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The Potential of Nanotechnology in Improving the Efficiency of Existing Building Performance
A Literature Review

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الملخص

ان مشكلة الاحتباس الحراري قد تساهم في جعل المباني القائمة غير فعالة وغير صالحة للسكن و بالتالي فأنها ستفتقد اهليتها للاستخدام بشكل كبير ليس فقط في الوقت الحاضر و انما ايضا في المستقبل، حيث تستهلك المباني جزءا كبيرا من الطاقة حول العالم في اغراض التبريد و التدفئة. للأسف معظم المباني في المستقبل القريب و التي ستكون قائمة في العقود القادمة قد تم بناؤها بالفعل دون الاخذ بنظر الاعتبار استهلاكها للطاقة و تأثيرها السلبي على السكان و البيئة. ان تقنية النانو الخضراء توفر امكانية تحسين اداء المباني القائمة و التأثير عليها لتطويرها نحو تحقيق الاستدامة وذلك للتقليل من المشاكل البيئية المستقبلية و لتوفير بيئة داخلية بجودة افضل. من المتوقع ان تساهم مواد و منتجات و تطبيقات تكنولوجيا النانو بشكل كبير في حماية البيئة من خلال توفير المواد الخام و الطاقة و تقليل غازات الاحتباس الحراري. إن هذه الورقة تهدف الي عرض الامكانيات و التطبيقات التي يمكن ان توفرها تكنولوجيا النانو للمباني القائمة لجعلها اكثر صداقة للبيئة. من اجل تحقيق الهدف من الدراسة تطرق البحاث الي بعض الدراسات النظرية السابقة ذات الصلة في هذا المجال. ان تطبيقات تكنولوجيا النانو ليست فقط مفيدة في الانشاءات الجديدة، بل هي اكثر فائدة في المباني القائمة بالفعل و بالتالي ستساهم بشكل مباشر او غير مباشر في استدامتها و دون ان يترتب على ذلك اي إضرار للمبنى نفسه.

الكلمات المفتاحية: المباني القائمة، مواد النانو، تقنية النانو، الاستدامة .

ABSTRACT

The problem of global warming is likely to make the buildings increasingly inefficient, and uninhabitable, not only in the present time, but also in the future, as a significant part of global energy is consumed by buildings for cooling and heating purposes. Unfortunately, most of the buildings that will be exist in the coming decades are already built without taking into account their energy consumption in addition to their impact on the inhabitant and the environment. Green Nanotechnology offers potential to improve existing building performance and influence their development toward sustainability to prevent future environmental problems and provide better indoor quality. Nano technologies, materials, products, and applications are anticipated to contribute impressively to environmental protection by saving crude materials, energy as well as by decreasing greenhouse gases.

This paper intends to address the possibilities and applications offered by nanotechnology for existing building to make them more environmentally friendly. In order to achieve the study aim the researcher will consult relevant literatures in the field. Nanotechnology applications are not only extremely useful in new constructions but also more beneficial in existing buildings which will directly or indirectly contribute to its sustainability without invasive intervention and consequent damage to the building itself.

KEYWORDS: Existing buildings, nanomaterials, nanotechnology, sustainability.

1. INTRODUCTION:

The prefix "Nano comes from a Greek word Nanos which means Dwarf “extremely small”. So, nanotechnology is the science and technology of small things that are less than 100nm in size [One nanometer is 10-9 meters long]. Nanomaterials have significant different features than same materials on large scale, therefore, unlimited potentials for improved structures, materials and equipment. Nanotechnology has many benefits in the resources saving. It provides in the production stages opportunities to reduce the use of materials that have a large environmental footprint by replacing them with other materials have fewer effects and therefore the most efficient use of raw materials. The revolution of Nanotechnology is not only bringing significant developments in the performance, energy efficiency, and sustainability of new buildings but also has a major influence in improving existing building. Sustainable environmental design standards are easy to implement in the design of new constructions but are difficult to apply to building that already exist, although, it is no longer difficult after the invention of nanotechnology.

