THE IMPACT OF USING SMART MATERIALS ON ENVIRONMENTAL PERFORMANCE IN BUILDINGS IN ARID REGIONS

By

Arch. Noha Hussein Hefnawy

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in partial fulfillment of the
requirements for the Degree of
MASTER OF SCIENCE
in
Architecture Engineering

Faulty of Engineering, Cairo University
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GIZA- EGYPT

2013

قال تعالى

يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنْكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ وَاللَّهُ بِمَا تَعْمَلُونَ خَبِيرٌ ﴿١١﴾ سورة المجادلة

صدق الله العظيم

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Dedication

I dedicate this thesis to my family. A special feeling of gratitude to my loving parents, my sister, and brothers.

I also would like to dedicate this thesis to my Grandmother's Soul — who is always in my heart.

اللهم اجعلها من سيدات الجنة

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List of Abbreviations

NASA	National Aeronautics and Space Administration
LEED	Leadership in Energy and Environmental Design
UV	Ultraviolet
MHZ	Megahertz
KHZ	Kilohertz
GSM	Gross square meter

Abstract

Smart materials are materials that receive, transmit, or process a stimulus and respond by producing a useful effect that may include a signal that the materials are acting upon it. Some of the stimuli that may act upon these materials are strain, stress, temperature, chemicals, electric field, magnetic field, hydrostatic pressure, different types of radiation, and other forms of stimuli. The effects produced can be a color change, a change in index of refraction, a change in the distribution of stresses and strains, or a volume change. This ability to produce a useful effect to respond the stimulates has rendered smart materials a considerable material to the architectural design since buildings are always confronted with changing conditions. The characteristics of smart materials can be grouped into: property change capability, energy change capability, discrete size/location, and reversibility. Using smart materials in architecture moreover dramatically reduces the energy and material cost of the buildings, enables the human to design of direct and discrete environments that providing better conditions in space for human occupants. In a hot arid climate, due to problems such as overheating and high solar gain, intelligent design strategies and technologies for buildings such as using smart materials are necessary.

Keywords: Smart Materials, New Technologies, Arid regions, Arid climate, Arid region problems.

Introduction

Selection of materials for use in architecture is always based on various criteria. Performance and Cost have an obvious role in this selection, but final selection is often done based on appearance, beauty and aesthetic, ease of construction with regard to human resource skills, availability of local or regional, as well as materials used in the building.

Building materials had several development stages. The first stage was the natural building materials (stone – wood-clay..) which were chosen according to their utility , availability and appearance. The second one is industrialized building materials (steel-glass …..)and Materials made by the development in the material science and technology such as smart materials , materials are highly engineered materials that respond intelligently to their environment.

Smart materials are often considered to a logical extension of materials development toward more selective and specialized performance. For many centuries, the architect had to accept and work with the properties of a standard material such as wood or stone, designing to accommodate the material's limitations, whereas during the 20th century architect could begin to select or engineer the properties of a high performance material to meet a specifically defined need. Smart materials allow even a further specificity because their properties are changeable and thus responsive to transient needs. Indeed, terms like interactivity and transformability have already become standard parts of the architects vocabulary even insofar as the necessary materials and technologies are far beyond the economic and practical reality of most building projects.

Traditional building materials static tend to resist the forces of the building, while the smart materials are dynamic in this respect treat in order to respond to conditions in the energy contexts. While using a smart material we should do consider that what we want that material to do not what it want to see. Understanding smart materials should be more about simplicity and superficial understanding of material properties. In addition, it must exist complete and satisfactory knowledge of physical and chemical reactions of these materials with the environment surrounded them.

Arid regions are an important part of the world as they cover a big part of the land surface and they can provide sufficient opportunities for the extensive developments. However, buildings of this region are facing a set of climatic problems which has to be taken into consideration. Nowadays, it's become so important to adapt new development approach for this region, as it became the main target to solve the climatic problems of buildings in arid regions.

Using smart materials to make new environmental treatments for energy consumption, and reducing waste, toxicity, non-renewable resource consumption, reaching out for thermal comfort . All of these treatments will help in solving building problems at hot region such as high temperature , humidity , dust penetration and energy consumption. The results show the potential for a significant decrease in cooling loads and energy for lighting, and increase in thermal and visual comfort, if appropriate building envelope alternatives are evaluated and implemented in the early design stage.

