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Using Computer Simulation for Smart Materials in Buildings in Cairo

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Abstract: In the age of modern technology, the world is witnessing a massive shift towards the use of the Internet of Things and smart materials in a variety of fields. The Internet of Things is a technology that enables different devices and objects to communicate and interact with each other, while smart materials are those that have special capabilities such as sensing and automatic response. At the present time smart materials applications got a widespread in commercial buildings and became an aspect to measure building marketability and functionality like (durability, energy conservation, cost efficiency…. etc.), and with the new projects in Egypt specially the new administrative capital which include a wide range of (administrative, mixed-use, residential…etc.) buildings it became a must to use smart material for its function and to keep up with the new technologies and applications. In this article, we will explore the importance of the Internet of Things and smart materials and their innovative applications in buildings. Through case studies to show the benefits of using smart materials in administrative and mixed-use buildings. an applied study using the simulation in Design Builder v 7.0 using smart glass in administrative buildings.

Key Words: *Smart Materials, Internet of Things, New Administrative Capital, Building's Façade, Sustainable Practices.*

Introduction:

Modern buildings are seeing significant advances in the use of IoT technology and smart materials to improve energy efficiency and user experience. The Internet of Things is the communication of devices and objects within a building with each other, while smart materials have capabilities such as sensing and automatic interaction. [15] Smart materials are state-of-the-art applications in fit-out and finishing materials Most Middle Eastern countries, especially Gulf countries and a lot of leading countries like (Qatar, UAE…. etc.) use it to enhance building performance and to keep up with the new technologies and applications and it brought a great benefit for them technically and commercially.

The use of IoT and smart materials in buildings faces a number of challenges that must be carefully addressed. Below are some of the most important challenges that may face the use of the Internet of Things and smart materials in buildings: [16],[17]

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Fig 1 the most important challenges that may face the use of the Internet of Things in buildings

1-Privacy and security issues: IoT technologies and smart materials require the collection and sharing of data between different devices and objects. This may lead to privacy issues and personal data being compromised. Strong security systems must be put in place and the necessary procedures must be adopted to protect data and ensure its privacy.

2-Cost: IoT technology and smart materials can be expensive initially. It may require installing smart sensors and equipment and upgrading existing infrastructure. The potential costs and benefits of modernizing buildings must be studied and the return on investment assessed.

3-Availability and Compatibility: Availability of necessary technologies, smart devices and materials can be limited in some areas. There may be challenges in obtaining the necessary components and ensuring their compatibility with existing systems in the buildings.

4-Integration and operation: IoT devices and smart materials must be effectively integrated with existing systems in the building. This may require compliance with specific standards and protocols. There must also be the ability to operate and maintain these technologies effectively to ensure their continued operation.

5-Control and analysis capability: IoT and smart materials technologies can generate large amounts of data. The necessary control capabilities to analyze and use this data effectively, such as data management systems and artificial intelligence, must be in place. This requires improved storage, processing and analysis infrastructure. [18],[19]

The use of the Internet of Things and smart materials in buildings: [20], [21]

1. **Intelligent lighting management system:** Intelligent sensors and controls can be used to achieve energy saving in building lighting. The lights can be connected to a connected network that responds to movement and natural lighting, allowing lighting to be automatically adjusted according to need.
2. **Smart Energy Management System:** Smart sensors and controls can be used to monitor and analyze energy consumption in buildings. The data collected can be analyzed to identify opportunities to improve energy efficiency and implement automated changes to achieve energy savings.
3. **Temperature and air conditioning control system:** Smart sensors can be used to monitor temperature and air humidity in buildings. Heating and cooling systems can be automatically adjusted according to environmental conditions and users' preferences, resulting in improved comfort and energy savings.
4. **Intelligent security and safety system:** Intelligent sensors and controls can be used to enhance security and safety in buildings. For example, smoke detectors and connected alarms can be used to detect fire situations early and notify users in real time.
5. **Smart waste management system:** Smart sensors and controls can be used to improve waste management in buildings. Waste levels can be monitored, emptying times determined, and maintenance teams notified when containers need to be emptied.
6. **Smart building management system:** Smart management platforms can be used to collect and analyze data related to building performance, energy and water consumption, and other factors. These platforms can provide useful insights on how to improve building performance and achieve energy savings.
7. **Using smart devices in home appliances:** Smart home devices such as refrigerators, washing machines, air conditioning and central heating devices connected to the Internet can be used to achieve control and improvement in energy consumption. They can be programmed to operate at specific times or in response to sensor signals, saving energy and improving efficiency.
8. **Wearables and Smart Health:** Wearables and smart sensor technologies can be used in buildings to bring greater comfort and better health to users. They can be used to track physical activity, fitness levels, sleep, and other health related information.
9. **Remote Appliance Control:** Remote control technologies can be used to control building appliances through mobile applications or other smart control devices. Devices can be turned on, off and their settings adjusted remotely, providing convenience and flexibility to users.
10. **Using smart connectivity technologies:** Smart connectivity and Internet technologies can be used to connect buildings to public networks and cloud services. They can be used to improve user experience and provide access to information and services remotely.

