PROPER MAINTENANCE WAY FOR THE MULTIFUNCTIONAL WINDOWS

Amal Shamseldin*

Department of Architectural Engineering, College of Engineering, Ain Shams University, Cairo 11566, Egypt;
Department of Civil Engineering, College of Engineering, Taif University, P.O. Box 11099, Taif 21944, Saudi Arabia

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Abstract:

Recent developments have helped create windows that can fulfill their contrary functions effectively in addition to generating energy, which are known as multifunctional windows. Permanent maintenance is required for windows to achieve their functions properly, but the current window cleaning methods can harm and are not appropriate for the recently developed multifunctional windows. The author presents a suggested multifunctional window and sheds light on the disadvantages that could be accomplished when using the current methods to clean it. Using analytical and logical methods, this paper shows the proper way of the multifunctional window maintenance. This way depends on the self-cleaning features. The author proposes a solution for the disadvantages that could accompany that features. The main result is the validity of a successful multifunctional window that can be maintained with minimum disadvantages and maximum efficiency. Therefore, this study contributes to the window industry by presenting the proper way of maintaining multifunctional windows. Thus, future maintenance research should be redirected properly to conserve and benefit the efforts spent in impropriate directions and technologies

1 Introduction

Environmental variables affect the continuity of achieving building functions over time and under various conditions. Windows environmental functions are all important and must be continually achieved, despite their numerous related variables affecting them. A raised question is; can ordinary windows do all window functions? These functions have contrary requirements and relations with the affecting external and internal variables; thus, having a window that can achieve all these functions with minimum conflicts for the maximum possible time has always been a challenge and a required research field [1]. The importance of applying dynamic building envelope system strategies to adapt occupant interactions and external variables while satisfying the desired building energy demands has been frequently proven [2]. That's why an assessment method was set to evaluate the building's capability to reduce the conflict between their environmental functions when using the same building's elements during different periods [3].

The multifunctional window is the future window case that should be the focus of the coming studies and improvements. Several researchers discussed ways of achieving maximum continual window functions along with reducing their conflicts. For example, a dynamic modulation of the spectral properties of glazing was presented to allow the adaptation of visual and thermal behavior to the ever-changing environmental conditions and building location [4]. An increase in the smart materials field has helped to develop systems with more adaptive characteristics to achieve multiple functions besides their ability to sense the changes that simulate actuation [5]. Windows adaptation characteristics can also be achieved using sensors, control units, and sophisticated equipment [6]. Hydrogel-based smart windows, for example, have multi-functionality in light

* Corresponding author
E-mail address: amal.kamal@eng.asu.edu.eg; ashamseldin@tu.edu.sa

and temperature control with low energy consumption and durability [7]. Multi-pane glazing is considered a good example of function integration when using coatings such as low-emittance coatings to reduce heat transfer, and thus improve the energy use efficiency in addition to the utilization of daylight and viewing the surroundings [8][9]. Different layers may also be added to multi-pane glazing, such as a controllable absorbing layer, which changes its visual characteristics, leading to a direct way of controlling the solar heat flux entering the windows for heating, cooling, and lighting [10]. Turning the glass into a photovoltaic solar cell that absorbs unwanted light energy through windows and provides energy should also be considered [11].

Besides the integration of window functions, there should be insurance for applying these functions with minimal difficulty and the utmost permanent efficiency. Maintenance plays an important role in the building's life cycle toward sustainability and is an important factor in ensuring the best achievement of almost all building functions. Maintenance is considered one of the basic building function and performance management elements and has a significant role in building life cycle energy analysis. The worth of buildings decreases over time unless proper maintenance is applied, and the physical life of buildings can be extended as long as proper maintenance is imposed [12][13][14]. If a building lacks proper maintenance, it will affect the occupants' well-being, quality, and productivity, bring more pollutants and waste, and require more energy and water consumption to continue operating that building [15].

When focusing on the maintenance of developed multifunctional windows, the current methods of cleaning the windows, including the robotic method, should be reconsidered, and their impact should be carefully studied. The main argument of the paper starts here, as a gap occurs between the research orientation of producing better multifunctional windows and the research orientation of window maintenance methods. Although there is a lot of research regarding the two orientations, the relation between them needs more attention to be compatible with each other if they both target their application for more effective facades. Thus, ongoing research should relate the best cleaning method to recent window technologies. Table 1 shows the main divergence between the two research orientations and the resulting gap in between.

Table 1. The gap between two important research orientations for Windows functions.

Research orientation to produce better multifunctional windows	Research orientation of windows maintenance
This orientation takes into consideration achieving all windows functions despite their contradictions. The main goal is to apply all windows functions to perform as perfectly as possible while exposing the least conflicts.	This orientation takes into consideration limited windows functions, such as the visual function. Its current main goal is to maximize the efficiency of these functions with no interest in what happens to other windows functions.
Concerns about the most recent window materials and characteristics as long as they help more effective functions achievement.	Deals with the common window materials and characteristics, mainly the normal clear and single pane glass.
All of these orientation outcomes are likely to be recommended and used in the near future.	If the examined glass characteristics change, all of this orientation results must be reformulated.
Recent outputs of this orientation depend on materials and technologies that are mostly affected by electric and magnetic fields.	Recent outputs of this orientation rely on the use of electric or magnetic field technologies.
Some studies that support this orientation are as follows:[4] [5] [6] [7] [8] [9] [10] [11] [16] [17] [18] [19] [20] [21] [22] [23]	Some studies that support this orientation are as follows:[12] [13] [14] [15] [24] [23] [25] [26] [27] [28] [29] [30] [31] [32] [33] [34]

This study aims to orient further research and development toward the maintenance of multifunctional windows rather than ordinary ones that do not meet the coming aspirations. This study uses analytical and logical methods to present the proper way of maintaining multifunctional windows with the least disadvantages. The manuscript consists of three main steps: the first step is suggesting a multifunctional window, the second step is showing the validity of the self-cleaning feature integration with that window, and the last step is proposing a solution to help apply the self-cleaning feature properly against the disadvantages it may face when used. The final output is a comprehensive building element to achieve its maintenance function besides its other multi-contrary functions. The main result is the validity of achieving multifunctional window maintenance with the least disadvantages by integrating self-cleaning features. Thus, the paper suggests reducing all wasted efforts in the current research orientation of window maintenance, which results in ways that will most likely change with the rapid growth of new window types. These efforts should be redirected toward improving a more proper way, which is the integrity of the self-cleaning features.

2 Methods

According to the argument regarding the capability of maintaining multifunctional windows with the least disadvantages; this article uses analytical criticism and logical reasoning methods as follows. Analytical criticism was used to discuss the problem of the windows' multi-contrary functions and discuss the effect of current cleaning methods on the recent development of these windows. The result was the significance of a proper way of maintaining the multifunctional windows without affecting the technologies used for achieving their functions. The logical reasoning method was then used to implement the previous requirement in several steps. Starting by suggesting a type of window that is an integration of several recent technologies, to benefit their different function applications continually as possible. Then, represents a method for maintaining the previous multi-functional window by adding self-cleaning features. Finally, a solution is proposed for the self-cleaning disadvantages that could occur over time and place. Each step was supported by applicable applications and had a logical consequence. The manuscript forms some previous knowledge in a new output besides adding a proposed solution. The article ends with the conclusions.

3 Windows contrary functions and their need for maintenance

Some building elements are responsible for achieving several environmental functions with varying requirements that cannot be met by the same actions; due to their different or changing internal and external related characteristics. When two functions are related to the same building elements, some environmental functions may be ignored to achieve other functions that conflict with their achievement requirements. Achieving continuity and minimizing the conflict of different environmental functions using the same building component/s is an important challenge. Windows functions are the most obvious example of such a challenge, and they are a very good example of buildings' multi-contrary function components. Thus, in ordinary cases, if the window characteristics are chosen to achieve a certain function for the longest time, they may not be suitable for another function to be achieved with the same quality [3][16][35]. The environmental functions of windows include internal thermal comfort, visual comfort, acoustical comfort, bio-physiological comfort, chemical comfort, safety, privacy, views, pollution and dust protection, ventilation, and energy conservation, besides energy production, when possible [17].