Thesis Aim

The study aims to identify the possibility of utilizing smart materials to solve building problems in arid regions in order to achieve thermal and visual comfort and energy efficiency. This will be through: exploring smart materials and recognize their nature , behavior and their relation to the energy system. Understanding their potentials for energy conservation and reduced waste, toxicity, non-renewable resource consumption and for reaching out for thermal comfort, and analyzing the outdoor and indoor climatic conditions, to understand the problems of overheating, discomfort, and the energy needed to achieve indoor environmental quality. And it will try to clarify how much building performance depends on early smart architectural design decisions or if it can be left exclusively to later intelligent technological devices.

Problem Definition

Buildings in arid regions are facing many ecological problems which affect building performance and user comfort. Therefore a study of smart materials; their characteristics, types, applications and how can they help in solving these problems was needed to result in a better building performance.

Hypothesis

In relation to the problem definition, hypothesis can be formulated:

Arid regions face a set of ecological problems which have to be solved. These problems could be solved by devising new environmental treatments depending on smart materials and their applications to help in solving building problems in arid regions.

Methodology

The thesis will use two main methods: data collection through literature review, and Case study analysis.

In order to cover all the sides of the thesis, there will be three main parts:

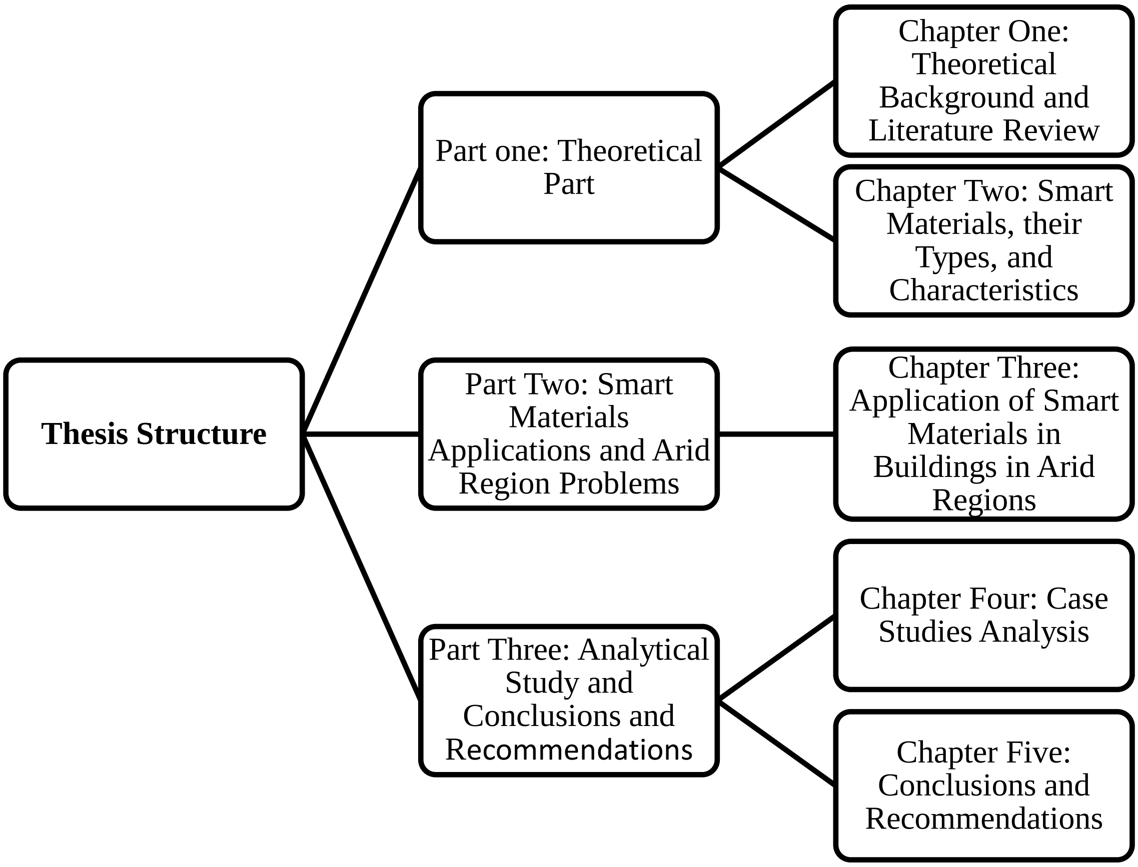
The first part is the theoretical approach: which shows the developments of materials through the ages, the classification systems of smart and traditional materials, and define smart materials, their types, and characteristics.