The use of the Internet of Things and smart materials in buildings provides many advantages and benefits. Here are some key features: [22],[23]

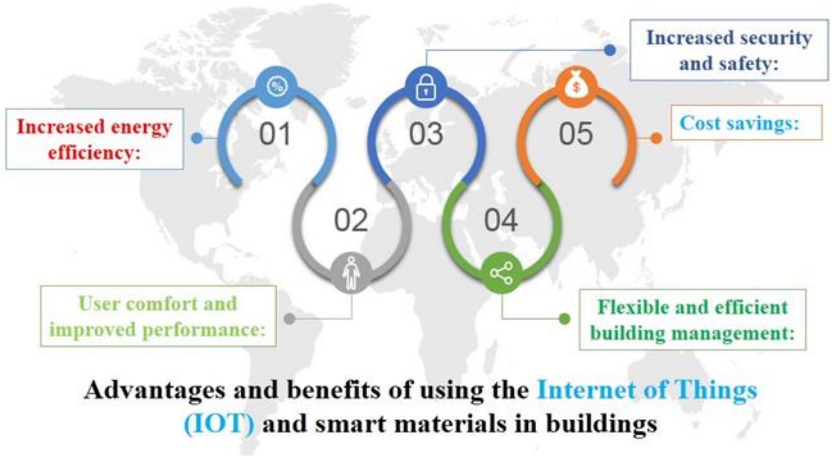


Fig 2 Advantages and benefits of using the Internet of Things (IOT) and smart materials in buildings

1. **Increased energy efficiency:** The use of the Internet of Things and smart materials improves the energy efficiency of buildings. Advanced control of smart appliances and systems allows for optimizing energy consumption and reducing waste, such as automatically adjusting the temperature of rooms according to the weather forecast or automatically turning off unnecessary appliances when no one is in the building.
2. **User comfort and improved performance:** Smart technologies can contribute to improving the comfort of users in buildings by centrally controlling lighting, temperature, and air quality according to their individual needs. Data can also be collected and analyzed to improve overall building performance, such as improving space distribution and making recommendations to improve resource use.
3. **Increased security and safety:** IoT and smart materials can be used to enhance building **security** and user safety. For example, sensors and alarm systems can be used to detect potential hazards, such as a gas leak or fire, and send immediate notifications to relevant authorities or emergency procedures.
4. **Flexible and efficient building management:** The Internet of Things and smart materials can facilitate more effective and flexible building management. Devices and systems can be controlled remotely, continuously monitor performance and maintenance, and alert officials when maintenance or repair is needed. Information and data can also be stored in the cloud for easy and shared access.
5. **Cost savings:** By using IoT technologies and smart materials, costs related to energy, maintenance and building management can be saved. Improving energy efficiency can result in lower energy bills and improved environmental sustainability. In addition, building layout can be improved and resources used more effectively, reducing overall building costs.

Egypt's strategic plan aims to expand its build-up area to new cities on (the 6th of October and 10th of Ramadan. The new administrative capital is a new city planned to be the new capital to transform the central management from Cairo to non-central management, the new capital has a **business zone** that includes a wide range of high-rise & mixed-use buildings these buildings are a perfect candidate for applying smart materials to improve its performance (energy consumption, user's satisfaction…. etc.) thus, using smart materials is a must for its role in enhancing building performance.

Research Problem:

The research problems are:

1. Smart materials practice in Egypt does not exist.
2. The new nature of building's design in Egypt doesn't adopt smart material as a design option.