Windows protect the interior from the exterior environment in terms of weather conditions, pollutants, dust, pests, noise, glare, etc. They also provide internal spaces with heat, daylight, fresh air, and ultraviolet rays for security, privacy, and views. They are also responsible for maintaining a good ambient relaxing and working environment related to the psychological health of occupants. They are responsible for air filtering, controlling ventilation, redirecting fresh air to the inside, and redirecting exhausted, smoked, or polluted air to the outside. In addition, they are one of the most sensitive building parts in terms of energy performance, as they are the most important parts for managing heat transfer (loss or gain) in buildings [15][36].

Windows start their need to be maintained as soon as they are built; due to a variety of natural factors as well as user usage. Natural factors have different effects depending on spatial characteristics such as climate, and building characteristics such as design and materials. If windows do not receive the care they need over time, they will not accomplish their functions and may lose durability. Usually, higher costs are incurred for window replacements or renovations than if they are maintained constantly. Appropriate maintenance requires funding, but notable results can be obtained at a limited price [24]. Almost all windows' function efficiency is connected to their maintenance achievement, as windows cannot provide internal spaces with heat, daylight, fresh air, and views; avoid pollutants, dust, and pests; and maintain a good internal ambient environment for the users if not cleaned regularly. Moreover, if windows were catching the recent trends to integrate the glass of the windows with solar cells to produce energy while performing its other functions, it should be noted that the accumulation of dirt and ruins on the cells over a long time can notably reduce their performance and affect light absorption by solar panels [37][38].

4 Suggested multifunctional window

By considering the multi-contrary window functions, the windows' futuristic design should always be about merging all of their various requirement features (requirements for the same function over time and under different conditions, or requirements of different functions) to achieve those functions continuously with the least conflict. The goal is to build an adaptive skin that can continually achieve multiple functions and reduce their possible contradictions [4]. Table 2 summarizes the key features of multifunctional windows. Combining some of the most recent advanced glazing technologies may help achieve as many window functions as possible. Some of the main glazing technologies that are proposed to be applied and combined for successful multifunctional windows are presented in the following sections.

Table 2. The main description and characteristics of multifunctional windows [3][17][39].

Goal	Continue achieving all windows functions for the longest possible time before they conflict with others; by adapting the affecting internal and external variables on achieving these functions. These contradictory functions are all important and cannot be ignored or overlooked, but they can be achieved according to a function priority scale that can be determined based on the building type and spatial aspects for each time period to be done once the conflict occurs.
Related Functions	Achieving thermal comfort (cooling, heating, and controlling airflow) – ventilation - achieving visual comfort - achieving acoustical comfort – energy conservation and production when possible (air flow energy, and solar energy) – controlling Pollutants entry - providing psychological needs (outdoor connectivity, safety, and privacy) - good look facades – maintenance.
Way of work	A responsive system that senses effects and stimuli and then changes and controls properties. The responding actions could be mechanical or physical. The mechanical actions can be done by changing the whole or part of the window’s position, angle, etc. It can include tilting, rotating, overlapping, cascading, adding or removing parts, etc. While physical actions can be performed by changing the materials' thermal values, color, transparency, texture, absorption, reflection values, etc. without causing noticeable position differences.
Possible Tools	Mutation materials, integrated films or layers, sensors, and Building Integration Systems (BIS).

4.1 Multi-pane glazing windows

Several multi-pane glazing designs use air or gas (such as argon) within two, three, or more panes [6]. According to numerous studies, using multi-pane glazing can result in significant energy savings when compared to standard glass window types [8]. They aid in achieving great sound insulation, safety, and thermal comfort. Recent years have seen the emergence of several multi-pane technologies, including vacuum glazing, aerogel windows, intermediate polymer films, and six-pane glazing [9]. When a structure requires additional treatments to ensure thermal comfort, such as the necessity for exterior sun shade, multi-pane glazing facades are less expensive [9][18].

4.2 Semi-transparent PV windows

The surface area necessary to generate enough electricity is one of the key problems that solar cell applications encounter. Hence, translucent photovoltaic (TPV) cells have been proposed as a solution to the problem of efficiently utilizing space [11]. All photovoltaic (PV) types can be incorporated and/or laminated in glass, however, only thin-film photovoltaics will be translucent [6]. Due to their numerous uses, semi-transparent photovoltaics (STPV) is regarded as one of the most promising glazing technologies. In addition to having the ability to produce clean energy, it can increase building energy efficiency through aesthetic and thermal factors [19]. Many scientists are working on the development of this technology including the use of thin-film techniques with various deposition techniques, the absorption of ultraviolet (UV) and near-infrared light (NIR) while transmitting visible light, and the discovery of new structures that would be translucent yet supply a significant amount of electricity [4][11][20][36].

4.3 Smart windows

Dynamic envelope systems can be informed by internal and external inputs of the necessary occupant and environmental responses, thus responding to them [2][36]. To accomplish a variety of goals, several glazing enhancements have been made, including darkening films, tinted glass, reflective glass, and glass coatings such as low-emissivity (Low-E) coatings and nanoscale thermal coatings. In addition to the ensuing energy efficiency, these characteristics are geared toward creating thermal comfort by adjusting the received solar gains per the needs of the various seasons and/or attaining visual comfort through glare-free natural illumination [5][20]. Two types of smart glazing can change their properties: passive materials that are affected by environmental factors like the amount and direction of sunlight, rain, wind, and so on; and active materials that can change their optical properties in response to external stimuli like an electric field, voltage, heat, light, or ion diffusion [6][20]. Three various techniques are known to derive switchable windows: chromic materials, liquid crystals, and electrophoretic or suspended-particle devices. Chromic devices are in four groups, Thermochromic, Photochromic, Electrochromic, and Gasochromic [4][36]. The multi-functional hydrogel-based smart windows that are shown in Figure 1 are a current challenge. They rely on the hydrogels with bright color alteration with contraction–tumefaction response to temperature, ion strength, and an alternating magnetic field. The porous structure and magnetism of the hybrid hydrogel help it to be a possible carrier for hydrophobic molecules [7][21][22].

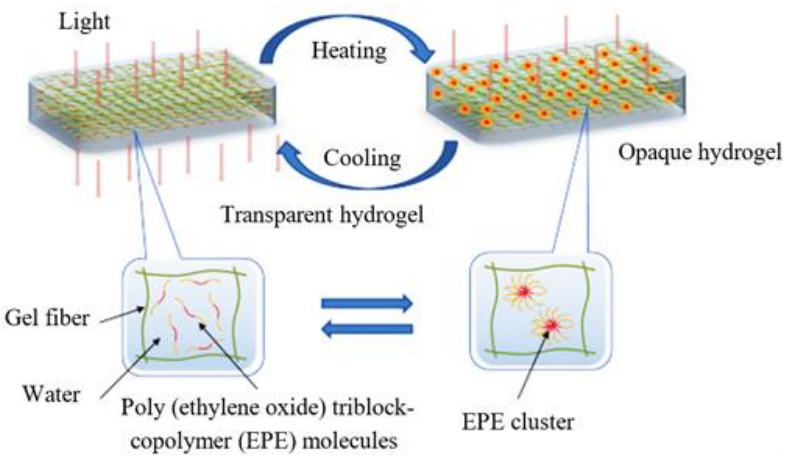

Figure 1. Hydrogel smart windows way of work [21].

5 Current ways of cleaning windows in buildings

Along with the increased number of glass-windowed buildings, the need for their maintenance is increasing as well. Dust that adheres to surfaces is reducing the efficiency of their different functions [15]. Current window cleaning methods have degraded from manual methods to robotic methods. Through the following sessions, the main current methods of cleaning the windows are presented. Table 3 presents the main advantages and disadvantages of these methods.

Table 3. Main summarized advantages and shortcomings of the current ways of cleaning the windows [23][26][30].

Current Ways of Cleaning Windows	Advantages	Disadvantages
Manual Method	• Cheap • Low mechanical energy consumption • Uncontrolled water consumption	• No guarantee of efficiency • Difficulties in reaching • Waste of human time and effort • Affected by human variables
Semi-Mechanical Method	• Less human involvement, thus more precision • Less human time and effort • More possibilities for reaching than the manual method	• Dangerous for human life • Costs much money • Consume more mechanical energy than the manual method • Still lacks precision
Robotic Method	• High guarantee of efficiency • Safe cleaning • Fast and accurate • Simple software is needed • Limited water consumption • High possibility of reaching	• Lack of standardization • Under development • Most robots are expensive. • Rely on mechanical energy, which could be non-renewable. • Still needed human assistance.

