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The role of transparent Nanomaterials in achieving optimal Indoor environment quality

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Abstract:

A healthy human environment comes from indoors, so Indoor environment quality has a great impact on human health. Time spent in buildings has a direct impact on health and productivity, architects should take action before designing our buildings by using new technologies having the ability to save human health, nanotechnology plays an important role to create healthy buildings and changes the architecture from solid to transparency. This paper will present Factors of Indoor environment quality, nanotechnology and its effect on architecture, The benefits of nanotechnology in air pollution control, The benefits of transparent Materials with nanotechnology to achieve the optimal Indoor environment quality, The WELL Building Standard that is focused exclusively on occupant health. Then the paper will present Examples of international buildings got on WELL certificate, finally the application of Building that applies Fitwell standard by using nano technology (low -E glass).

Keywords: *Indoor environment quality, nano technology, Transparent Materials with Nano technology, WELL Standard.*

1- Introduction

A healthy human environment comes from indoors, So Indoor environment quality has a great impact on human health. Technology for the facades has evolved over time with the advent of new architectural currents, such as translucent facades with the ability to create the optimal indoor environment quality.
Europe is the area in which this idea was publicized and accepted especially for office development. Designers and builders try to add transparency, smoothness, and efficiency to both new buildings and those being renovated.

Nanotechnology plays an important role in these facades, The continuous pursuit of stronger, lighter, and more transparent materials that can perform multiple functions, The most important of which is to make buildings more healthy, That is the focus of this study.

1-1 Research problem

The buildings became closed to their occupants, The significant amount of time we spend indoors increases the health risk associated with poor indoor environment quality, so diseases spread.

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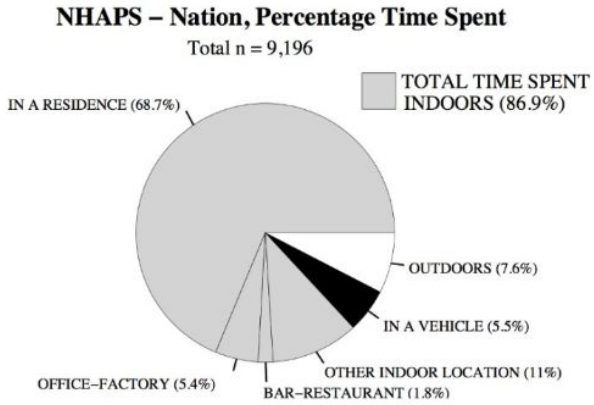

Fig-1: Percentage time spent
Source: NHAPS

This pie chart shows that Americans spend 86.9% of their time indoors, Plus another 5.5% inside a vehicle.

1-2 Research Objective

Time spent in buildings has a direct impact on health and productivity, so we need to take action by designing our built environments in an optimal manner, this study aims to create a new Design for buildings that achieves healthy building for occupants depending on nanotechnology by the WELL Building Standards.

1-3 Research Questions

- What are the Elements of Indoor environment quality?
-how can nanotechnology affect architecture especially Indoor environment quality for heathy buildings?
-What are the standards that can make building more healthy?
- How Can we apply these standards to the buildings?

1-4 Methodology

- **Theoretical study**

  -Indoor environment quality (IEQ)

  -Impact of nanotechnology on architecture

  -Transparent Materials with nanotechnology

- **Analytical study**

  -Analyzing WELL standard

  -Analyzing models of international buildings got on a WELL certificate

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2-Indoor environment quality (IEQ)

Indoor environment quality (IEQ) indicates the relationship between building environment and health and wellbeing of occupants staying inside, which can be determined by many factors.[1]

2-1 Factors of Indoor environment quality (IEQ)

There are four main factors that makeup what is called a good indoor environment:

2-1-1 Ventilation and indoor air quality

Natural ventilation is an essential component of the quality of the indoor environment. Good ventilation improves health and thus productivity.[2]

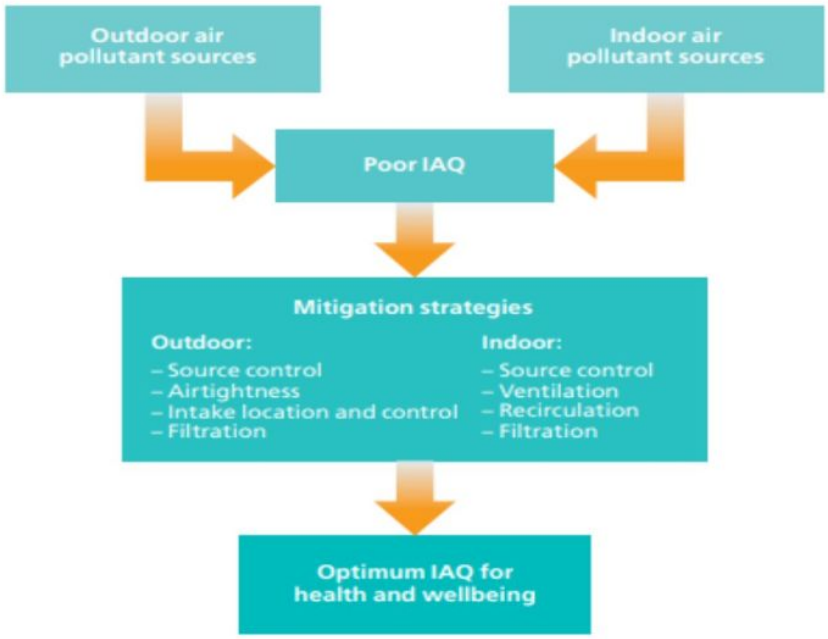

Fig-2: Air pollution mitigation strategies to give optimum indoor air quality
Source: Vina Kukadia and Stuart Upton, Ensuring good indoor air quality in buildings, article, March 2019