Research Aim:

The research aims to:

1. Review smart material types and use cases to use it in Egyptian case study.
2. Proving that the new Egyptian vision needs smart applications and technologies like using smart materials.

Research Methodology:

The research adopts the descriptive approach to describe the types and uses of Smart materials and their role in the building's façade and spaces.

1. Smart materials definitions characteristics [8]:

NASA defines smart materials as “materials that (remember) configurations and can form to them when given a specific stimulus”

Smart materials, according to the definition of architecture, are high-tech materials that, when used in a building, respond logically to climatic variations throughout the year (summer, winter, etc.).

According to researchers’ Smart materials are “highly engineered materials that respond intelligently to their environment,” born as a response to the 21st century’s technological needs.

Smart products and materials are those that can comprehend, process, and respond favorably to environmental occurrences. In reaction to the physical or chemical impacts of the environment, these materials are therefore capable of changing and are able to alter shape, form, color, and internal energy in a reversible manner.

1.1. Smart materials characteristics:

Smart materials have the ability to reversibly modify their properties based on different stimulus-response interactions. The five key qualities that distinguish smart materials from more traditional materials used in architecture, regardless of whether they are molecules, materials, composites, assemblies, or systems, are as follows. [9]:

Immediacy	Transiency	Self-actuation	Selectivity	Directness
They respond in real time	They respond to more than one environmental state	Intelligence is internal to rather than external to the “material”	The response is local to activating event	The response is local activating event

Fig 3 Smart materials characteristics

2. Smart material types:

Three categories of traits can be applied to all smart materials. [10]:

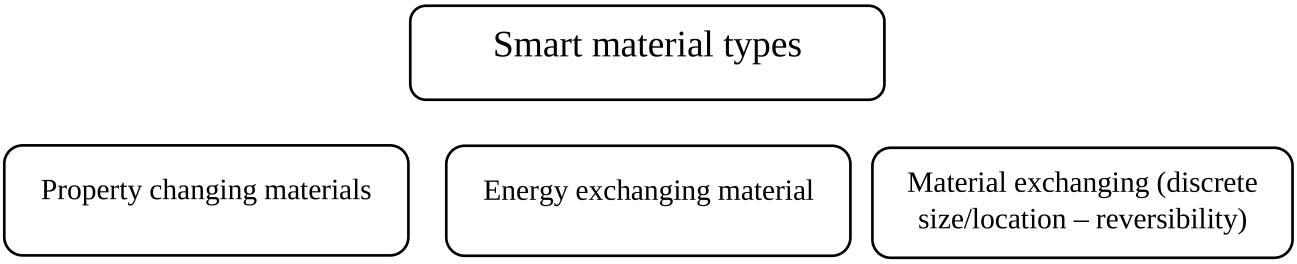


Fig 4 Smart materials types

There are numerous possible uses for the first class in architecture, whereas actuators and sensors from the second class would be used in building maintenance, and insulators from the third class would be used in construction.

Table 1 Smart Materials Types

Smart material types				
	Type 1	**Characteristics**	**Type 2**	**Characteristics**
changes in one or more of their properties			**Materials transform energy from one form to another.**	
1	**Thermochromics**	Thermal energy changes material’s color.	**Light-emitting materials**	include converting an input of energy into a visible spectrum output of electromagnetic energy.
			Photoluminescent	The radiation energy from the UV spectrum is used as input.
			Electroluminescent	Input is electrical energy.

			Chemoluminescent	The chemical reaction is the input.
2	**Phototropic**	change color when exposed to light.	**Piezoelectric**	Switching the inputs and applying electrical current results in deformation and strain.
3	**Magnetorheological**	When a magnetic field is applied, the micro-structural orientation of the fluid changes, resulting in a change in viscosity.	**Thermoelectric**	When an electrical current is applied, the opposing sides of the material experience a temperature difference.
4	**electro-rheological**	The employment of electro-rheological induces a shift in micro-structural orientation, which changes the fluid's viscosity.	**Photovoltaics**	An electrical current is produced when visible-spectrum radiation energy is supplied.
5	**Thermotropic**	Thermal energy applied to the material causes a phase transition, which affects its microstructure.	**Electrostrictives**	When a current is applied, it creates elastic energy, or strain, which deforms the material's shape.
6	**Shape memory**	Thermal energy changes the microstructure by causing a crystalline phase transition.	**Magnetostrictives**	When a magnetic field is applied, it creates elastic energy, or strain, which deforms the material's shape.
7	**Mechanochromics**	Color-changing materials because of induced stresses and/or deformations.	**Light Emitting Diodes - LEDs**	
8	**Chemochromics**	When exposed to chemical conditions, certain materials change color.	**Shape memory alloys.**	
9	**Electrochromics**	When a voltage is applied to a substance, it changes color.		
10	**Phase-changing materials**	To store and release heat, chemical linkages are used.		

