areas close to the city center in Diyarbakır, where intense amounts of dust may occur especially in the summer months, was investigated. In the study, expressing daily dust amounts in mass (grams) increased predictability in glass-faced object structural elements placed in any region outside Diyarbakır province. Especially in regions that do not receive rainfall for a long time, the penetration of daylight into the interior decreases due to pollution and dust on glass surfaces. In any application where glass surfaces are exposed to dust and daylight-related functions are involved, large amounts of efficiency loss occur depending on the amount of dust.

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