2-1-2 Thermal comfort

Thermal comfort is one of the most important physiological factors that strongly affect a person's condition, and a person feels thermal comfort when the surrounding atmosphere can remove excess body heat and moisture at the same rate of their production. The climatic factors represented in solar radiation, air temperature, relative humidity, and air movement are the factors that directly affect a person's sense of comfort or not.[3]

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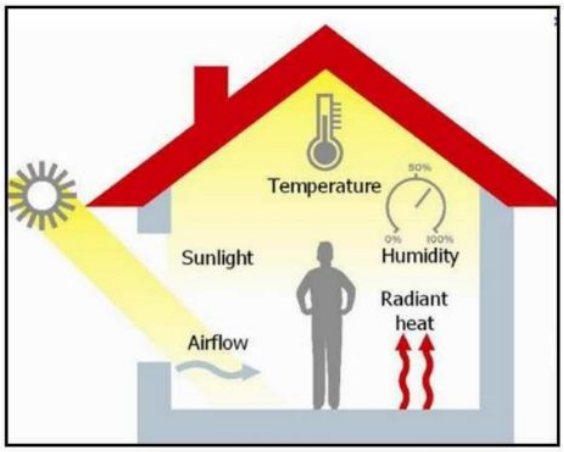

Fig- 3: The most important environmental factors affecting thermal comfort
Source: Mamdooh Alwetaishi, Impact of Building Function on Thermal Comfort, American Journal of Engineering and Applied Sciences, paper,2016

2-1-3 Noise

Noise causes disturbance and nervous tension, and if the noise exceeds 90 decibels, a person may lose hearing. Noise can be treated inside buildings by using soundproofing materials.[4]

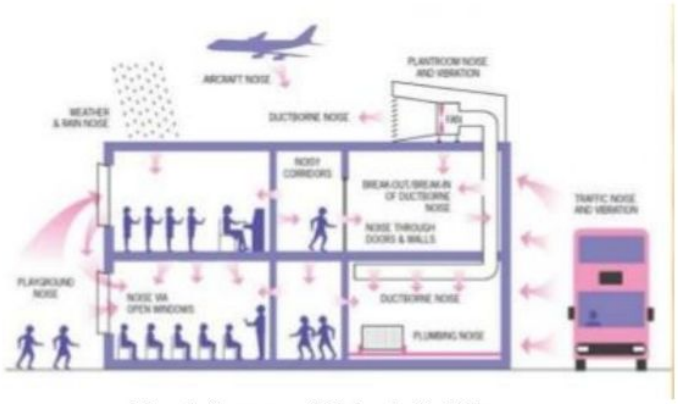

Fig- 4: Sources of Noise in Buildings
Source: https://theconstructor.org/building/noise-control-in-buildings-acoustic/14640/

2-1-4 Natural lighting

It is the light that comes from the sun, and natural light is of great importance in the interior design, as it helps to provide psychological comfort to the occupants of the building spaces, as it links the occupants of the building visually with the external environment, in addition to regulating the biological functions in the human body.[5]

Several factors determine the amount of natural lighting, which are:

-The orientation of the building

-The direction of the openings and their relationship to the direction of the sun

-The glazed area such as windows and skylights

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-The optical properties of the glass material.[6]

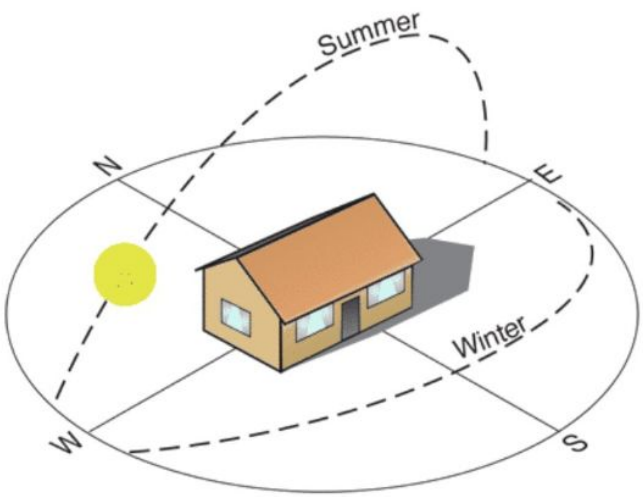

Fig- 5: The orientation of the building
Source: https://theconstructor.org/building/building-orientation-for-hot-dry-climate/9008/

3- Nanotechnology

3-1 Definitions

Nano: It is the smallest metric unit of measure equal to one of a thousand million of a meter, that is, one of a billion a meter, or one of a million of a millimeter.[7]

Nanotechnology: It is the production of materials, systems and devices with unique properties and functions that contain nanoparticles.