11	**Adhesion-changing materials**	When exposed to light or an electrical field, the attraction forces of atoms or molecules change.		

3. Importance to use smart material in buildings facades [8]:

In the field of building, smart materials and their manufacturing techniques may offer a number of advantages, such as:

1. Extremely high toughness, ductility, and strength.

2. Enhanced robustness/service life

3. Enhanced resistance to abrasion, corrosion, chemicals, and fatigue.

4. Savings on both initial and ongoing costs.

5. Improve readiness for catastrophic occurrences like fires and natural catastrophes.

6. Simplicity of application and installation.

7. Environmental friendliness and aesthetic appeal.

8. The capacity for self-diagnosis, self-healing, and structural control.

4. The Smart material systems:

A smart material can only do one thing, but by mixing different smart materials, a system can be created. In addition to sensing the change that triggers the actuation, the system can carry out a number of other tasks. Based on how the system reacts to inputs, smart material systems are categorized. Systems can be divided into three categories: passive, active, and hybrid.

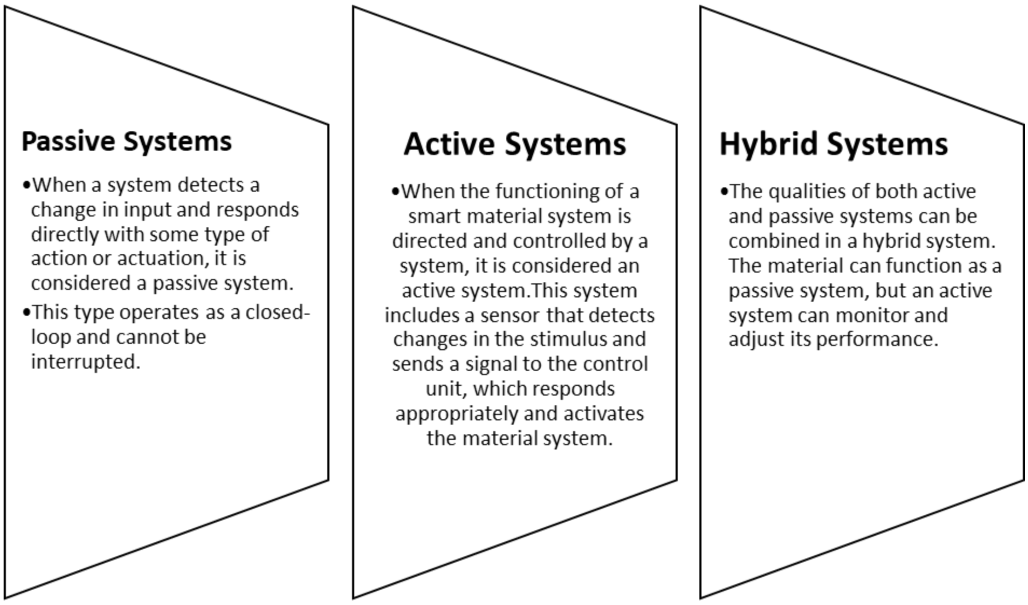


Fig 5 Smart material system types

The new smart material concept is to combine multiple materials, according to research done by (Abdullah, Y.S. and H.A. Al-Alwan) [11] Because it is less complicated and can control system response, active systems are used more than passive and hybrid systems.

5. Case studies:

5.1. Al Bahar Towers -Abu Dhabi-UAE:

Fig 6 *Al Bahar Towers - Abu Dhabi*

Source: (https://www.archdaily.com/270592/al-bahar-towers-responsive-facade-aedas [4]

Overview:

The structure responds to sunlight via a system of fiberglass louvers that control the opening and shutting of the front grilles to control the amount of heat absorbed from the sun. The exterior frame is mounted with the facade screens, which are installed at a distance of 2 meters. At dawn, mashrabiya will begin along the structure's east side. The vertical strip will move in a straight line with the sun. [12].