5.1 Manual method

The fundamental components of the cleaning process in this method are people. This approach has several drawbacks, including difficulty in reaching windows, fatigue, the risk to the man, unreliability, poor cleaning precision, and time consumption [23]. Figure 2 shows the introduction of a magnetic window cleaning system. This device contains a master and slave unit that employ magnetic force to clean both sides of the panes simultaneously. The tool employs a replaceable cleaning surface and has adjustable magnetic strength to clean single- and multi-pane windows of various thicknesses [25].

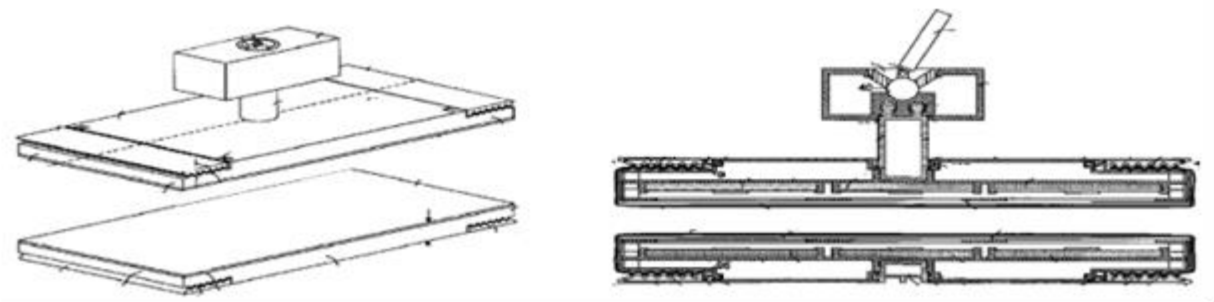

Figure 2. Magnetic manual window cleaning device [25].

5.2 Semi-mechanical method

Man built a collection of mechanical mechanisms called forklifts that raised him to places that were high or could not be reached. Although cleaning is still done by humans, these mechanical systems have advanced significantly and are beneficial to people because they cut down on the time required for cleaning [23][26]. Forklifts can only clean one side of the structure; personal labor is needed to move them to the subsequent side. The Automated Skyscraper Window Cleaning System (ASWCs), which employs a successful algorithm to ensure an ideal clean curtain wall glass for tall buildings, is another semi-mechanical technique [27]. Figure 3 depicts the two semi-mechanical technique procedures. The semi-mechanical method lacks precision in the cleaning process, is expensive, and is still seen as dangerous. [23].

Figure 3. Two semi-mechanical methods are used for cleaning external glass windows of buildings [23][28].

5.3 Robotic method

Robots of various kinds have been developed, and more are anticipated. They aim to quickly and efficiently clean glass windows in even the most dangerous and important locations. The robotic high-rise building maintenance system uses an automated system to carry out activities including inspecting, cleaning, and painting the exterior high-rise buildings' walls. These systems have some limitations, such as the need for labor when placing the maintenance device, relocating it, or removing it from the exterior building wall. On the other hand, they lessen accidents by minimizing the strenuous labor performed by humans, improving the accuracy and efficiency of maintenance, and speeding up the cleaning of large glasses [23][29][30]. Research has led to the invention of several robotic systems, including a cleaning robot that can move on its own without human assistance, recognize the amount of dirt present thus adjust its energy usage accordingly, and effectively clean the dirt on various surfaces [23]. In Figure 4, this robot is displayed. Another robot has two parts that enable it to connect perfectly to both sides of the glass and execute climbing and window-cleaning jobs simultaneously. It features a sensor to identify its position both vertically and horizontally, can clean windows of a wide range of thicknesses, and can move quickly [26]. Another robot is capable of scaling building windows, utilizing suction cups to produce a vacuum and press firmly against the glass surface while cleaning [28]. The lightweight, compact robot can be propelled by a suction cup mechanism with an electric motor. With the help of the sponges that are attached, this motor can move the robot in a predetermined swinging pattern over the window pane [31]. A robot was created to distinguish between the shape of window glass and its frame [32]. Another robot can change from one window panel to another by employing a technique that uses multiple types of sensors that are active at the same time on the Robot Operating System to determine its direction [33]. A wall-climbing cleaning device may also recognize a variety of actions, including avoiding obstacles, wall-walking, wall-climbing, turnover, and cleaning modules [34].

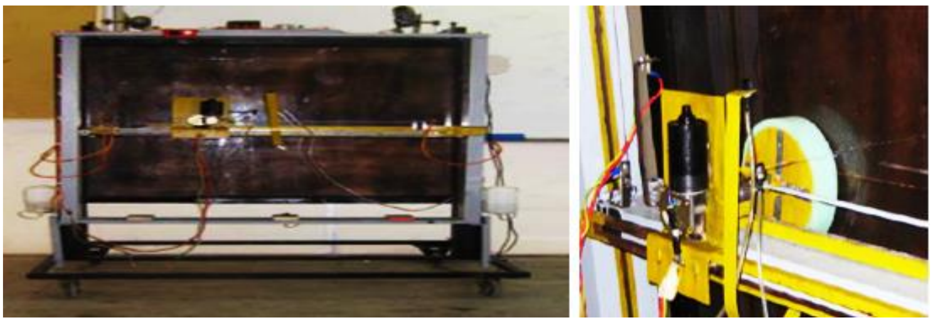

Figure 4. Window cleaning robot with an attached wiping bar and a water pump [23].

6 Problems with using current cleaning ways to clean the suggested multifunctional windows

Notably, current cleaning ways are tended toward mechanization, which mainly depends on the use of magnetic and/or electric fields even. When taking into account the multifunctional windows features, an important question regarding the compatibility of such windows types with the current maintenance orientation raises. The manuscript sheds light on the expected effect of magnetic and electric fields on multifunctional windows. The use of a magnetic field showed manually as mentioned for the manual device. The semi-mechanical way such as ASWCS uses automated brushes for cleaning and a platform that hangs from the building's top and glides across its glass surface with the aid of attached rollers and a motorized pulley that is adjusted following the structure's measurements [27]. Magnetic and/or electric fields are mainly used in the robotic approach. Permanent magnet motors are often required by robots to provide field flux for beginning torque capabilities with adequate speed management [23].

They use magnetic modules that move over the window surface while removing ruins and dirt from the surface using an activated, powered agitator. [31][40]. To achieve safety and energy efficiency, magnets are occasionally used to assist the movement of stable robots, such as when an inner unit and an outer unit are sandwiched between several powerful permanent magnet pairs on opposite sides of the glass and hold one another in place by adhering to the surface of the window glass. Whether or not the window is powered, the magnets are regulated by a magnetic sensor that is permanently fastened neatly to the window surface [26][30]. The magnet may also attract small self-propelled robots that can clean windows for an affordable price [32]. Ordinary window glass' efficiency is unaffected by magnetic and electric fields, but the suggested multifunctional window glass, which has many coatings and internal layers, will be influenced over time, decreasing its efficiency. The potential drawbacks of the suggested multipurpose windows from this issue are listed in Table 4. These are a few of these results as follows.

Table 4. The most significant negative effect that current cleaning methods could have on the proposed multifunctional windows.

Main current cleaning ways problem	Negative possible effect on multifunctional windows		
	Multi-Pane Glazing Windows	Semi-Transparent PV Windows	Smart Windows
The use of magnetic and electric fields	Effects on the trapped layer of gas	Effect on PV efficiency	Effect on different applications' performance

6.1 Effect on multi-pane glazing windows

For the multi-pane glazing windows, there shouldn't be any harmful effect on the trapped layer of gas (usually argon) or air to ensure that the efficiency of the windows will continue as it was planned for them for as long as possible. Breakdown voltages in low-pressure gases for argon and nitrogen discharges are influenced by a longitudinal magnetic field. The breakdown is encouraged by the magnetic confinement of electrons, which minimizes the electron losses and raises the collision frequency between electrons and the gas particles at a given reduced field, therefore raising the ionization. Even ordinary air is affected by the presence of a magnetic field; it is roughly 1 % argon, 21 % oxygen, and 78 % nitrogen [41][42]. Nitrogen gas is discovered to flow through the air more quickly when it moves in the direction of a diminishing magnetic field produced by a regular electromagnet. This observation is explained as a result of magnetic field inhomogeneity affecting the interface of gas groups with different magnetic susceptibilities [43].