Nanomaterial: It is the material in nano scale added to building material to give it new and better properties.[8]

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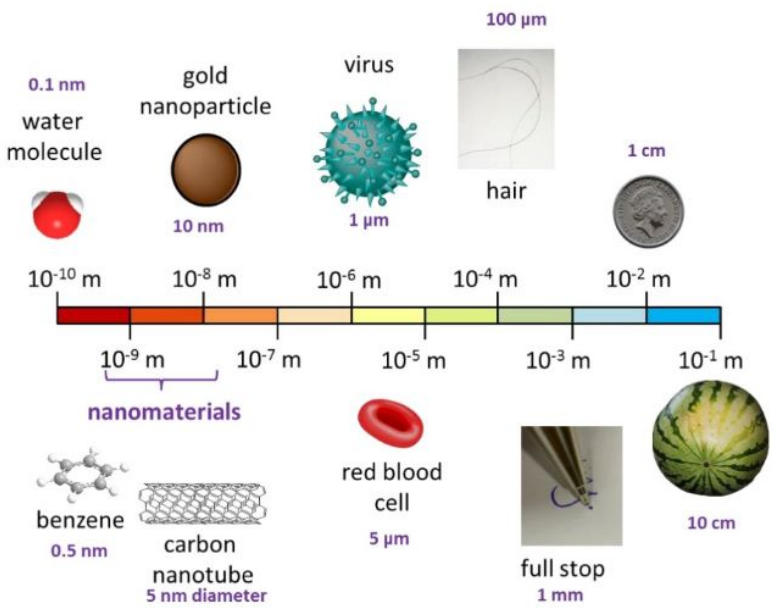

Fig- 6: Nanoscale
Source: https://chembam.com/definitions/nanotechnology/

3-2 Impact of nanotechnology on architecture

3-2-1 Architectural Thought Change

The architect now chooses the building materials that he will rely on in his design before starting to develop his idea and plans, and it has also become necessary to cooperate with the Structural engineer. to produce materials that serve the design idea.

3-2-2 New architectural forms

-Flexible and dynamic architectural forms with high rise

-Dynamic architectural forms

-Biological architectural forms that mimic nature

-The formation of spaces with large areas without the structural elements[9]

3-2-3 Healthy buildings (Optimal indoor environment quality)

-Purifying the outside air

-Reducing carbon dioxide emissions

-Resisting weather conditions from heat, humidity, and water expulsion

-Providing natural lighting with UV protection

-Sound insulation, and fire resistance.

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3-3 Benefits of Nanotechnology in air pollution control[10]

This could be mainly divided into three categories:

Fig- 7: Categories of Nanotechnology in air pollution control
Source: Researcher

3-3-1 Treatment and Remediation

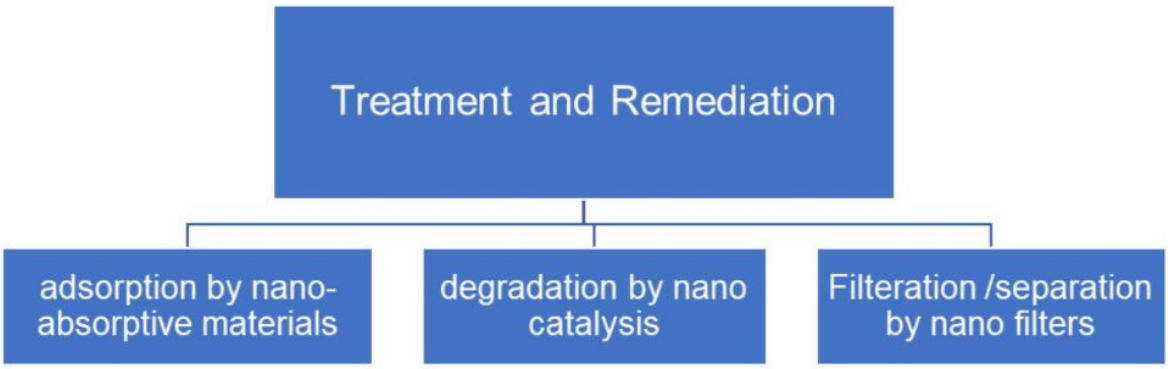

Fig- 8: Categories of Treatment and Remediation
Source: Researcher

i- Nano adsorbents

Carbon nanostructures have extremely physical properties like average pore diameter, pore-volume, and surface area making them significant for industrial applications as Nano adsorbents with high selectivity, affinity, and capacity. Further, the highly reactive surface sites or structures bonds can also play an important role in the adsorption.

ii- degradation by nanocatalysis

The photocatalytic properties of titanium dioxide nanoparticles (TiO2) are being exploited to manufacture "self-cleaning" coatings that are capable of de-pollution atmospheric contaminants such as nitrogen oxides, The photocatalytic reduction reaction can be divided into 4 main steps.

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(1) pollutant adsorption.