2. Applications of Appropriate Nanotechnology for the Sustainable Development of Existing Buildings

Since the last decades, the global market of nanomaterials has raised rabidly. Nanotechnology is expected to be a mature industry by 2025 (Helal, 2016). The applications of nanotechnology in today's construction is more related to green design.Using nanoparticles to typical building materials can result in stronger, more durable, self-healing, heatinsulating, air purification, fire-resistant, and easier to clean products. Nano materials also improve the durability and performance of construction components, safety and energy efficiency of the buildings as well as providing increased living comfort. The line chart below shows the dramatic growth of Nano technology market.

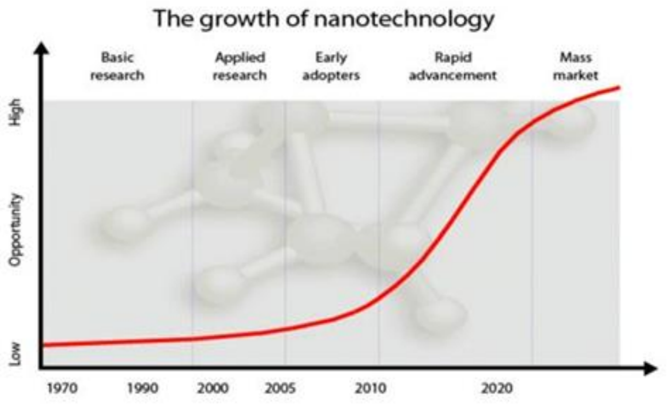


Figure1. Growth of nanotechnology market since 1970

Nanotechnology can alter the nature of existing building and its relationship with users and environment. At this stage we are going to illustrate some building materials and technologies that could be used on existing buildings to improve their efficiency of performance.

1- Air purification

The internal environment in the building is one of the elements that must be characterized by a high level of quality to achieve the appropriate level of comfort for the occupants. So it should be free of any contaminants, whether dust, bacteria or odors. The level of humidity and temperature also greatly affect the performance of the users. Many factors that affect indoor air quality, including the environment surrounding the building, building construction techniques and sources of pollution such as building materials, furnishing and activities inside and outside the building. The shortage of indoor air quality because of harmful organic molecules leads eventually to the symptoms of sick buildings syndrome or buildings related illness. An important number of

Nano-engineered materials and products have been emerged in order to purify and improve the indoor air. These products are vary and differ in how they work such as:

1-1 Paint protection system ,nanowood and nanostone

Paint protection system, nanowood and nanostone relay on the idea of using mixture of nanomaterial which can be painted, sprayed, rolled or in case of smaller objects they can be sunk into solution. The product is environmentally friendly. So, alcohols or vo;atic organic compounds (VOCs) are not released during application, as well as suitable for all surfaces such as floors, furniture and walls.

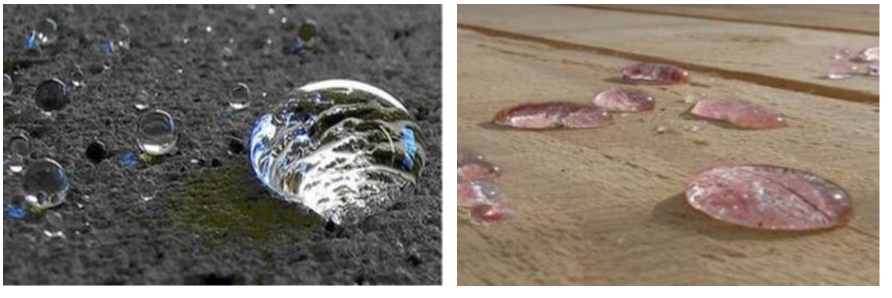


Figure2. Nanostone and naowood applications,

1-2 Photocatalysis nanotechnology for the development of filters equipment's

According to Son Le, et al, (2015), There are many traditional methods for air pollution treatment such as adsorption, separation or using chemical disinfectants, but they have the same weakness, pollutants just move from one place to another without being thoroughly resolved or there is the potential formation of by-products toxic for human health.

Lately, the photocatalytic pollution treatment method using nano-TiO2 (titanium dioxide) material has been discovered and is considered as a breakthrough solution. "Nanostructured titanium dioxide has been widely researched for application towards the photocatalytic treatment of purification of water and air, “self-cleaning” and uperhydrophilic coatings for surfaces, and dye-sensitised voltaic cells". (Byrne, et al, 2006)

Titanium dioxide when being irradiated with ultraviolet (UV) light destroys chemical. Compounds as well as bacterial cells to form CO2 and H2O. Table (1) presents a comparesion between tradional purification systems with photocatalyst method.