6.2 Effect on semi-transparent PV windows

The magnetic field's existence affects the quality of various solar modules. The influence of magnetic fields on PV efficiency was demonstrated in several experimental studies. A photovoltaic module's electric output and conversion efficiency are two electrical metrics that are highly dependent on the strength of the applied magnetic field. An experiment revealed that the electric power output of the solar module, and consequently its transformation efficiency falls as the intensity of the magnetic field increases, indicating that the presence of the magnetic field nearby reduces the performance of the photovoltaic module [44]. In a different experiment, the impact of a magnetic field on the electrical characteristics of a silicon solar cell lit by a strong light concentration was determined. The conversion efficiency, external load electric power, external optimal charge load, and the fill factor were all factors in that effect [45]. It was also found that when the directions of a direct current (DC) magnetic field and junction electric field are opposite or the same as those of a silicon PV cell or module, it does not affect its parameters. On the other hand, the open-circuit voltage, photocurrent density, and power production of the silicon PV cell or module decrease when the DC magnetic field points in the other directions. When the DC magnetic field is applied in the direction perpendicular to the junction electric field, the reduction reaches its maximum [46]. In general, the magnetic field that is generated from transformers and other equipment could interfere with the performance of photovoltaic modules [44].

6.3 Effect on smart windows

The effect of the magnetic or electric field arises when the smart widow system itself uses them to perform. Several smart windows, such as switchable windows, rely on the use of electricity or magnetic fields. The Electrochromic windows change their opaqueness characteristics when a voltage is applied between two transparent electrical conductors, setting up a distributed electrical field. An electric potential then initiates redox reactions, and as the field moves, various coloration ions change the transparency and the glass color. Windows with suspended particles (SP) and liquid crystal (LC) are electroactive windows. When SP and LC windows apply alternating current voltage, randomly scattered and oriented particles are aligned, thus the window becomes transparent [6][36]. The functions of hydrogel-based smart windows rely on magneto-caloric responsiveness and magnetic-field-induced macroscopic reactions. In an alternating magnetic field, the colored oil-loaded hydrogel exhibits a regulated behavior during each reversible contraction-tumefaction cycle [22]. Anisotropic characteristics and unique performance were brought about by magnetic-field-induced ordered nano-assembly. Moreover, as demonstrated in Figure 5, the magnetic responsiveness of hydrogels containing magnetic nanoparticles that can result in the creation of functionality under magnetic fields [47]. Some smart glass types made with cobalt coatings can also lessen the forces between magnets on opposite sides of the glass. Cobalt films are particularly effective at reducing solar heat gain while letting most of the natural light through and minimizing solar glare. Although cobalt is a magnetic element, these magnetic atoms are normally not dense enough to create the sorts of lined-up magnetic domains, but they are highly magnetic when they somewhat line up while a field is applied, therefore the glass may attach to a magnet if used near it [48].

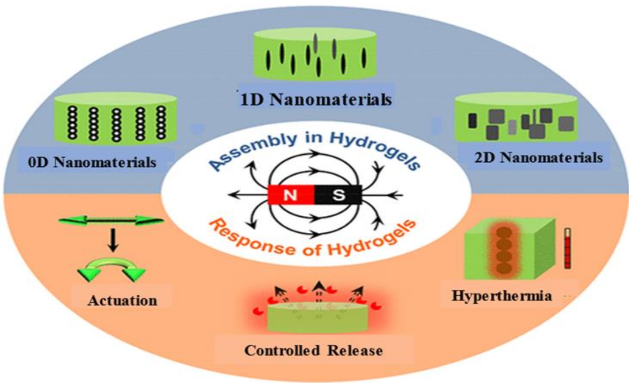

Figure 5. The magnetic responsiveness of hydrogels with magnetic nanoparticles under magnetic fields [47].

7 The proper way of cleaning the suggested multifunctional windows

Nature provides a vast and varied collection of adaptation processes and techniques that can be used to emulate nature to solve any given challenge [35]. Using a thin coated layer to control the wettability of the glass surface; nanotechnology has enabled the development of self-cleaning surfaces. Also, the creation of solar panels or the coating of windows may repel filth and grime. When a coating is applied and formed on hot glass, a strong, long-lasting bond is created with the glass surface. The self-cleaning glass is made possible by utilizing the capabilities of the sun and rain to effectively clean itself and eliminate grime. Self-cleaning windows require one or more of the surfaces listed below.

7.1 Hydrophobic surface

A hydrophobic surface aids in the removal of dirt and minerals from glass by forming a film of water across the surface. If something is hydrophobic—that is, it despises water and fully dries—liquid drops on a solid surface stay sphere-shaped. The surface can become hydrophobic by applying a thin coating of silicon dioxide (SiO_2). The contact angle of the liquid with the solid determines the solid's wettability. If the liquid contact angle on a surface is larger than 150° besides a sliding angle of less than 5 °; the surface is then known as a super-hydrophobic surface. Lotus leaf, taro, moth eyes, butterfly wings, dragonfly wings, etc. are naturally occurring hydrophobic surfaces [35][49][40][50][51][52].

7.2 Photocatalytic surface

When exposed to UV light, a photocatalytic surface aids in the degradation of organic soil and minerals. The ultraviolet (UV) rays from natural daylight, which are abundant even on cloudy days, are used to start the photocatalytic process. As long as the quantity of UV light is greater than the amount of absorbed dirt on a surface, the surface remains clean. Titanium Dioxide (TiO_2) coatings are the transparent photocatalytic that are used the most. The organic filth decomposition, organic atmospheric pollutants, dried watermarks, sea spray, and insect residues that land on the glass surface are all moved by UV rays when exposed to daylight. It disintegrates organic dirt and lessens the adhesion of inorganic (mineral) dirt to the glass surface. Ordinarily, living things like plants and animals are organic sources of dirt, such as bird remnants, but inanimate objects, such as plaster, are the inorganic sources of dirt. After exposure to daylight, the surface takes several days to activate. The advantages of photocatalysis include simple setup and operation at ambient temperatures, decreased energy usage, and elimination of post-processes. While a photocatalyst cannot instantaneously break down large amounts of stuff, it is more efficient at doing so with growing quantities of initially tiny substances, like bacteria. Moreover, certain dirt can be broken down by photocatalyst reactions to retain the antibacterial spectrum without cleaning [37][40][50][51][52].

7.3 Hydrophilic surface

Being completely wet suggests something is hydrophilic, or water-loving. Figure 6 presents the primary differences between the hydrophilic and the hydrophobic surfaces. A hydrophilic surface is one where the water contact angle is less than 90°, and a super-hydrophilic surface is one where it is less than 50°. Hydrophilic materials have high surface tension and can form "hydrogen bonds" with water. On a hydrophilic surface, the water creates a thin coating [40]. Windows dry more quickly than regular glass without spots and streaks, reducing unsightly streaks or marks. This is because when it rains or the window is hosed down, the water forms sheets on the glass rather than droplets, washing away the broken-down leftover dirt and rinsing the loosened inorganic and organic dirt away. As a result, windows stay clean for a long time and are simple to clean when needed. Rain usually suffices to keep the window clean. The same effects can be achieved in dry weather by swiftly spraying the glass with a hose [37][51][52].