(2) electron-hole pair generation by absorbing sufficient incident photon energy

(3) electron-hole pair separation and their migration to the photocatalyst surface

(4) pollutant reduction

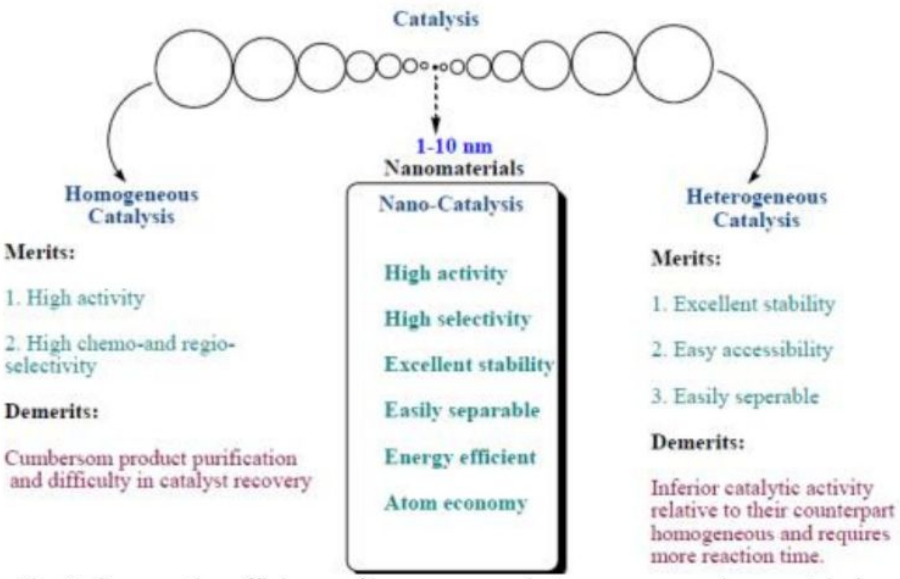

Fig- 9: Comparative efficiency of homogeneous, heterogeneous, and nanocatalysis
Source: Elham F. Mohamed, Nanotechnology: Future of Environmental Air Pollution Control, paper, Research National Research Centre, 2017

iv- Filtration /separation by nano filters

Nano fiber-coated filter media are used for air filtration (e.g., dust removal) at industrial plants and for filtration of the inlet air for gas turbines in particulate, nanoparticles and copper nanoparticles filters are widely used in the air filtration technology as antimicrobial materials to remove bioaerosols through air- conditional processes.

3-3-2 Nanotechnology for Air Pollution Prevention

Prevention of air pollution refers to a reduction in pollution sources and other practices that utilize raw materials, energy, utilities, and other resources effectively to reduce or eliminate waste generation.

Nanotechnology offers many innovative strategies to reduce waste production in various processes such as improving manufacturing processes, reducing hazardous chemicals, reducing greenhouse gas emissions, and reducing the use of synthetic plastics.

The application of nanotechnology can create an environmentally friendly substance or material, replacing widely used toxic materials. The advantage of this technology is the increased efficiency, reduced system costs and whole replacement, as well as reduced environmental impact.

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3-3-3 Sensing and Detection

nanotechnology plays a significant role in sensing the pollutants by improving sensors more specific and sensible for air monitoring. Nanosensors are presently being utilized for the detection of several toxic compounds at ppm and ppb levels in different environmental systems.

Nanotechnology plays an important role in sensing in many ways:

At first, the nanoparticles can be coated with several chemical and biological ligands helping to improve the sensor specificity.

Secondly, the surface/volume ratio of the nanoparticles allowed to vary the size and shape of the nanoparticles thus controlling the interaction with the pollutant molecule.

Finally, the conductivity and sensitivity are improved via the construction of nanoparticles of different metals.

New innovations have developed in the utilization of nanotechnology in environmental sensors, the main advantages of these sensors are; faster, high specificity, can detect the microorganisms at a lower concentration, rapid response, and detection of numerous analytes in the same device.

Nanotechnology will permit the production of verysmall 'multiplex sensors', thus leading to a decrease in the analysis cost and the number of devices used for the analysis.

3-4 Examples of nano units and their mechanism

3-4-1 Multifunctional nano solar cell

The nano-cell consists of a cylindrical shape, it transforms into a conical shape like a flower during cell work, it consists of an inner body of the nano cells and its center is nano air purification devices and around its conductive holes with water paths that open during rain, they are controlled by Nanosensors.

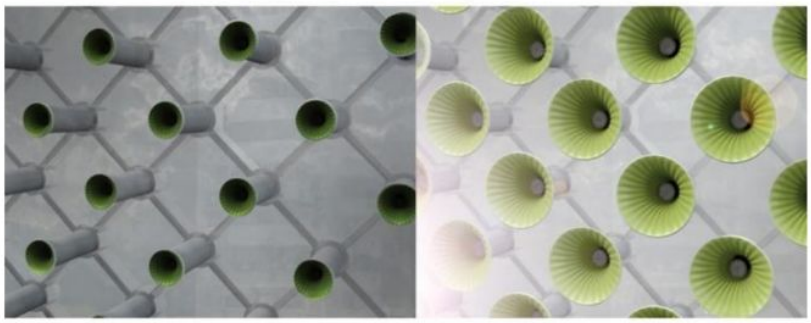

Fig- 10: Multifunctional nano solar cell mechanism
Source: https://www.yatzer.com/grid-sustainable-habitat-2020/slideshow/6

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-Light

The active skin of a building reacts to sunlight and automatically moves into the most efficient position to channel light and generate energy. By collecting and channeling the natural light no electricity will be needed during the day for lighting

- Air

The active skin of the building reacts to the wind. By channeling air and wind through the skin of the building energy will be generated and the air will be filtered to provide clean air inside the building. Compressed and dissipated through funnels, the air will also be cooled for natural air-conditioning. Outside air is cleaned and stripped of CO2 before being exhausted from the building.