The second part shows the arid region's problems and the smart materials applications, products, systems, and how can they used to solve these problems.

The third part is the analytical part which depends on case study analysis. It shows how smart materials help in solving many building problems and raise its performance to achieve user comfort, and energy conservation. Then it gives a general conclusions and recommendations.

Thesis Structure

The structure of the thesis consists of three main parts: first part which include chapter one: theoretical background and literature review and chapter two: smart materials their types, and characteristics, part two include chapter three: application of smart materials in arid regions, and part three which include chapter four: case studies and chapter five: conclusions and recommendations.



THEORETICAL BACKGROUND AND LITERATURE REVIEW

1.1 Introduction

Materials create an ambience and provide texture or substance to architecture. A designer needs to have an understanding of how materials have been used historically and an awareness of innovations in materials application in order to use materials effectively.

Contemporary designers are taking materials from different context and environments and applying them inventively in architecture, the standard convention of using traditional materials for building is changing as issues of cost and sustainability become ever more important. Thinking carefully about which materials to source and specify how far they have travelled and whether they can be recycled or reused in the responsibility of the architect when designing a building or space.

Beginning in the 19th century with the widespread introduction of steel, leading to the emergence of long-span and high-rise building forms, materials transitioned from their pre-modern role of being subordinate to architectural needs into a means to expand functional performance and open up new formal responses. The industrialization of glass-making coupled with developments in environmental systems enabled the ‘international style’ in which a transparent architecture could be sited in any climate and in any context. The broad proliferation of curtain wall systems allowed the disconnection of the facade material from the building’s structure and infrastructure, freeing the material choice from utilitarian functions so that the facade could become a purely formal element. As a result, today’s architects often think of materials as part of a design palette from which materials can be chosen and applied as compositional and visual surfaces.

For many centuries one had to accept and work with the properties of a standard material such as wood or stone, designing to accommodate the material’s limitations, whereas during the 20th century one could begin to select or engineer the properties of a high performance material to meet a specifically defined need. Smart materials allow even a further specificity – their properties are changeable and thus responsive to transient needs. For example, photo chromic materials change their color (the property of spectral transmissivity) when exposed to light: the more intense the incident light, the darker the surface. This ability to respond to multiple states rather than being optimized for a single state has rendered smart materials a seductive addition to the design palette since buildings is always confronted with changing conditions. As a result, many proposals speculating on how smart materials could begin to replace more conventional building materials.

Cost and availability have, restricted widespread replacement of conventional building materials with smart materials, but the stages of implementation are tending to follow the model by which ‘new’ materials have traditionally been introduced into architecture. Smart materials, however, represent a radical departure from the more normative building materials. Whereas standard building materials are static in that they are intended to withstand building forces, smart materials are dynamic in that they behave in response to energy fields.

This chapter is divided into two main parts: The first part is about the development of building materials through the ages and it includes development of natural materials such as stone and timber, and the development of industrial materials starting from concrete, glass and steel, composite materials, to smart materials, The second part is about the difference between smart materials and traditional materials according to their classification system and the internal structure and properties of materials.

The purpose of this chapter is to have a basic familiarity with the characteristics that distinguish smart materials from the most commonly used architectural materials, and understand the potential of these characteristics when deployed in architectural design.

1.2 Developments of Building Materials through Ages

The building materials have been developed with time. Starting from naturally occurring substance, such as clay, sand, wood and rocks. Many man-made products are also in use, some more and some less synthetic, such as concrete, glass, steel, composite materials and smart materials.

1.2.1 Natural Materials

They are one of the most important and environmental building materials. Stone and timber considered to belong to natural materials.

1.2.1.1 Stone

Stone is a versatile material. It can be used for a structure's ground surface, walls and roof (if carefully selected and cut); it can be shaped or sliced into thin slabs or heavy monolithic blocks, and its physical properties mean that it retains heat in the winter and remains cool in the summer. Additionally, there is a degree of symbolism associated with stone. It is often used for memorials or to mark a point in the landscape because it has a timeless, indestructible quality, which suggests a degree of permanence and solidity.[1]

1.2.1.1.1 Basics

Properties of stone vary greatly according to their type, and considerable variation can occur in the properties of different specimens from the same quarry. Durability depends not only on the chemical composition of the stone, but also on the atmosphere in which it is used and its degree of exposure to the elements.