Table 1. Purification technologies comparison

	HEPA[1]	ES Filter[2]	Ozone	UV[3]	Minus-Ion	Photocatalyst
Mold	Good	Normal	Good	Good	Normal	Excellent
Germs	Excellent	Normal	Good	Good	Normal	Excellent
Virus	Normal	Normal	Normal	Normal	Normal	Excellent
Dust Mite	Excellent	Good	Normal	Normal	Normal	Normal
Toxicant	Normal	Normal	Good	Good	Normal	Excellent
Odor	Normal	Normal	Good	Normal	Good	Excellent
Smoke	Good	Good	Good	Normal	Excellent	Good
VOCs	Normal	Normal	Good	Good	Normal	Excellent
Allergen	Good	Good	Good	Normal	Excellent	Excellent
Note:	[1] High Efficiency Particulate Air Filters [2] Electrostatic Filters [3] Ultraviolet					

1-3Photocatalytic activity of nanostructured coating

More energy is require by Current air-cleaning technologies , but a promising new solution is being developed. Window glass with nanostructured coating based on titanium dioxide TiO2 uses sunlight energy to destroy organic pollutants from indoor air by passing it between the inner panes of the window in a process called photocatalysis.

"Recently, pavement blocks of titanium-dioxide-impregnated cement have been used to mitigate air pollution from outdoor pollution in cities"(Stefanov, 2015). Figue 3 illustrates the Working mechanism of TiO2- coated window glass.

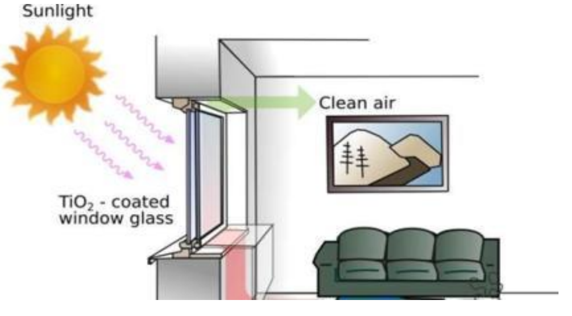


Figure 3. Windows with nanostructured coatings can cure 'sick' buildings.

2- Nano Insulation Materials for Energy Efficient Buildings

A considerable fraction of the total energy is consumed by building and, consequently have a large potential for conservation. For this reason, mankind are forced to think seriously about reducing the energy usage wherever possible. According to the

World Meteorological Organization (WMO) "buildings represent the largest energy-consuming sector with nearly 40% of global electricity consumed, and therefore, they are also responsible for about36% of global carbon emissions (CO2), mainly because of inefficient thermal insulation systems." For existing buildings, renovation has a high priority in many countries, because these buildings represent a high proportion of energy consumption and they will be present for decades to come. Several studies have shown that the best way to reduce the energy consumption in buildings remains the reduction of heat losses through the envelope" (Ibrahim & Biwole, 2015).

The design and construction of building envelopes traditionally involve the use of multiple layers of different materials to achieve a number of functionalities , including strength , light filtering , thermal insulations , sound insulations , weather resistance and architectural appearance (Lalbakhsh, E. & shirazpour, P., 2011).

Reduction in heat losses through the envelope by thermal insulation materials is an ideal ways to decrease the annual energy demand of buildings for heating and cooling purposes. "Nanotechnology promises to make thermal insulation more efficient, less reliant on non-renewable resources as an important strategy on the pathway to green buildings.The application of nano insulation materials to limit the wall thickness is one of the greatest potential energy-saving characteristics for the existing buildings" (Božić, 2015).

Nanotechnology-based thermal insulation materials generally have a better thermal insulation quality than traditional materials. They have a higher heat transfer resistance than traditional thermal insulation materials. U-value (Thermal transmittance) can be reduced by nanotechnology-based materials such as EPS Graphite, aerogel insulations, vacuum insulation panels which have a lower thermal conductivity than the traditional materials. (Bozsaky, 2016).