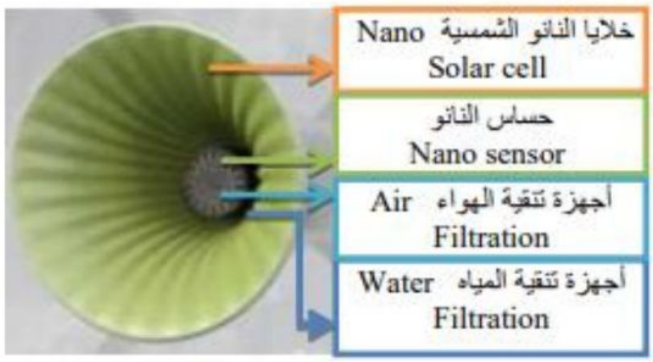

Fig- 11: Components of Multifunctional nano solar cell
Source:2017 ,محمد سيف النصر، دور تطبيقات النانو فى تحقيق العمارة المستدامه، بحث، مجلة جامعة الأزهر

3-4-2 Prosolve370e

-It is a decorative architectural module that can effectively reduce air pollution in cities when installed on building facades.

-It is made from lightweight thermoformed plastic panels coated with TIO2 installed on nano steel mesh.

Fig- 12: Hospital Manuel Gea Gonzales in Mexico City
Source: http://www.prosolve370e.com/

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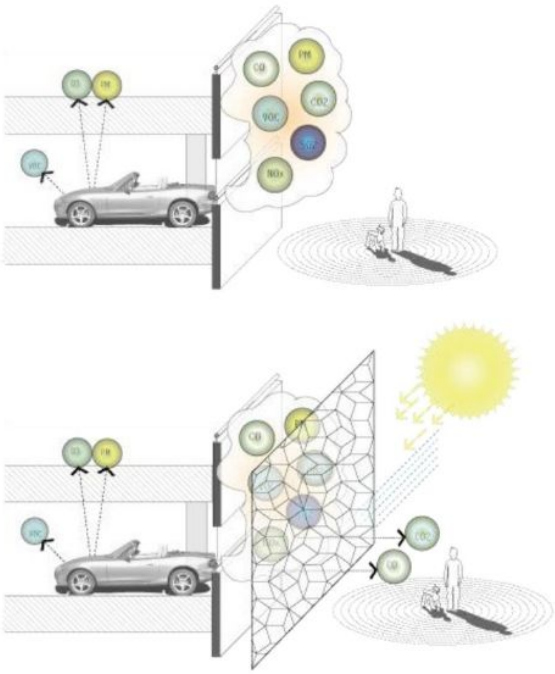

Fig- 13: Hospital Manuel Gea Gonzales in Mexico City
Source: http://www.prosolve370e.com/

-Top Illustration

Combustion engines emit harmful toxins such as NOx and VOCs while running, and also emit VOCs, ozone, and particulate matter while resting.

-Bottom Illustration

A photocatalytic screen positioned between cars and people would trap and filter many of the harmful by-products of combustion engines.

Benefits:

-light

The unit works as a filtering system for natural light and obtaining solar energy

-Air

-It works to purify the air through photocatalytic properties.

-Providing natural ventilation based on the module units.

4- Transparent Materials with Nanotechnology

4-1 Self-cleaning glass

SCG has a very thin layer of titanium oxide (TiO_2) or silicon dioxide (SiO_2) in the order of 10:25 nm coated on its surface to achieve the special cleaning properties. Besides self-cleaning properties, SCG has multifunctional properties such as:

- Anti-reflective, anti-fog

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- Improve thermal protection using energy
- Saving covers (Low-E)
- Changing glass (Electrochromic glass) - Solar protection (anti-UV) using color
- Self-cleaning ability using photocatalytic coating
- Antireflective coatings using SiO2 layer with nanohole arrays
- Antireflective coatings for reinforced glasses[11]

Fig- 14: Disabled-access housing for elderly people in Switzerland
Source: Leydecker, S. (2008). Nano Materials in Architecture, Interior Architecture and Design. Birkhauser, Germany.

-The glass has an extraordinary covering made of TiO2 nanocrystals which, when exposed to sunlight, interacts in two pathways:

The first one is the degradation of any organic pollutants deposited on the glass.

The second way, under the rain, water droplets form a sheet, then the pollutants on the surface are picked up by water and wash off the glass.