One of the great advantages of stone buildings is that they have survived the ravages of time and allow us to learn from architects past. In Europe the most dramatic and impressive architecture is made of durable stone. Stone buildings today remain

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[1] Farrelly, L., (2009), Basics Architecture Construction + Materiality, 2nd Ed., Switzerland, AVA Publishing SA.

synonymous with an idea of permanence, quality and solidity, and this suggests a connection between the architectural past, present and the future.

1.2.1.1.2 Types

Rocks are generally classified by mineral and chemical composition, by the texture of the constituent particles and by the processes that formed them. These indicators separate rocks into three types: igneous, sedimentary, and metamorphic. They are further classified according to particle size. The transformation of one rock type to another is described by the geological model called the rock cycle. Fig. (1-3) shows some sample panels of stone.

Metamorphic Rocks: are formed by the recrystallistion of older rocks, when subjected to intense heat or pressure or both, within the earth's crust. Clay is metamorphosed to slate, limestone to marble and sandstone to quartzite.

Igneous Rocks: are the oldest, having been formed by the solidification of the molten core of the earth or magma. The igneous rocks are defined as plutonic or volcanic respectively. In the plutonic rocks, slow cooling from the molten state allowed large crystals to grow which are characteristic of the granites. Volcanic rocks such as pumice and basalt are fine-grained and individual crystals cannot be distinguished by the eye, thus the stones are visually less interesting. Apart from crystal size, igneous rocks also vary in composition according to the nature of the original magma, which is essentially a mixture of silicates. A high silica content magma produces acid rocks (e.g. granite) while a low silica content forms basic rocks (e.g. basalt and dolerite).Granites are mainly composed of feldspar (white, grey or pink), which determines the overall color of the stone, but they are modified by the presence of quartz (colorless to grey or purple), mica (silver to brown), or horneblende (dark colored).[2] Fig. (1-1) shows different types of igneous rocks.

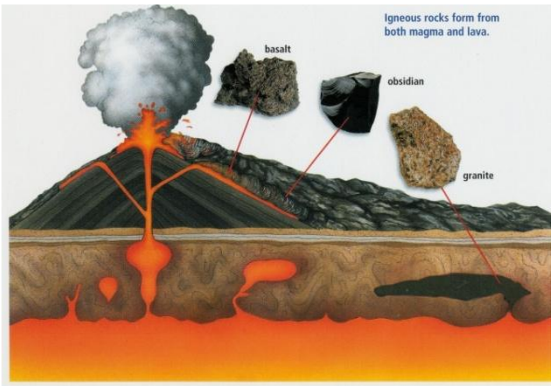

Fig. 1-1 Shows different forms of igneous rocks

Source: http://www2.chilton.k12.wi.us/sromekg/igneous%20rocks.jpg , accessed (21-5-2013)

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[2] Lyons, A., (2007), Materials for Architects and Builders, 3rd Ed., Oxford, Butterworth-Heinemann.

Sedimentary Rocks: are produced by the weathering and erosion of older rocks. Weathering action by water, ice and wind breaks the rocks down into small fragments which are then carried by rivers and sorted into size and nature by further water action. Most deposits are laid down in the oceans as sedimentary beds of mud or sand, which build up in layers, become compressed and eventually are cemented together by minerals such as calcium carbonate (calcite), quartz (silica), iron oxide or dolomite (magnesium and calcium carbonate) remaining in the groundwater[3], these different types are shown in fig. (1-2).

Fig. 1-2 Sedimentary rocks, expressing its different types.

Source: http://laloca89.tripod.com/sitebuildercontent/sitebuilderpictures/sedrocks.jpg , accessed (21-5-2013)

Limestone Marble Dressed Stone

Stone Wall Cladding Slate Wall Cladding Grey Granite

Fig. 1-3 Some sample panels of stone.

Source: Farrelly, L., (2009)

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[3] Lyons, A., (2007), Materials for Architects and Builders, 3rd Ed., Oxford, Butterworth-Heinemann.

1.2.1.1.3 Applications

Great Pyramid of Giza, Egypt (c.2560 BC)

Built by the Ancient Egyptians as tombs for their Pharaohs, the pyramids were constructed from huge limestone blocks that were brought to the site along the River Nile. A rough limestone was used for the main core of the pyramids and a finer, white limestone with a polished finish was used as the outer stone, as shown in fig. (1-4).