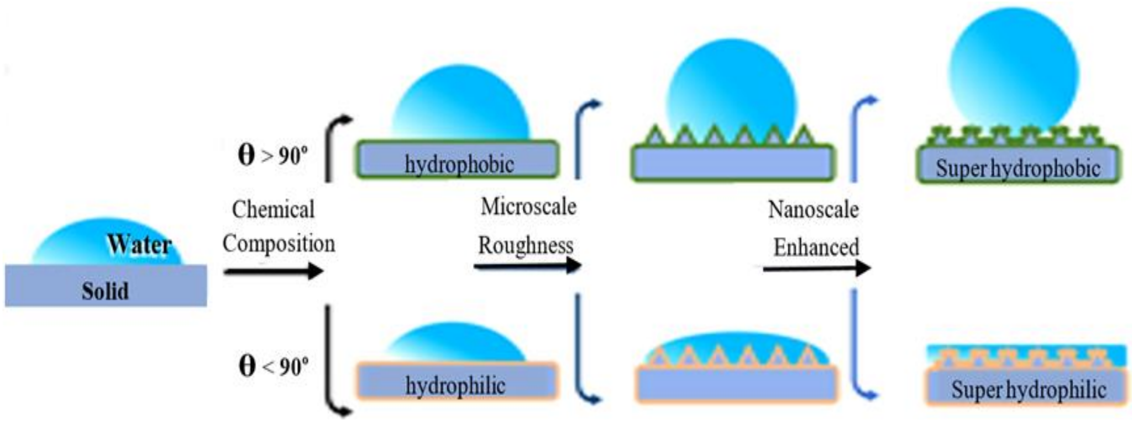

Figure 6. Comparison of the water relations among hydrophilic, hydrophobic, super-hydrophobic, and super-hydrophilic materials [51].

7.4 Anti-reflective surface

Anti-Reflective coatings are defined as the destructive interference between air-coating interfaces and light reflected from the coating substrate. By changing the coatings' porosity degree, anti-reflective coatings can be obtained. The roughness of the surface promotes the coating's hydrophobic and hydrophilic properties. Nevertheless, rough surfaces, due to scattering and diffusion, reduce the transmittance, therefore increasing the reflection. When the transmittance increases, photocatalytic activity decreases as the light intensity decreases. But anti-reflective surfaces are desirable in the self-cleaning glass. To achieve anti-reflective surfaces for solar cover glasses, a low refractive index, such as SiO_2, is required. The photocatalytic activity could be enhanced for hydrophilic self-cleaning glasses by using high-refractive-index materials such as titanium. Combining these two functionalities on a single glass by sol-gel dip-coating was investigated and succeeded. Anti-reflective has also been combined with photocatalytic properties by preparing SiO_2/TiO_2 double-layers [40][53].

7.5 Anti-fogging surface

One of the important problems associated with widows' cleanliness is the formation of fog on the glass, which also affects the visual window function [18]. Hydrophobic/ super-hydrophobic surfaces are a perfect solution to avoid liquid film formation and speed up condensed droplet removal. This removal can encourage the growth of new droplets and continuous nucleation. Thus, considerable efforts have been carried on to design hydrophobic/super-hydrophobic surfaces to promote condensation-based heat transfer efficiency [54][55]. It was attempted and successful to combine these two capabilities on a single glass using sol-gel dip-coating. By creating SiO_2/TiO_2 double-layers, anti-reflective and photocatalytic capabilities have also been coupled [51].

7.6 Switchable surface

The Cassie-Baxter-Wenzel transition is a quick transition between the two different liquid-repellent states. The two modes are super-hydrophobic and super-hydrophilic. Oily contaminants were difficult to remove from the hydrophilic surface, and when they stick to the surface, the ability of the surface to self-clean is compromised. However, when super-hydrophobic and super-hydrophilic materials were combined, the surface became effective at separating oil from water. Figure 7 demonstrates that the primary target of super-hydrophobic materials is solid contaminants. Super hydrophilic materials, however, primarily focus on liquid contaminants. So, it's crucial to combine the benefits of these two characteristics to create materials that are omnipotent self-cleaning, and super-wetting. This can occur frequently and fast, enabling the persistence of liquid repellence under rapidly changing, dynamic environmental conditions [37][40][45][56]. An array of magnetically responsive hierarchical micro-pillars on a substrate and an orientable lubricant layer may be necessary to modify the surface wettability. By adjusting the array's orientation according to the direction of an outside magnetic field, switching is applied [37][56][57].

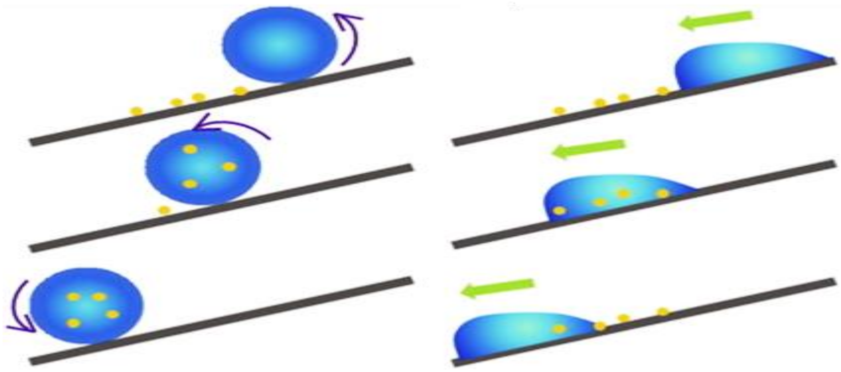

Figure 7. Water transports solid dust particles away from a hydrophobic surface (right) much more efficiently than a hydrophilic surface (left) [37].

Several other external stimuli could be used to induce the reversible changes in surface wettability, such as ion exchange, mechanical stress, plasma interaction, ultrasound, light, voltage, immersion in adenosine diphosphate aqueous solution, immersion in a solvent, chemical reactions, and dual temperature and/or pH sensitivity [45]. These various stimuli might be the same ones utilized for Windows' other operations. To integrate the self-cleaning feature with the other window functionalities, it might be possible to create uniform parts or materials. To increase their compatibility, the used method of changing the surface wettability could be selected based on the kind of window and technology. Table 5 lists the various self-cleaning surfaces that have been suggested as well as how they should be applied.

Table 5. Self-cleaning integrated surfaces with their main purposes and ways to be applied [35][37] [45][51][55][53][57].

Self-cleaning surfaces	Purpose	Way to apply: fabrication technologies
Hydrophobic Surface	help in repelling water	By adjusting the surface chemistry, coating a chemical film on the surface, or generating nanotextures. Examples of used nanoparticles are silicon oxide, titanium oxide, aluminum oxide, iron oxide, and silver.
Photocatalytic Surface	detoxification via visible light	By doping the titanium dioxide and adding activated carbon to increase the purifying efficacy.
Hydrophilic Surface	allow wetting of the surface	By dip coating technique, plasma coating treatment, ultraviolet (UV) light irradiation, corona discharge, and coating or grafting hydrophilic polymers. Examples of used materials: carboxyl (COOH), hydroxyl (OH), amide (NHCOR), ester (COOR), sulfonic (SO_3H), amino (NH_2), and dihydrogen phosphate groups (PO_4H_2) that could make hydrogen bonds.
Anti-Reflective Surface	decrease the amount of reflective light	By using immersion plating on the two surfaces, or dipping the low-iron glass in different solutions of metal oxides.
Anti-Fogging Surface	protection against fogging	By the use of hydrophilic materials such as indium tin oxide (ITO), silicon dioxide SiO_2, zirconium dioxide (ZrO_2), and graphene oxide (GO), or the use of photo-responsive materials.
Switchable Surface	Switching between super-hydrophobic and super-hydrophilic states	By three main steps starting from the fabrication of hierarchical structures on the surface (template replication, photolithography, electrospinning, etching, or Sol-gel processing), then surface modification (chemical modification, physical adsorption, or surface coating), and finally surface wettability patterning.

8 Advantages and disadvantages of self- cleaning multifunctional windows

The proposed self-cleaning surface's main advantage is its ability to be combined with other glass environmental products and features. Related to multifunctional windows; it can be integrated with other materials based on the micro Nanoscale, and it can be incorporated into double and multi-glazed units. Besides, it could be available in a laminated or toughened composition for security and safety increment [40][52]. It can also raise the performance of the photovoltaic device by reducing the accumulation of dust on the surface, which results in a considerable reduction in light transmittance and material degradation [50]. The coating requires just a small amount of sunlight to activate, so the self-cleaning function will work in different weather conditions, such as on cloudy days, overcast days, at night, and in shaded areas. It can work with different orientations, and even north-facing will receive adequate exposure. Soft water swill during dry periods will keep the windows clean. It is ideally installed at sloping angles of 30^{o} or more to ensure good water flow but may be installed vertically or at sloping angles of less than 10^{o}. It is environmentally friendly, with less freshwater and no detergents needed for cleaning, besides saving cleaning time and costs. It is ideal for hard-to-reach areas where organic dirt normally collects, such as roofs, and inaccessible windows such as skylights. Its transmission of damaging ultraviolet energy is reduced by about 20% – 40% versus a clear glass window, and the solar heat gain coefficient (SHGC) is better by about 0.05 points compared to usual glass. Besides, the self-cleaning glass does not affect the glass's strength and has several other advantages, such as ease of fabrication, neutral colour, reflective quality, permanent coating, being safer than other cleaning methods, and harmless chemical substances [40][50][52].