In vacuum insulation panels VIP (figure4), the interfaces of silica crystals are very small, which causes difficulties in thermal conduction. It is one of the most effective heat insulation materials in the future. Thermal conductivity of VIP is in the range of only 0.003 to 0.004 W/mK, which is ten times better than conventional materials such as min eral or glass fibers or polystyrene

Figure 4. Vacuum insulation panels

Aerogels are becoming one of the most promising materials for building insulation because of their highly insulating features. "due to its low thermal conductivity (0.015 W/mK), only 10 mm aerogel based insulation panel is needed to achieve the same level of insulation of 25 mm thickness of standard Expanded Polystyrene Panel" (Guinoaa, 2017).

The coating was manufactured by mixing natural lime with granular aerogel manually in different percentages, see figur (5). Nowadays, aerogel-based materials cost remains high because of raw materials expense. "This cost is expected to decrease in the following years as a result of the advancement in the aerogel production technologies as well as the large-scale material production leading to lower unit costs." (Ibrahim & Biwole, 2015).

Three U.S. firms, Aspen Aerogel, Cabot, and American Aerogel al ready have consumer products on the market, and their production levels are on rising. Meanwhile, current research efforts aim to bring about significant cost reduction in high-performance insulation manufacturing. If these efforts are successful, aerogels may become competitve over the next few years with existing thermal insulation technololgies (Shukla, Et al, 2012)

Figur 5. Aerogels application as a thermal insulation for inner wall,

Aerogel is also used as nanoporous translucent glass. It is preferably used as a thermal insulating window like curtain walls, skylight window and transparent partition wall. In addition to having excellent performance for thermal and solar gains, aerogel is a good acoustic insulation material could be used in existing buildings. See figure (6).

Figure 6. Aerogel as nanoporous translucent glass

3- Self Cleaning feature

In designing or selecting buildings materials, surface properties are fundamental importance. The need for surfaces that are easy to clean (self-cleaning) or that have antibacterial or antimicrobial properties is fundamentally important in the design.

Many nano-based products designed for self-cleaning using coatings, paints or films containing nanoparticles and added to traditional materials, although certain formulation may include surface layers through which nanoparticles are specifically blended into the raw material, two primary techniques were used to achieve self-cleaning feature (Schodek, Et al, 2009)

The ability to make :

- Hydrophobic(water-repelling) surfaces "**Lotus Effect**".
- Hydrophilic (water- attracting) surfaces " **Photocatalytic nanotitanium dixide(TiO2)**".

3-1 Self-cleaning I - the "Lotus Effect":

In Asian countries the louts flower has long been a sign of innocence. Thogh rising in muddy waters, its leaves still look clean.The plants' leaves are superhydrophobic, i.e. drops of water roll off free of remains, taking any dirtiness with them.

Lotus plants leaves are coated with teeny wax crystals around 1nm in diameter which repels water, droplets falling onto them bead up and, if the surface slopes slightly, will roll off. Lotus effect is now one of Nanomaterials, best-known ways of modeling surface.

Self-cleaning behavior is normally achieved using hydrophobic surfaces with nanostructured features, see figure (7). These are influenced by the Lotus flower leaves which integrate nanoscale surface roughness with water repellent wax. It can be engineered, or imitated, using nanocomposite materials made up of nanoparticles in a polymeric matrix.

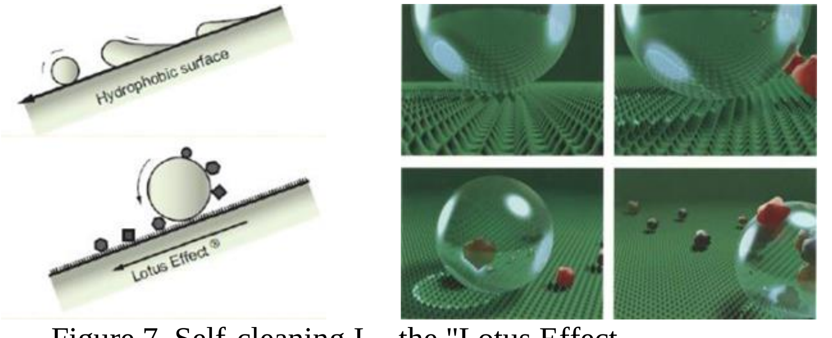


Figure 7. Self-cleaning I - the "Lotus Effect

"Lotus-Effect" products include ceramic roof tiles, architectural glass and a spray for industrial use which makes surfaces temporarily non-wettable and self-cleaning, using those products in existing buildings could seviously reduce the cleaning requirement, and surfaces that are frequently exposed to water remain clean (Jobs, Nano, et al, 2011).