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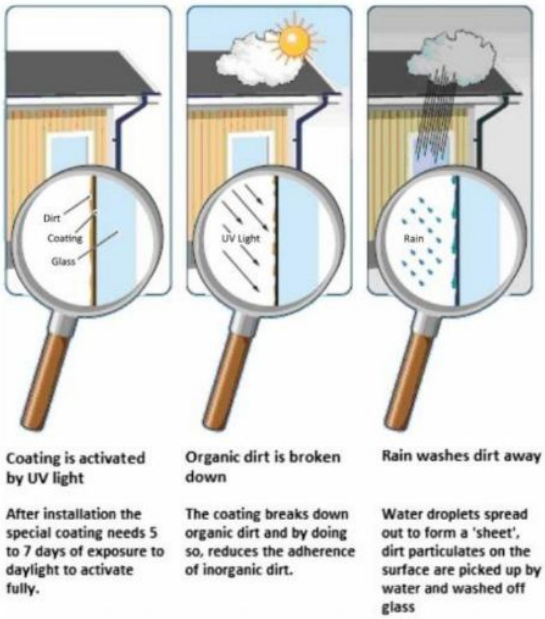

Fig- 15: mechanism of self-cleaning glass
Source: Ian Sofian Yunus, Harwin, Adi Kurniawan, Dendy Adityawarman & Antonius Indarto, Nanotechnologies in water and air pollution treatment, paper, Environmental Technology Reviews, 2012

4-2 Nano Steel

-Vanadium and molybdenum nanoparticles delay the problems associated with high strength bolts and also improving the steel's micro- structure Bolted Welding connection

-The addition of nanoparticles of magnesium and calcium makes the HAZ (Heat Affected welded Zone) grains finer in plate steel and this leads to an increase in weld toughness.

Fig- 16: Astana Stadium in Kazakhstan
Source :2017 علا عمر، لؤى مرهج، العمارة فى ظل تقنية النانو، بحث، مجلة البعث،

4-3 Aerogel

Aerogel is a synthetic porous material derived from a gel, in which the liquid component of the gel has been replaced with a gas. The result is a solid with extremely low density and thermal conductivity. Aerogels are almost completely composed of gas.

-Transparent insulation materials, which in addition to the low thermal conductivity of silica -aerogels also utilize solar radiation for daylight and solar heating purposes.

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-Nanotechnology assisted in developing pores of dimensions of mean sizes of just 10 nm, allowing for a very low coefficient of thermal conductivity of just 0.018 W/mK

Fig- 17: The Sculpture building and gallery of Yale University
Source: https://www.aia.org

4-4 light Transparent Concrete

Optical nanofibers are combined with concrete, these optical fibers can transmit light from natural and artificial sources into spaces enclosed by the translucent concrete panels. The main reason for using optical fiber in concrete is that it can transmit light even an incident angle greater than 600.

Fig- 18: The Italian Pavilion at the 2010 World Expo in Shanghai
Source :2017 علا عمر، لؤى مرهج، العمارة فى ظل تقنية النانو، بحث، مجلة البعث،

4-5 ETFE

-Ethylene tetrafluoroethylene, ETFE, a kind of plastic, was designed to have high corrosion resistance and strength over a wide temperature range. Technically ETFE is a polymer, and its systematic name is poly(ethylene-co-tetrafluoroethylene). ETFE could be combined with carbon nanotubes or graphene to get 40% or more improvement in structural strength.[12]

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-Compared to glass, ETFE transmits more light, insulates better, and costs 24 to 70 percent less to install. ETFE is only 1/100 the weight of glass, and it has properties that make it more flexible as a construction material and a medium for dynamic illumination.[13]

-Researchers at Yale University have also found that CNTs can kill Escherichia coli bacteria. In their experiments, roughly 80 % of these bacteria were killed after one hour of exposure.

-According to the researchers, CNTs could be incorporated during the manufacturing process or applied to existing surfaces to keep them microbe-free.[14]

Fig- 19: The Rainforest exhibit at the Cleveland Metroparks Zoo
Source: https://www.vector-foiltec.com/projects/cleveland-metroparks-zoo-transparent-dome/

5- WELL standard (WELL and Fitwell)

Two important certification frameworks have emerged within the past five years to respond to the need for healthier buildings: The WELL Building Standard (WELL) and Fitwell.

Fig- 20: WELL and Fitwel
Source: https://www.vector-foiltec.com/projects/cleveland-metroparks-zoo-transparent-dome/

5-1 WELL [15]

It was launched in late 2014 as the first rating system that incorporates different types of measures for the advancement of human health and wellness in buildings. WELL, had its first major update in 2018 (WELL v2). WELL, is explicitly prioritizing health through 10 concepts plus Innovations and more than 100 features.

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The level of certification is Certified (40-49 points), Silver (50-59 points), Gold (60-79 points), and Platinum (80+ points).

Fig- 21: WELL concepts
Source: https://www.wellcertified.com/

5-2 Fitwel [16]

To optimize the opportunities for different types of projects, Fitwel is providing a tailored scoreboard for several building types, including multifamily residential, retail, community, and workplace.