The self-cleaning glass also has several disadvantages. It decreases the amount of passing light by about 5% compared to regular glass. Besides, the self-cleaning function performances differ according to the environment and the glass position, which influence the type, extent, and amount of dirt, type of pollution, exposure to light and wind, the volume of rain that the glass receives, proximity to the sea, etc. The self-cleaning glass does not need to be cleaned if kept utilizing the natural elements (rain and UV light from the sun). If the glass is exposed to a small amount of UV, it will be activated; thus, the main problem is related to the presence of rain, especially in dry regions and spells. Although the self-cleaning glass ultimately breaks down excessively heavy deposits of organic dirt, it cannot break down inorganic dirt or huge areas of solid, mineral dirt such as varnish, silicones, paint, and cement. It only makes them adhere less to the glazing; thus, spraying enough water is essential to drain and remove loose inorganic dirt. Long dry periods or intensive industrial pollution may cause contaminants to build upon the coated surface; thus, it will be less effective or won't work if the dirt accumulation prevents the UV from reaching the glass.

The surface can become stained with tough marks that cannot be removed easily when hosing the window down. Regular water spray on the glass is essential for its performance, so depending on natural rain alone won't be logical, as there is no guarantee of daily rain anywhere [40]. Therefore, it cannot be completely maintenance-free if the amount of deposited material on the surfaces overwhelms the glass's self-cleaning abilities. Or if the glass is not washed clean by the rain. However, cleaning the windows will be much easier when necessary because less grime and dirt will stick to the surface. Just spraying or hosing down the glass with water rapidly would be sufficient to clean it and eliminate any accumulated dirt, the glass may then be allowed to dry naturally. It could also be manually washed with soapy warm water and a soft cloth before receiving a final water flush. After then, the glass will be reactivated in a few days [40][50][52]. The use of rubber squeegees or pressure washers must be avoided since they could damage the coated surface. Rinsing must also be done during the coolest part of the day and out of the sun. The best way to spray is in a zigzag motion from top to bottom. Due to the minerals in the water, in some locations hosing down could result in a milky look or white lines on the coated surface. To reduce the effect, it is advised to add a solvent-free detergent using the proper applicator in these areas. The warmest part of the day should not be used to rinse the glass to further reduce these white stains [52]. Table 6 summarizes the main advantages and disadvantages of the suggested cleaning method.

Table 6. Potential pros and cons of the suggested multifunctional windows cleaning way.

Self-Cleaning way of Windows	
Pros	**Cons**
• Can be applied to multifunctional windows with no fear for their efficiency. • Can be developed if focused on, and can compete with other cleaning methods easily and quickly, as it is already present in the research and practice areas but needs more attention.	• The need for regular enough water spraying on the glass surface by natural means (rain) or alternative artificial means. • Dry climates leave considerable deposits of dirt, so mechanical cleaning is essential to maintain the ideal performance of the self-cleaning glass. • If any circumstances lead to dust accumulation, the glass will need a few days to reactivate after cleaning, so regular enough water spraying should be guaranteed even in wet climates.

9 Proposed method to improve the multifunctional windows cleaning way

A separate system to ensure the regular gathering and spraying of water on the glass surfaces is proposed to operate during the necessary periods of no or not enough rainfall. This is done in response to the cited drawbacks of the proposed self-cleaning method as shown in Table 6. Since rain keeps glass clean, these issues do not arise in regions with heavy rainfall, but they do during dry spells in these areas [37][38]. Nature served as inspiration once more to find solutions to the issues of preventing dust accumulation throughout the year that prevents UV access to the glass and providing daily water spraying on the glass in the absence of rain, in addition to ensuring the use of mineral-free cleaning water. Fog is well recognized by the scientific community for its ability to be deposited and transported on asymmetric surfaces, therefore several researches have been made to make use of it [58]. Many suggested actions addressing the above issues could be completed in the sections that follow.

9.1 Harvesting water from air

The 37.5 million billion gallons of water in the atmosphere can be used to provide an endless supply of pure water. In semi-arid and arid areas, many plants and animals depend on dew water to maintain their activity. Nature can serve as an inspiration for several methods of collecting water from the air, including desert beetles, spider silk, cactus spines, shorebird beaks, butterfly wings, wheat awns, and green bristle grass [54][58][59]. The most popular approach for removing water from the air is to cool it below its dew point. Desiccant vapor absorption from the air should be followed by a condensing method to recover the water. There is currently widespread interest in atmospheric water-harvesting generator (AWG) technology for extracting water from atmospheric air [54][60][61]. Fog droplets can be captured by utilizing a rectangular mesh that is perpendicular to the direction of the wind and exposed to a foggy environment. Fog harps concurrently capture and drain fog reliably and worthily using ultrafine-scale and untreated metal wires. Even for micrometric wire sizes, the vertical wires parallel to the drainage channel aid to reduce the pinning force of caught droplets, which results in efficient drainage of microscopic water droplets [61].

The choice of water harvesting techniques depends on climate elements and monetary considerations. Factors including wind, humidity, temperature, and radiation affect an AWG's ability to absorb water, determine its operating source, and determine whether or not it can be used [62]. According to a study, the ideal relative humidity level for using AWG was 40% or higher, with an annual average of roughly 60% [62]. The output rises when the humidity rises, and vice versa. The ideal location would be a warm, humid seaside environment. The amount of water produced varies between 100 and 5,000 liters in a 24-hour cycle depending on the product, and it may operate in the driest conditions with humidity levels as low as 30%. According to the various conditions and the selected water generator product, there is a water calculator that can be used to calculate the amount of water created annually. For instance, one of the products can produce at a temperature of 30°C and a relative humidity of 80%. This product was made to create 100 liters of water every 24 hours, or 36622 lifters of water annually. The output rises when the humidity rises, and vice versa. The ideal location would be a warm, humid seaside environment. Certain devices that can produce 10, 20, and 50 gallons of water per day can also operate on off-grid power [63][64]. Another method uses about 40 square meters of fog collectors to produce 200 liters each day. If the system is maintained, it can survive ten years [65]. From an energy standpoint, the Moisture Harvesting Index (MHI) is designed to categorize areas based on their capacity to extract water from the air. This indicator links the condensation's latent heat to the dehumidifier's overall heat transfer.

The study also recommended favoring the use of AWGs in areas with an MHI lower than 0.33 [62][66]. To describe the state of water production, the WET (Water Energy Transformation) indicator for AWGs was proposed. It is the ratio of the energy E [kJ] to the condensation energy needed to condense a mass of water, m [kg]. It is a standardized tool for contrasting different AWGs [66]. Another suggested method of water harvesting can be utilized depending on the building's air conditioning system, especially in hot, arid conditions. Especially, if the feasibility study of water harvesting from the air is not appropriate. Condensate water is significant, dependable, and of good quality, and is frequently connected to drainage systems, thus recovering it could be a prudent water supply. [67]. An illustration of such technology is the condensate recovery system utilized in Borj Khalifa, which collects water from the cooling coil of the air conditioning system. This system may produce up to 6280 cubic feet of water in a single day, as shown in Figure 8, and roughly 9.8 million gallons of water each year [68]. Similar to this, a facility on the Education City Campus in Doha, Qatar, collects and stores more than 1.6 million gallons of condensate water from the building's air conditioning systems each year [69].