Case Summary:

1. **Benefits:** Solar Energy Control, Energy Conservation, And Environmental Factor Resistance.
2. **Type Of Smart Material**: Energy Exchanging.
3. **Smart Material System Usage**: This Case Used Smart Material System

5.2. National Convention Center - Qatar:

Fig 6 *National Convention Center - Qatar*

Source: https://www.designcurial.com/news/qatar-national-convention-center-applies-for-green-certification) [6]

Overview:

The building has a bright and warm climate, and it invests in sunlight with 3700 square meters of solar panels. The massive building system, simulating the Sidra tree, is one of the most remarkable aspects of the building. Reduce resource consumption, improve internal environment and CO2 emissions.

Case Summary:

1. **Benefits:** Solar Energy Control, Energy Conservation, And Environmental Factor Resistance.
2. **Type Of Smart Material**: Energy Exchanging.
3. **Smart Material System Usage**: This Case Used Smart Material System

5.3. Zayed National Museum - Abu Dhabi - UAE:

Fig 7 *Zayed National Museum - Abu Dhabi - UAE*

Source: (https://www.archdaily.com/92372/zayed-national-museum-foster-partners) [3]

Overview:

The Abu Dhabi building is notable for its five towers, each of which rises to a height of 124 meters. The towers' design and look were influenced by the region's well-known falcon wings. The building uses heat exchangers and photovoltaic panels to heat water using solar radiation. Concepts of environmental sustainability are applied to lower energy consumption.

Case Summary:

1. **Benefits:** Ventilation Control, Energy Conservation, And Environmental Factor Resistance.
2. **Type Of Smart Material**: Energy Exchanging.
3. **Smart Material System Usage**: This Case Used Smart Material System

5.4. Lighthouse tower - Dubai – UAE:

Fig 8 *Lighthouse tower - Dubai – UAE*

Source: (https://inhabitat.com/the-lighthouse-dubais-1st-low-carbon-commercial-tower/) [5]

Overview:

The Lighthouse faceplate is made to take use of passive cooling and lighting. Solar and wind energy are used in the façade to cut down on water and energy usage by 25% and 65%, respectively.

Case Summary:

1. **Benefits:** Ventilation Control, Energy Conservation, And Environmental Factor Resistance, Heat Control, Durability.
2. **Type Of Smart Material**: Energy Exchanging.
3. **Smart Material System Usage**: This Case Used Smart Material System.

5.5. Yas Hotel - Abu Dhabi - UAE:

Figure 9 Yas Hotel - Abu Dhabi - UAE

Source: (https://www.archdaily.com/43336/the-yas-hotel-asymptote) [2]

Overview:

The structure is situated on Elias Island, a 500-room resort with a curved structure that is covered with a variety of steel panels that are managed by an RDM system. By adjusting the brightness of the network, which also affects how much heat and light the bulb produces, it is lit using an LED system.

Case Summary:

1. **Benefits:** Solar Energy Control, Energy Conservation, And Environmental Factor Resistance., Heat Control.
2. **Type Of Smart Material**: Energy Exchanging.
3. **Smart Material System Usage**: This Case Used Smart Material System.

5.6. Louvre - Abu Dhabi -UAE:

Fig 10 *Louvre - Abu Dhabi - UAE*

Source: https://www.archdaily.com/886180/the-engineering-behind-the-louvre-abu-dhabis-striking-geometric-dome) [7]

Overview:

This Abu Dhabi building was created to be in harmony with the local surroundings. 3,900 panels of ultra-high performance concrete (UHPC) make up the museum's front. The dome's interior is composed of aluminum plate and its four exterior layers are made of stainless steel, which are divided by a steel frame.

Case Summary:

1. **Benefits:** Solar Energy Control, Energy Conservation, And Environmental Factor Resistance.
2. **Type Of Smart Material**: Energy Exchanging, Property -Changing
3. **Smart Material System Usage**: No, This Case Didn’t Use Smart Material System.

5.7. Doha Institute – Qatar:

Fig 11 *Doha Institute – Qatar*

Source: (https://www.facebook.com/dohainstitute.edu.qa/photos/a.1561670384052405/3011038719115557)

Overview:

The basic design of the Doha building is inspired by the old urban environment and texture in a modern way. Arabic calligraphy has been used in its facades, distinguished by respect for the environment, especially in terms of heat gain, use of shaded areas and interior window screens.