Fitwel aims to influence 7 impact categories as in the following figure:

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Fig-22: Categories of Fitwell
Source: https://www.fitwel.org/

Fitwel strategies are divided into 12 sections:

1. Location
2. Building Access
3. Outdoor Space
4. Entrances and Ground Floors
5. Stairwells
6. Indoor environment
7. Workplaces
8. Shared Spaces
9. Water Supply
10. Cafeterias and Areas for Prepared Food
11. Vending Machines and Snack Bars
12. Emergency Preparedness

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5- Examples of international buildings

There are many WELL certified buildings, as follows:

5-1 WKU's Ogden College Hall [17]

Table1: PROJECT INFORMATION
Source: https://www.wku.edu/news/articles/index.php?view=article&articleid=8543

Project	WKU's Ogden College Hall
City/country	United States
Architect	ROSSTARRANT ARCHITECTS
COST	$40,000,000
Area	Four-story, 82,889 square feet
Year	2018

Ogden College Hall holds over 30 laboratories for biology, chemistry, physics, and astronomy classes, along with student advisory offices, a 300-seat auditorium, and the office suite for the Ogden College of Science and Engineering.

WKU's Ogden College Hall is the first educational laboratory in the United States to achieve WELL v2 Gold Certification by the International WELL Building Institute, maximizing the safety, health and overall wellness of the building's occupants.

The Aim:

This building aims to be student-friendly, utilitarian, energy-efficient, and a healthy environment for work, and learning.

Air Quality:

At Ogden College Hall an air quality cage is constantly monitoring indoor air metrics on the following pollutants:

- PM-2.5 Particles
- PM-10 Particles
- TVOCs
- Carbon Monoxide and Ozone

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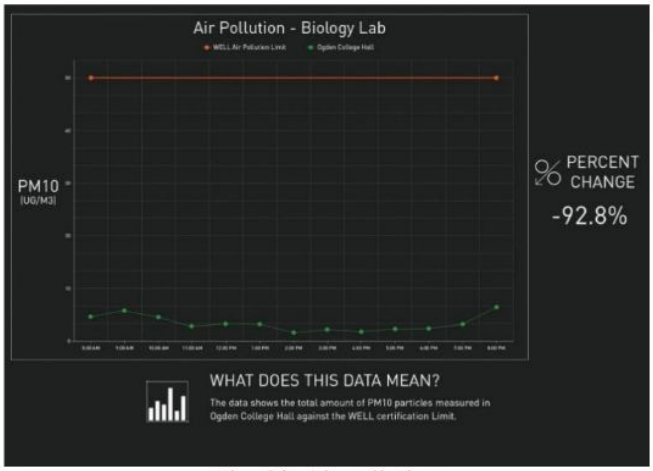

Fig- 23: Air pollution
Source: https://www.cmta.com/results/case-studies/ogden-college-hall

Light Quality:

-One of the building's most easily recognizable features is its use of natural light.

-Views outside provide occupants with a direct link to nature and aid in orientation while the sun reinforces healthy circadian rhythms.

-Inside, natural light offsets the need for electrical lighting while helping people stay alert, focused, and happier.

-Special laboratory fume hoods designed with glass backing even bring daylight into laboratory spaces where access to natural light is usually limited.

-Selecting the LED lights with the increased blue spectrum for Ogden College Hall CMTA has helped to increase alertness and support the student's sleep-wake sleep cycles.

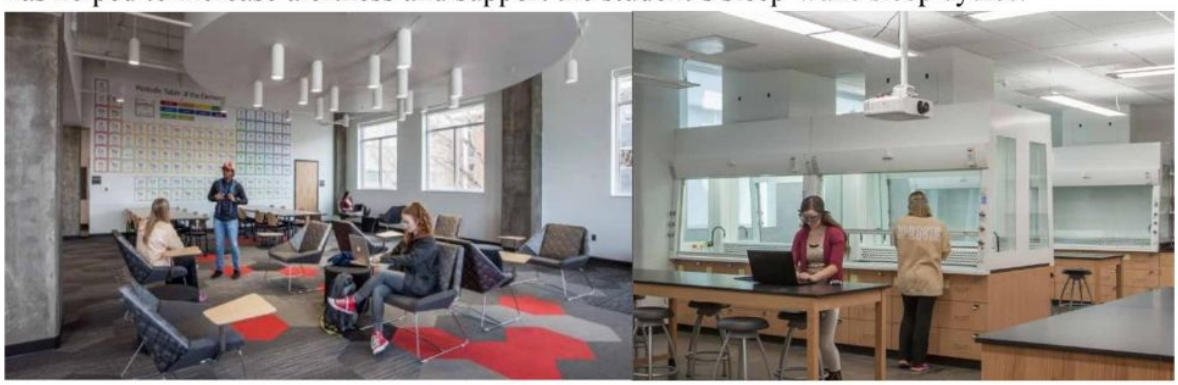

Fig- 24: Ogden college hall
Source: https://www.cmta.com/results/case-studies/ogden-college-hall

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5-2 Cundall's London office [18]

Table2: PROJECT INFORMATION
Source: https://www.igbc.ie/case-study-cundalls-london-office-becomes-first-project-europe-achieve-well-certification/

Project	Cundall Office
City/country	London, UK
Architect	Studio Ben Allen
Collection	Flow Shore
Area	1500 m2
Year	2016

Cundall's new London office is the first building in Europe to achieve WELL Certification through the WELL Building Standard™ (WELL) at the Gold level.