The advantages are self-evident: a cleaner appearance and considerably reduced maintenance demands.Products based on the lotus effect are best used where there is frequent general washing from rain or other sources.

3-2 Self-cleaning II – photocatalytic nanotitanium dioxide (TiO2)

This kind of self-cleaning action comes from coatings with thicknesses at the nanoscale that have particular photocatalytic and hydropilic properties, normally titanium dioxide (TiO2).

A coating of nanotitanium is exactly the opposite manner to a surface whose self-cleaning properties are based on the "Lotus-Effect". Due to its high surface strength, titanium dioxide is hydrophilic, thus water does not shape drops on a surface covered with it, but rather a sealed water film. Coating thickness is on the order of 15nm, it is also transparent and can therefore be used on glass, see figure (10).

The way TiO2 coating works:

- Coatings of thin titanium dioxide show hydrophilic and photocatalytic action.
- When the coatings are subjected to ultraviolet (UV) light, the photocatalysis process oxidizes foreign particles such as, for example, fats, oils, soot or plant materials and decomposes them.
- When the coating are subjected to washing or rain, the hydrophilic action then causes dirt particles to be carried away, (Schodek & Daniel, 2009).

A further advantage is that light transmission for glazing and translucent membranes is improved as daylight is obscured less by surface dirt and grime. Energy costs for lighting can be reduced accordingly, also odors caused by dirt are broken down and reduced as they are organic molecules oxidized by the process of photocatalysis.

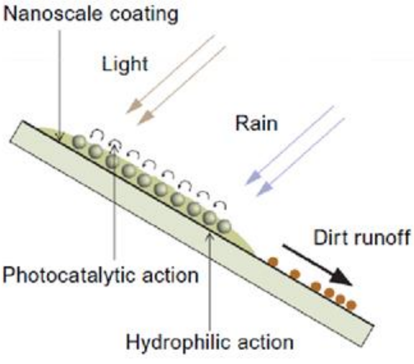
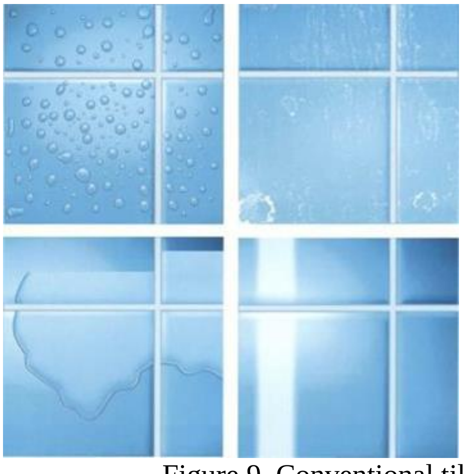


Figure 8. Self-cleaning II – photocatalytic nanotitanium dioxide (TiO2)

Photocatalytic processes based on UV light are obuiously promarily suitable for exterior surfaces of existing buildings where sunlight is present, outdoor building finishing materials such as glass wood and tiles,and works into cement or apply in a layer on concrete, see figure (9).



Before
On **conventional tiles**, water forms droplets that dry leaving behind dirt deposits.

After
On the hydrophilic surfaces of photocatalytic tiles, water forms a film that runs off taking any loose dirt deposits with it

Figure 9. Conventional tiles, Photocataly tiles,

4- Energy coating

The sun offers us a continuous source of clean, free energy. Solar represents less than 5 percent of today's energy market, but is growing 30 percent annually, and buildings use almost 40 percent of all energy used in the world(Elvin, 2007). Similar to how a plant absorbs sunligh and transforms it into chemical energy to support a plant's growing, energy coatings capture sunlight and indoor light and turn it into electrical energy (Hemeida, 2010).