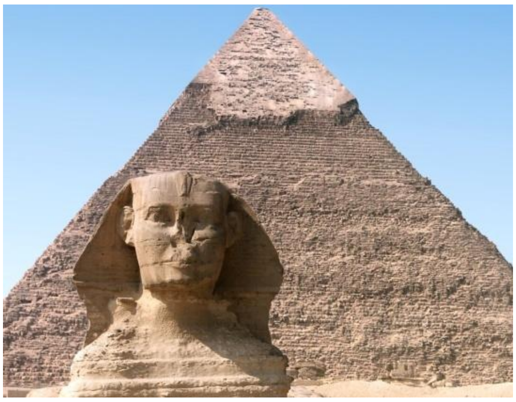

Fig. 1-4 Great Pyramid of Giza, expressing the using of limestone in its construction.

Source: http://www.culturefocus.com/egypt/pages/sphinx-27.htm , accessed (15-11-2012)

Coliseum, Italy (C.70–80)

This amphitheatre was built as an arena for public spectacles and gladiator contests. The exterior was made of travertine stone and the interior areas were later built from brick, as shown in fig. (1-5). Originally, the building had wooden floors and temporary structures built within it.

Fig. 1-5 Coliseum, Italy expressing the use of travertine stone in the exterior.

Source: http://www.destination360.com/europe/italy/images/s/italy-rome-colosseum.jpg , accessed (15-11-2013)

Cupola of the Basilica di Santa , Italy (1420)

Designed by Filippo Brunelleschi, the cupola of the Basilica di Santa Maria, consists of a double-walled dome made of several million bricks, with large stones supporting the main structure, as shown in fig. (1-6). The base of the dome is held in tension with iron chains.

Fig. 1-6 Cupola of the Basilica, expressing the use of stone in the dome to support the main structure.

Source: http://briggl.com/italy2/images/070705_003/campanile070.jpg , accessed (15-11-2012)

1.2.1.2 Timber

Wood is natural, organic, light weight strong, readily accessible, and simple to work with in construction. Its wide variety of colors, textures, grain patterns, and fragrances give designers a versatile and adaptable expressive tool for construction. Its warm aesthetic and easy workability has made it an appealing architectural material for centuries.[4]

1.2.1.2.1 Basics

The basic anatomical structure of wood includes fibers and cells. This structure, along with its chemical composition, determines the strength and technical characteristics of a particular type of wood, wood is anisotropic, which means that its inherent qualities are dependent on the direction of the grain.

Most wood used in structural framing is softwood, while hardwood is generally used for the finish woodwork, furniture, and the finer details in construction. Softwoods, such as pine, fir, spruce, or cedar, are less expensive and more plentiful, while hardwood, such as oak, cherry, ash, walnut, poplar, or birch, generally have a finer grain, a better appearance, and are more expensive.

The amount of moisture in a piece of wood affects many of its characteristics. Wood expands as its moisture content rises and shrinks as it lowers. This must always be taken into account when designing and detailing any wood structure. Dry lumber has increased strength and resistance to decay, fungi, and insects. This can be done either through the relatively slow process of air-drying or through the use of kilns.

Wood is highly resistant to acid, bases, salts, and other chemicals. The connection materials that are often used in wood buildings must also be considered in their resistance to chemicals and their corrosion resistance. Chemical treatments increase wood's resistance to fire, decay, and insect infestation.

1.2.1.2.2 Types

Wood is classified into two major categories: softwood and hardwood. Soft woods generally grow much quicker, are softer, and easier to work with than hardwood. Some common softwood includes fir, pine, cedar, Douglas fir, redwood, hemlock, and spruce. Both hardwoods and softwoods have examples of strong and durable species, but hardwoods are generally more durable as a reflection of their slower rates of growth and tighter annual ring patterns. Some common hardwoods include beech, oak, ash, elm, sycamore, birch, balsa and walnut.[5]

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[4] Farrelly, L., (2009), Basics Architecture Construction + Materiality, 2nd Ed., Switzerland, AVA Publishing SA.

[5] Bell, V., Rand, P., (2006), Materials for Architectural Design, London, Laurence King Publishing.