Cundall has applied WELL criteria such as:

-Testing and monitoring air and water quality.

-The lighting design combines both the careful layout of the office to maximize the use of natural daylight with light level sensors that reduce or increase lux levels when appropriate.

Fig- 25: Cundall office
Source: https://www.skyscrapercenter.com/building/bank-of-america-tower/291

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5-3 Bank of America Tower (Fitwel certificate and nanotechnology)

The Bank of America Tower recently received a three-star rating from Fitwel

Table3: PROJECT INFORMATION
source: https://www.skyscrapercenter.com/building/bank-of-america-tower/291

Project	Bank of America Tower
City/country	Manhattan in New York City.
Architect	Rick Cook
Architectural styles	Deconstructivism, High-tech architecture
Area	: 2,099,985 sq ft (195,095.0 m^2)Floor area : 234.5 m (769 ft)Top floor
Height	234 m, 366 m to tip
Year	2006

Fig- 26: Bank of America tower
Source: https://www.skyscrapercenter.com/building/bank-of-america-tower/291

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The vision:

The occupant scale was to create the highest quality modern workplace by emphasizing daylight, fresh air, and an intrinsic connection to the outdoors.

Fig- 27: The internal space of the building
Source: https://www.skyscrapercenter.com/building/bank-of-america-tower/291

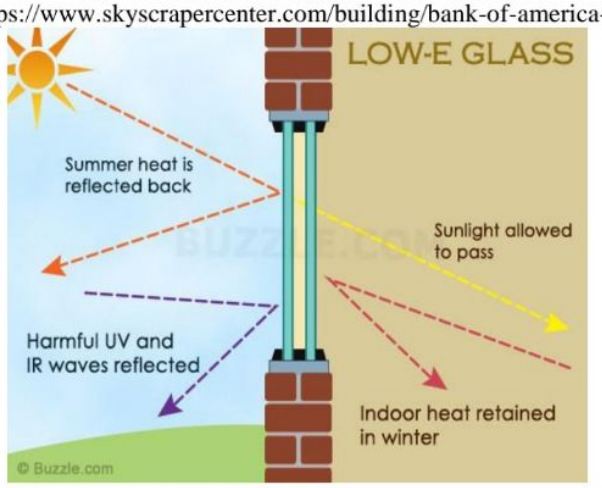

Fig- 28: Low- E glass
Source: https://houstonwindowexperts.com/understanding-low-e-coatings/

Bank of America Tower was graded using a wide variety of Fitwel criteria, which assessed the unique features of the building and the surrounding community including:

-Selecting sites that are optimally located for walkability and access to public transit.

-Promoting and enhancing those connections through design and operations, incorporating stairs into building design.

-Access to indoor/outdoor fitness opportunities including onsite fitness or walk/run/bike trails, and providing bike storage and shower facilities.

-Improving indoor air quality through tobacco-free policies and integrated pest management.

-Enhancing workplace safety through comprehensive emergency procedure policies.

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- Creating workspaces with abundant daylight, views of nature, outdoor air and access to active workstations. [19]

Table4: The impact of nanotechnology application in the building of the bank of America tower
Source: Researcher

The impact of nanotechnology application in the building of the bank of America tower												
Nanomaterials	Self -cleaning glass			Nano steel	Transparent concrete			Aerogel		ETFE		
	✓											
WELL standard (Fitwell)	Location	Building Access	Outdoor Space	Entrances and Ground Floors	Stairwells	Indoor environment	Workplaces	Shared Spaces	Water Supply	Cafeterias and Areas for	Vending Machines and	Emergency Preparedness
	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nanomaterials For achieving well standard	Optimal indoor environmental quality -95% filtered air -Abundant natural daylight -Round-the-clock air quality monitoring -Views through a clear glass -Minimizing solar heat gain -Reduce artificial lighting with an automated daylight dimming system, reducing lighting and cooling energy by up to 10%.											
Results	-The building applies Fitwel standard -The building uses nano material that helped the building to get Fitwel certificate by achieving optimal IEQ - The building is a perfect example for the modern buildings that change occupant's mind and enhances his health											

This table shows that the bank of America tower is using nanomaterial (self-cleaning glass) that achieved optimal indoor environmental quality and helped to get a WELL certificate.

6- Conclusions

Nanotechnology plays an important role indoors, By transparent materials treated with nanotechnology such as Self-cleaning glass, Nano Steel, Aerogel, Transparent concrete, And

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ETFE material, We can create healthy buildings and optimal indoor environment quality for occupants by The WELL Building Standard (WELL) and Fitwell, which as follows:

-Air quality

-Light quality

-Thermal comfort

-Sound

-View

7- Recommendations

-Identify nanotechnology and materials which affect the occupant's health.

- It is necessary to work on increasing scientific and research integration between Egyptian universities and local centers in the field of nanotechnology and its practical applications.

-It is necessary to integrate nanomaterials into the green pyramid system through the Housing and Building Research Center.

- Cooperation between Arab and foreign countries to exchange scientific research in the field of nanotechnology by organizing annual official conferences and workshops.

-The use of nanomaterial should be in constructing laws to encourage using it, especially it is a sustainable material.

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