4-1 Thin film solar

Solar collection devices often rely on silicon technology, but new solar nanotechnologies based on thin film materials, nanocrystalline materials, and conducting polymeric films offer the prospects of cheaper materials, higher efficiency, and flexible features. These solar modules capable of converting light into electrical power with more than 50% efficiency instead of the current 20% or so, (Green, 2006), see figure (10).

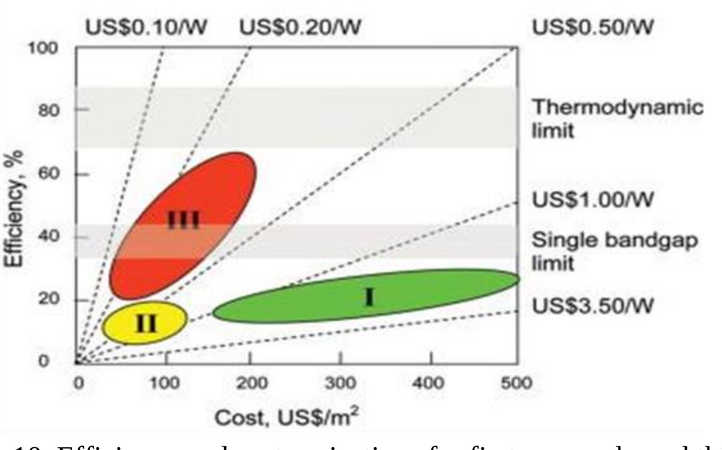


Figure 10. Efficiency and cost projections for first-, second-, and third-generation photovoltaic technology (wafers, thin films, and advanced thin films, respectively

A thin-film solar cell is made by depositing one or more thin layers, or thin films (TF) of photovoltaic material on a substrate, such as glass, plastic or metal. Film thickness varies from a few nanometers (nm) to tens of micrometers (µm).
The nature of these ultra thin film cells allows them to also be flexible, lightwaight and have less drag of friction then traditional silicon-based solar cells. They can be used in building integrated photovoltaics and as a semi-transparent, photovoltaic glazing material that can be laminated onto windows, see figure (11).
These thin-film solar cells can be easly integrated into existing buildings facades, roofs,windows , fabrics, tents, sails, glass,and all sort of surfaces, "Nanotechnology could turn rooftops into a sea of power-generating stations" (Carlstrom, 2005).

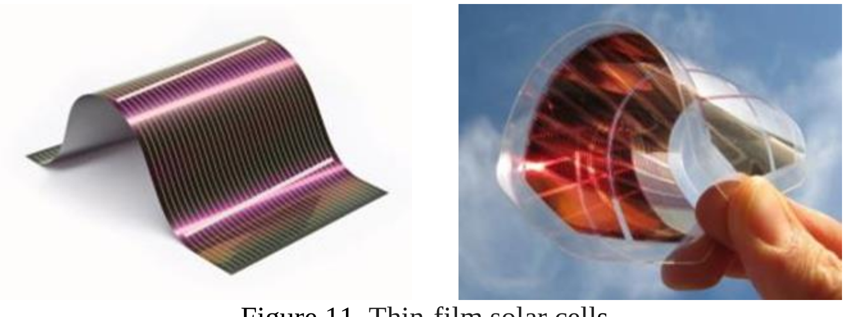


Figure 11. Thin-film solar cells,

5- Lighting

Artificial lighting plays a significant role in daily light, both for indoor and outdoor lighting installations as lighting and other devices use one-third of the energy used in building (Elvin, and George,2007), and according to the International Energy Agency, nearly 20 percent of conducted electricity worldwide is used for lighting purposes.

5-1 Ultra Low Energy High Brightness Light

Nanotechnology may significantly reduce the amount of energ y used for lighting.This will change the way existing buildings use lighting absolutely, " said Professor Ravi Silva of the University of Surrey's Advanced Tecnology Institute, the developers of such a project. "Ultra Low Energy High Brightness Light (ULEHB) will produce the same quality light as the best 100 watt light bulb,but using only a fraction of the energy and last many times longer"(Elvin, 2007).