Softwoods are typically used for general construction purpose while hardwoods are usually used for flooring, paneling, trim pieces, and other finishing elements. Hardwoods are sometimes sliced into thin veneers and joined to lesser expensive woods for cost savings. Fig. (1-7) shows some sample panels of timber.

Red Beach Douglas Fir European Oak

European Beech Maple Cork

Fig. 1-7 Some sample panels of timber.

Source: Farrelly, L., (2009)

1.2.1.2.3 Applications

Oslo Airport, Aviaplan (1988)

The main terminal building of Oslo's Gardermoen Airport was designed by the Aviaplan group, they uses timber to incredible structural and aesthetic effect. It is believed to be the world's only major airport with a wooden structure and is the largest laminated structure in the world. Fig. (1-8) shows the using of timber in the roof structure.

Fig. 1-8 Oslo Airport, expressing the use of timber in the roof structure.

Source: http://www.uvsystem.com/images/oslo-airport-gardermoen-closeup.jpg , accessed (15-11-2012)

Moonah Links lodges (2007) , Hayball Leonard Stent Architects

Winner of the 2007 Australian Timber Design Awards, the Moonah Links lodges are located at the Moonah Golf Resort on the Mornington Peninsula in Victoria, Australia. They use timber for decorative effect; mixing rough sawn timber with planed timber to give a natural finish, as shown in fig. (1-9).

Fig. 1-9 Moonah Links Lodge, expressing the use of timber for decorative effects.

Source: <u>http://www.timberawards.com.au/images/stories/2007/moonah-links-lodges-235x181.png</u>, accessed (15-11-2012)

1.2.2 Industrialized Materials

They have been developed through ages starting from concrete that makes a great revolution in building construction, then by the usage of steel the revolution was even greater as it makes the architects capable of designing high building with large spans, until reaching composite materials, and smart materials that change the concept of traditional materials as they can respond to the surrounding environment.

1.2.2.1 Concrete

Concrete is a mixture of cement, aggregates and water, with any other admixtures which may be added to modify the placing and curing processes or the ultimate physical properties. Initially when mixed, concrete is a plastic material, which takes the shape of the mould or formwork. When hardened it may be a dense load-bearing material or a lightweight thermally insulating material, depending largely on the aggregates used. It may be reinforced or pre-stressed by the incorporation of steel.[6]

1.2.2.1.1 Basics

As a material it is strong in compression, and when enhanced by steel reinforcement it can also have great tensile strength. Concrete can take any shape or form through casting, and can have a variety of surface textures, finishes, and colors.

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[6] Lyons, A., (2007), <u>Materials for Architects and Builders</u>, 3rd Ed., Oxford, Butterworth-Heinemann.

Concrete's uses in architecture are numerous and diverse. It can be used for structural members including columns, beams, roofs, floor slabs, footing, and foundations, as well as for cladding and paving. It is neither a fireproof construction material, as it neither burns nor rots. It is also relatively low in cost. Perhaps its most advantageous quality that it is a shapeless material in which form, size, and texture must be designed.

Concrete varies in quality according to the proportions and characteristics of the cement, water, and aggregate from which it is made. Its strength is determined by its water/cement ratio: generally, the less water, the more strength. This ratio also affects the material's water resistance and durability. Admixtures- materials added to the base of water, cement, and aggregate- can be mixed into concrete to improve its workability or to change its characteristics, such as increasing its strength, speeding or slowing its curing time, or changing its color or texture.

The strength of a concrete mix also depends on its aggregate. Portland cement is a fine, grey powder, and is manufactured from a number of raw materials, including lime, iron, silica, and alumina. Concrete's specified compressive strength is generally developed within twenty-eight days after placement, but its strength continues to increase as the hydration process evolves.