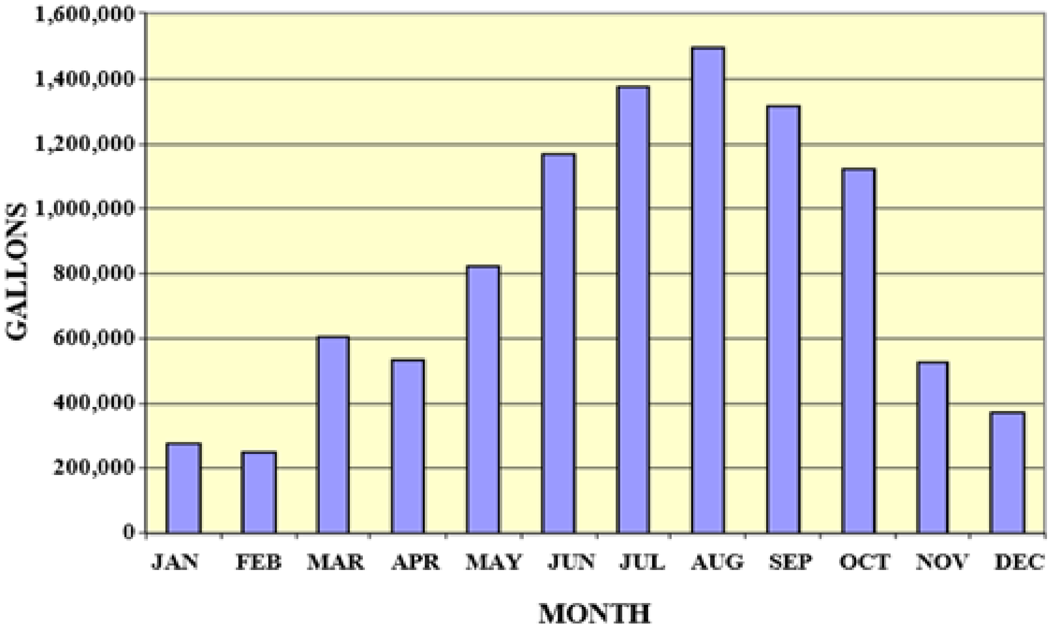

Figure 8. Cooling condensate (gallons per month) water recovery in gallons per month in Burj Khalifa [68].

9.2 Transporting harvested water from air

The cone-induced Laplace pressure gradients and the surface energy are considered the main forces for continuous directional liquid transport on surfaces. The directional water transport is achieved as a result of the structural feature of second-order microgrooves with periodic duck-billed microcavities. The multi-scale peristome surface structure encourages a capillary rise in the transport direction and prevents water from flowing backward. This method may be applied to design bio-inspired fluid-transport systems for practical applications [51][58]. Applying uneven forces to a droplet's opposite side is the secret to moving it in a specific direction. External stimuli including vibration, light, magnetic field, and temperature may be used alone or in combination to produce this gradient in the presence of liquid droplets [54][59]. The fabrication of a Super Hydrophilic-Hydrophobic Integrated Conical Stainless-steel Needle (SHCSN) is made simple. The advantages of rapid fog deposition on a hydrophobic region and swift transit on a super hydrophilic surface are combined in this integrated needle surface. Due to the large Laplace pressure and the self-driven incident at its super hydrophilic-hydrophobic boundary, SHCSN has a substantially higher droplet transit velocity rate than other surface types [54][58].

9.3 Storing harvested water from air

The Texas horned lizard and other moisture-harvesting lizards have unique skin modifications that allow them to obtain water sources like moist sand and dew, allowing them to thrive in parched areas. Little capillary tubes between the scales collect the water, which is then carried to the snout where it is eaten. As seen in Figure 9, the integument has a waterproof network of capillary tubes between the overlapping scales that helps to prevent water loss by evaporation. Directed transport towards the snout illustrates an extra specialization that helps the utilization of even smaller amounts of water transportation [70][71]. These characteristics guarantee the area's growth and the right environment for the potential condensation of air humidity. A suitable derivation system will gather the condensed water vapor along a hemisphere's surface. The outer and inner surface's condensed water is subsequently delivered immediately to a storage area, much like how a lizard gathers water in its mouth [51][70][71]. External pipe from the air handling units to a storage space with sufficient space could be used when relying on air conditioning condensate collection [69].

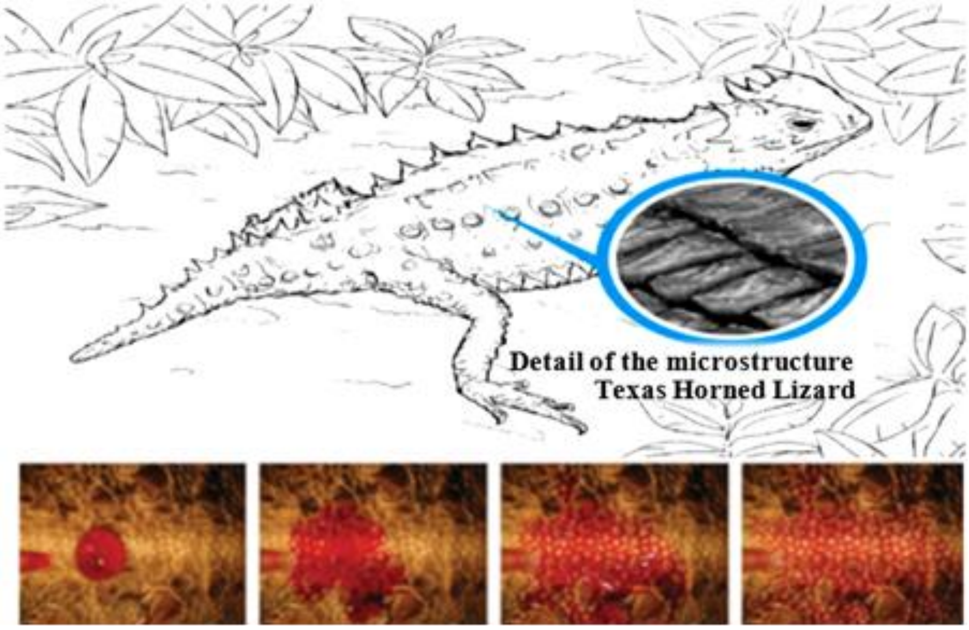

Figure 9. Texas Horned Lizard skin with the sequence of a colored water droplet, which is transported on the dorsal integument [70].

9.4 Spraying the collected water on the glass

It is proposed to give the multifunctional glass a daily spray to ensure that the glass is continuously cleaned and reactivated and that continual self-cleaning is ensured. This spray should be applied in an adequate amount to avoid any dirt stains that may result if the water drops evaporate before removing the dirt; thus, it varies from one location and time to another. Depending on the previous natural surfaces' properties and their applications, proposed integrated hosepipes to the window frames or borders could be designed to harvest water from the surrounding air, then transport it to the upper sides of each window panel. Thus, collecting the harvested water during all-day hours with minimal evaporation, until the proposed connected sensors allow these sides to pump the collected water on the glass surface daily in their coolest period from the top to the bottom in a zigzag pattern; therefore, ensuring the self-cleaning performance with mineral-free water. Fire hydrant installation systems can be a near-conceptual example; they consist of pip work connected immediately to the water supply to provide water to every hydrant outlet.

The proposed system is similar to those systems and depends on the buildings' proportions and dimensions. Figure 10 shows the main components of the proposed systems integrated into the self-cleaning multifunctional windows to avoid the self-cleaning cons.