These new ultra-low energy lighting devices will be produced using organic carbon nanotube composites. ULEHB lignting can provide cost-effective and safe alternative options of fluorescent lamps not only for new and existing buildings, also for signage, displays, street lighting, and commercial lighting. The technology can also be used for low-cost development of solar cells(Fahmy, 2010).

5 -2 Nanotechnology-based lighting systems: Organic light-emitting diode (OLED)

Their function is based on nanotechnology-structured organic semiconductor materials. According to experts, this novel lighting technology will revolutionize both interior and exterior lighting as well as the display area (TVs, monitors, telephones) in the near future and in part replace existing systems.

OLEDs are large-area light sources, offering new design options with respect to lighting, such as large-area illumination of rooms, flexible luminous foils, flexible monitors or transparent light sources (BMBF 2012). They are particularly suitable for monitors (e.g., TVs, computer screens, monitors) and displays (e.g., for mobile phones and digital cameras). As such, they are already widely used on the market. In contrast to conventional technologies, their advantage is that the organic semiconductor material at the same time acts as image emitter and light source, achieving better energy efficiency and high resolution.

The light emitted by OLEDs contains neither infrared nor UV radiation, making it especially suitable for sensitive areas, such as museums. OLED lighting products have been available on the market since 2010. OLED lighting systems might partly replace conventional lighting systems in existing buildings (US DOE 2011).

They provide brighter, crisper displays on electronic devices and use far less energy than LEDs. TVs will be less than ¼ inch thick and will be able to be rolled up when not in use. OLEDs can be applied to any surface, flat or curved, to turn it into light source. In the future, light panels will replace light bulbs –walls, floors, ceilings, curtains, cabinets and tables could all become sources of light (Fahmy, 2010).

6-Environmental Sensing:

Nanosensors are nanoscale devices that measure physical quantities and convert those quantities to signals that can be detected and analyzed, capable of collecting and transmiting large amounts of information about our environment and its users.

There are already sensors with equal or lower diameters than 1µm, 2.5µm, and 10 µm that detect airborne pollutants, such as carbon monoxide, in and around a house.

It also could collect information on environmental conditions such as humidity and air temperature (Elvin, 2007).

By using these nanosensors in existing buildings can save enerty and resources throw gathering and transmitting data on temperature, humidity and other factors influemcing indoor air quality.

Existing constructions must integrate a rich network of interactive, intelligent objects, from light-sensitive photochromic windows to use conscious appliances; they must constantly shift, as their components communicate continuously with their customers, their environment and each other

7-CONCLUSION

Nanotechnology is an advanced application of sustainability and green architecture applications, as nanotechnology products and applications provide architectural solutions to all environmental problems related to existing buildings and even raise their efficiency in all stages of the building life cycle. It can also assist to solve some problems related to energy issues in building consumption and generation . Among its benefit is that it is used in improving the internal environmental conditions as it helps to protect the environment and improves pollution detection and treatment. Moreover, nanotechnology seems to be expensive to some extent ,but it is more economically efficient in the long term, and it reduces the cost of building maintenance. Fortunatelly, the costs of nano products is expected to decrease in the following years as a result of the advancement in the production technologies as well as the large-scale material production and hence its widespread use in the market.

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TABLES RESOURCES

Table 1: http://www.greenearthnanoscience.com/air-purification.php

FIGURES RESOURCES

Figure1: http://substance-en.etsmtl.ca/nanoscience-nanotechnology/

Figure2: https://www.slintec.lk/what-we-do/smart-textiles/

Figure3: http://textilelearner.blogspot.com/2012/12/application-of-nanotechnology-in.html

Figure4: https://www.sciencedirect.com/topics/engineering/vacuum-insulation-panel

Figure5 : http://www.coreprosystems.co.uk/insulation-systems/aerogel-wall-insulation-iwi

Figure6: https://patents.google.com/patent/US20090029147A1/en

Figure7: (Schodek & Daniel, 2009), https://pdfs.semanticscholar.org/

Figure8: (Schodek & Daniel, 2009), https://pdfs.semanticscholar.org/

Figure9: https://pdfs.semanticscholar.org/

Figure10: Green, 2006.

Figure11: https://www.sfgate.com/business/article/As-solar-gets-smaller-its-future-gets-brighter-2656362.php#photo-2133971