Case Summary:

1. **Benefits:** Solar Energy Control, Energy Conservation, And Environmental Factor Resistance., Durability
2. **Type Of Smart Material**: Energy Exchanging.
3. **Smart Material System Usage**: This Case Used Smart Material System.

New administrative capital overview and description:

The new administrative capital is located to the east of Cairo with an area of 170,000

acres and is connected to Cairo by many roads, such as Cairo - Al-Aim Sokhna road and 45 km from downtown Cairo. Connectivity - sustainable city - smart city - walking city - business city - residential and living) and it includes residential areas and trees. (symbolic tower), administrative towers (C01 to C12) and buildings in areas B and D, built to be close to the Suez Canal, regional roads and main axis, with a population of 5 million during the first phase and will accommodate 40-50,000 government employees and about 100,000 employees after the first 3 years.

Fig 12 *(1) the Iconic tower (2) Administrative tower C01*

Source: (Documents and reports from [1])

6. **Smart glass is widely used in office buildings to improve energy efficiency and provide comfort to users. Here are some common applications of smart glass in office buildings:** (24),(25)

1. Transparency control: The transparency of smart glass can be adjusted to provide more privacy in offices and executive rooms by changing the degree of light reflection. The glass can be completely transparent when viewing the outside view is required and can be opaque when privacy is needed.

2. Solar radiation control: Smart glass can control the transmittance of heat and solar radiation to reduce overheating and reduce the use of air conditioning systems. The glass can reduce the amount of heat and ultraviolet rays entering the building to maintain a comfortable temperature and reduce the effect of harmful radiation.

3. Sound insulation: Smart glass can contribute to improving the sound insulation in office buildings. When the glass is in an opaque control state, it can reduce the transmission of noise from outside to inside and improve the working environment and concentration.

4. Safety and security: Smart glass can be shatterproof and provide a high level of safety in office buildings. In the event of a breakage or damage, the glass can become transparent to facilitate escape and facilitate emergency evacuations.

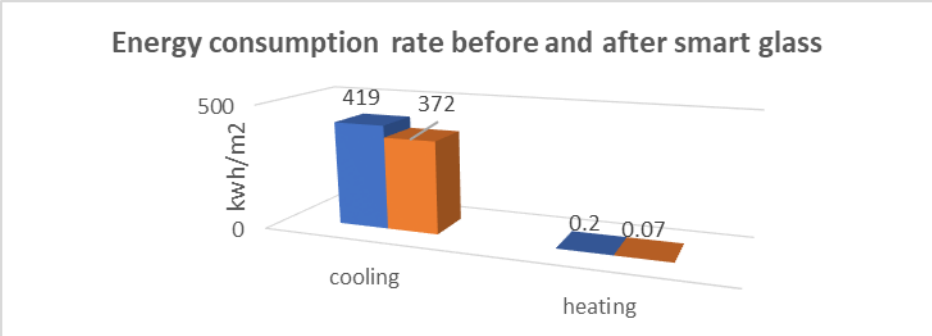
5. Energy management: Smart glass can be integrated with home automation and energy management systems to achieve intelligent control of lighting and air conditioning. Smart glass can be set to interact with motion and lighting sensors to achieve energy savings and improve the overall efficiency of the building.

The application of smart glass in administrative buildings provides many benefits in terms of comfort, energy efficiency and safety. It contributes to improving the working environment and enhancing the user experience in administrative buildings.

7. Simulation study:

Simulation results for a building in the administrative capital for the energy consumption rate and the carbon dioxide emissions rate in the basic case and after using smart glass for the building:

- **First**, the simulation was done using the Designbuilder v7.0 program for the energy consumption rate and the carbon dioxide emissions rate in the base case and after using Smart glass for the building:

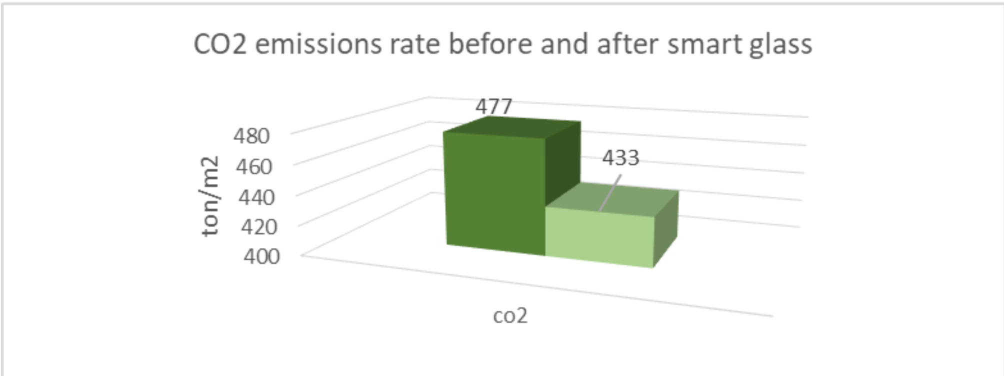


	cooling	heating
BC	419	0.2
Smart Glass	372	0.07

Fig (13) shows the energy consumption rate for the base case after using smart glass for the building.

The results indicate an improvement of 11.22% in the energy consumption rate compared to the base case after using smart glass for the building. - Secondly, the simulation was done using Design builder v7.0 for the carbon dioxide emissions rate in the base case and after using smart glass for the building: The results indicate an improvement of 11.22% in the energy consumption rate compared to the base case after using smart glass for the building.

- **Second**, the simulation was done using Design builder v7.0 for the carbon dioxide emissions rate in the base case and after using smart glass for the building:



	co2
BC	477
Smart Glass	433

Figure (14) shows the rate of carbon dioxide emissions before and after using smart glass for the building.

The results indicate a 9.22% reduction in carbon dioxide emissions compared to the base case after using smart glass for the building.

8- Conclusion:

This research reviews several issues like Smart material types which represented in table (1) and discussed in the following parts in the research the case studies show the following:

1. Most of the used materials are property and energy exchanging types.
2. Smart materials systems used more than the use of sole material because it's controllable and manageable.
3. The used systems brought tons of benefits for its owners and stockholders.
4. The buildings which used smart materials gained a lot of appreciation in both academic and real estate fields by being a (Icon) and case to follow and to study.

For the above-mentioned reasons, the existing and new buildings in the new administrative capital should use smart materials to keep up with the new technologies and applications and to take place with other Arbian and foreign countries which used and get benefits of using smart materials.

Recommendations for using the Internet of Things and smart materials in buildings:

- **Early planning:** It is advisable to include considerations related to the Internet of Things and smart materials in the early planning stage of the building. The specific objectives and requirements of the smart technology used must be defined and appropriate devices and systems for the application identified.
- **Adequate infrastructure:** Adequate infrastructure must be provided to support the use of IoT and smart materials in the building. This includes wireless communications networks, electrical installations, local area networks and appropriate control systems.
- **Sensing and monitoring:** It is advisable to install appropriate sensors in the building to collect data about the environment and performance, such as temperature, humidity, air quality and energy consumption. This data must be monitored and analyzed to improve building performance and make smarter decisions.
- **Integration and compatibility:** The devices and systems used must be able to be integrated and compatible with each other. The IoT standards and protocols used must be compatible with other devices and systems in the building to ensure seamless communication between them.
- **Security and data protection:** Security and data protection should be of paramount importance when using IoT and smart materials in buildings. Strict security measures must be in place to protect sensitive information and ensure the integrity of devices and networks.
- **Training and Awareness:** Training and awareness must be provided to users and technical teams involved in building management. They must be aware of the smart technologies and systems used and how to use them effectively and safely.
- **Continuous improvement:** The use of IoT and smart materials in buildings requires continuous improvement and regular evaluation. The data collected must be analyzed, areas that can be improved identified and actions taken to improve performance and increase efficiency.
- **Sustainability and the environment:** The Internet of Things and smart materials can be used to enhance the sustainability of buildings and reduce their environmental impact. Energy and water consumption and waste management can be effectively controlled through smart technology.
- **Leverage data:** Real value can be achieved from IoT and smart materials by analyzing collected data. This data can be used to make strategic decisions, improve operations, and achieve continuous improvement.
- **Flexibility and scalability:** It is recommended to design infrastructure and choose technologies that provide flexibility and scalability in the future. The system must be able to accommodate new technological updates and developments and expand usage without disrupting current operations.

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