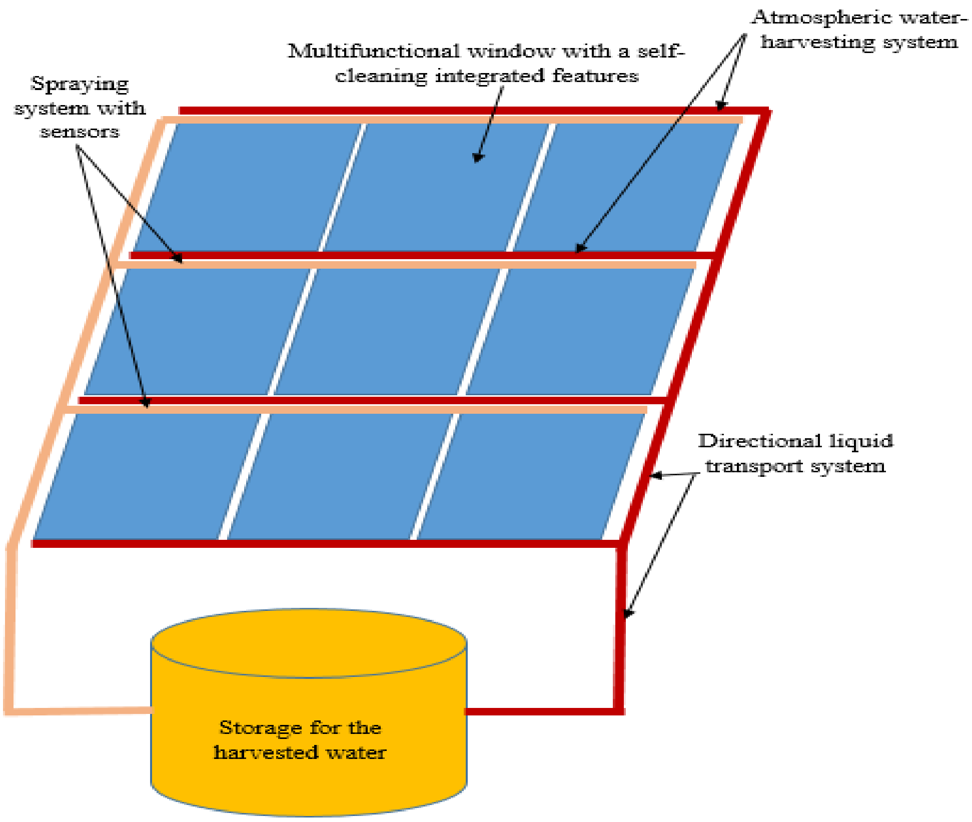

Figure 10. Main components of the proposed way to improve the multifunctional window cleaning method [Author].

It should be noted that in hot regions, a cooling system is required for PV panels. Thus, spraying the harvested water on the glass that integrates semi-transparent PV cells can minimize the amount of electrical energy needed for cooling the solar panels. Mathematical and cooling models can be used to determine when to start cooling the PV panels and how long it takes to cool them down to their normal operating temperature [72]. The findings of such studies could be accompanied by the cleaning spray sensors and system to help merge the two functions.

10 Discussion

Maintenance of windows can be performed in several different ways. An early decision on the preferable way with the most minor disadvantages is important to allow its improvement and research focus. Table 7 presents some comparison aspects between the current window cleaning methods and the self-cleaning method. This comparison shows that the self-cleaning maintenance method is more compatible with the future window types, besides other benefits that it could gain. Future research should then comply with this maintenance orientation.

Table 7. A brief comparison between the current cleaning ways and the self-cleaning way.

Some Comparison aspects	**Way of maintenance**	
	Current cleaning ways	**Self-cleaning integrated feature**
Relevance to the recently developed windows	Possibility of affecting the surfaces, materials, and/or window performance and application of developed window features, particularly when cleaning with magnets and/or electric fields, which can be found in almost all recent current cleaning methods.	Possibility of integrating this feature with the other recently developed features in windows, such as added coatings or added layers, without affecting them. Besides, when using a switchable glass surface between the superhydrophobic and hydrophilic states, the stimuli ways used for the switching could be related to and compatible with the other window technologies processes of stimuli.
Need for energy consumption	The latest methods are mechanized and thus need mechanical energy, even if they were developed to minimize their consumption.	This method uses natural energies, such as sun and rain power, but to provide continuous water spray on the surface, electrical energy consumption may be needed for harvesting and spraying water. But it should be noticed that these actions could also be applied in passive ways, mimicking nature, or could make use of renewable energy that is allowed safely to be integrated into the glass in this case.
Need for detergent use	Most methods require chemical detergents.	Water is enough to perform the cleaning.
Need for human intervention	Humans always have a role, even if limited.	As long as it operates without interruption, no human intervention is required.
Cleaning time	Considerable time will be needed sequentially for each of them.	The cleaning time will be related only to the water spraying time when there is no rain.
Cleaning costs	The continually needed cleaning processes are added costs to the operational building phase.	The main cost of cleaning is limited to the initial facade construction phase only.
Slopped, Irregular shape, and hard-to-reach windows	The difficulty of cleaning.	The ability to clean any window's position and shape neatly bedsides, the window slope helps the water drop movement, preferably more than 30^o.
Benefits to users' visual comfort	Possibility of external condensation that affects the window's viewing function. Besides the moving needed humans and/or devices can interrupt the visual function.	No external condensation, especially when using the anti-fogging surface feature. No interrupting movement of humans or devices on the glass.
Benefits to users' thermal comfort	In hot climates and periods, they can help cool down the windows when using the water on their surfaces, but for a short time before drying them sequentially to avoid dirt stains.	In hot climates and periods, the daily rinse helps the cooling down of windows by evaporation as long as the water exists until drying normally with no stains.
Benefits to PV cells	No guarantee of continuous cleaning and cooling of PV cells to ensure their efficient performance.	The cooling down process helps solve the overheating of PV cells problem that may reduce their efficiency dramatically if not treated [72]. Besides, the PV needs continuous cleaning to not lose its efficiency when dust accumulates on it.

11 Conclusion

Windows are the most obvious and interesting building components that are responsible for several contrary functions. They are exposed to both internal and external environments and are therefore affected by different spatial and time variations besides human needs. The achievement of windows functions continually and efficiently is a great challenge for all designers and specialists due to their contrary requirements. One of the main building research orientations is related to the challenge of creating a window that integrates its different function requirements to achieve them continually with the least conflicts over time. Several researches of that orientation resulted in developed solutions to achieve integrated windows functions. Another main building research orientation is related to windows maintenance to ensure the windows' efficiency over time. Several researchers of that orientation presented different cleaning solutions. Both research orientations did not meet together to show the best maintaining way to clean the recently developed windows. Recommendations from the first research orientation were not to use the ordinary glass types or replace them with more efficient ones, while the recommendations from the second research orientation deal with the ordinary glass types. Developed multifunctional windows from the first research orientation mostly have characteristics that may be affected by the currently recommended cleaning ways from the second research orientation.

The question here is the ability to make a developed multifunctional window capable of adding its maintenance function to its other functions; to avoid the possible inconsistency of the required futuristic window with the available applied maintenance ways. A proposed window that can be smart, multi-pane glazing, and integrated with semi-transparent PV can achieve almost all the human functions that the windows are responsible for, besides producing energy. The current ways of cleaning the windows affect the suggested multifunctional window, as they are usually used devices that produce magnetic or electric fields, which in turn may reduce the efficiency of the coatings and materials of the multifunctional window. Self-cleaning windows is a technology that has been inspired by nature. This technology has been already applied to several glass products and integrated with other windows features. The use of window coating that is hydrophobic, photocatalytic, hydrophilic, anti-reflective, and anti-fogging is the proper way to maintain multifunctional window cleanliness. These features are applied to the glass of the window depending on nano-technology coatings, which can be integrated with several other proposed features.

The main disadvantage of the resulting multifunctional self-cleaning windows is the need for regular rain to avoid the accumulation of dust on the glass surface, thus preventing the UV rays from reaching the window's coating, noting that, even in the rainy regions draft spells may occur. Therefore, inspired also by nature, the paper proposes adding another feature to the previously suggested window to solve self-cleaning-related problems. It depends on several steps starting from harvesting water from the surrounding air using hosing pipes at the windows borders, transporting the harvested water to the upper sides of each window panel to collect them every day, then spraying the collected water on the windows using specific sensors sprays in the coolest time of the day; to prevent any watermarks. This system could be used also for cooling the PV panels integrated into the glass to their operating temperature when spraying the water once in a while, especially in hot regions.

The paper resulted in clarifying the proper way of maintaining successful multifunctional windows with minimum disadvantages. These are the targeted futuristic windows that use recent technologies to achieve continuity of the windows' contrary functions. Therefore, guiding the maintenance research fields to match the coming windows generation by adding the maintaining function to the other several windows functions as integrated features, not a separate technology. The self-cleaning function could be done through the added layers that apply self-cleaning features. Further research is recommended to obtain the maximum integration and efficiency of the multifunctional and self-cleaning window.

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