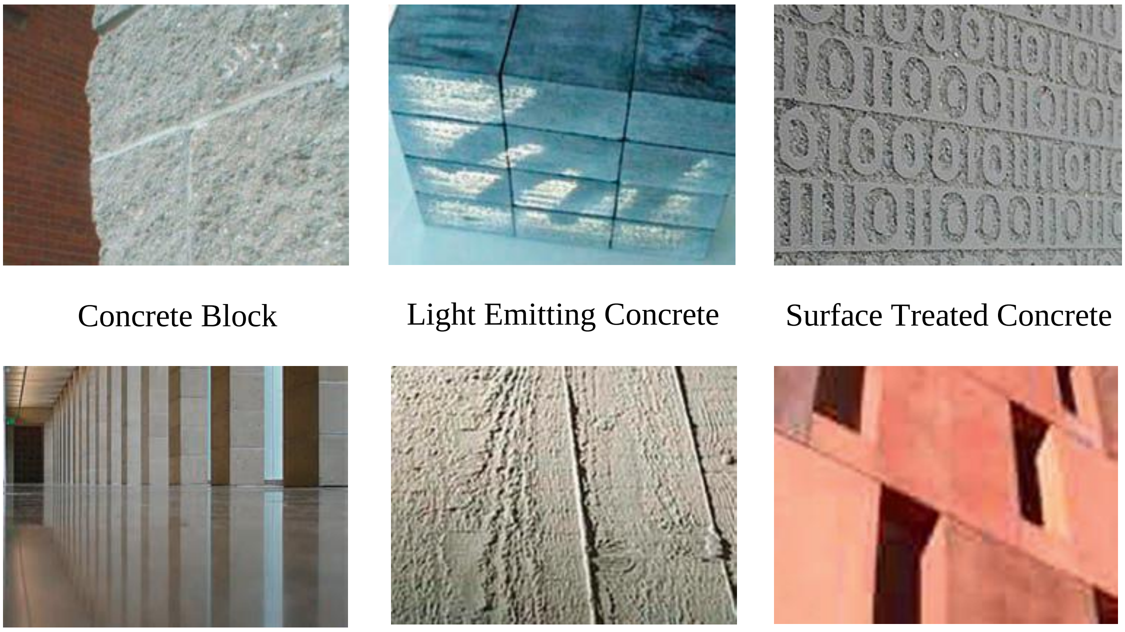
1.2.2.1.2 Types

There are many types of concrete, designed to suit a variety of purposes, as shown in Table (1-1). Fig. (1-10) shows some sample panels of concrete.

Types of concrete	Fibrous Concrete	Shotcrete
Plain Concrete	Self-Compacting Concrete	Prepacked Concrete
Reinforced Concrete	Polymer Concrete	Mass Concrete
Pre-stressed Concrete	Light-Weight Concrete	Gap Concrete
Precast Concrete	Heavy-Weight Concrete	Nailing Concrete
High Strength Concrete	Architectural Concrete	Sulfur Concrete

Table 1-1 Different types of concrete

Source: Emam, M., (1999)



Concrete Block

Light Emitting Concrete

Surface Treated Concrete

Polished Concrete

Transferred-surface concrete

Colored Concrete

Fig. 1-10 Some sample panels of concrete.

Source: Farrelly, L., (2009)

1.2.2.1.3 Applications

Pantheon, AD 125

The dome was built using stepped rings of concrete that diminished in both density and thickness as it rose from its base. The dome sits on a cylinder 6.4m thick masonry walls, which are constructed with a set of eight barrel vaulted voids and recesses lined with travertine. The dome was not in any way reinforced and still holds the record for the largest unreinforced concrete dome in the history of architecture[7]. Fig. (1-11) shows the structure of the unreinforced dome.

Fig. 1-11 Pantheon, expressing the largest unreinforced dome in the history of architecture.

Source: http://surveryofart.blogspot.com/2009_10_01_archive.html , accessed (16-11-2012)

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[7] Bell, V., Rand, P., (2006), Materials for Architectural Design, London, Laurence King Publishing.

Orly Airport Hangars

Eugene Freyssinet (1916)

Freyssinet was the inventor of the 'pre-stressing' technique, which was devised to overcome difficulties in creating curved shapes in reinforced concrete. Freyssinet's hangars at Orly Airport in Paris needed to house large structures and concrete had the flexibility to provide a high, wide spanning structure using a barrel vault construction[8], as shown in fig. (1-12).

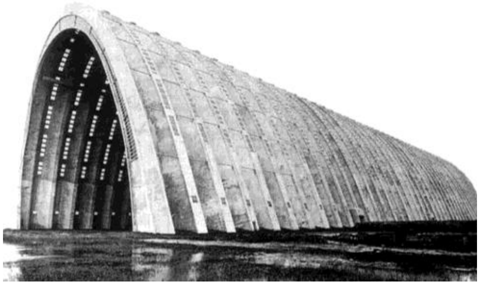

Fig. 1-12 Orly Airport Hanger, expressing the curved concrete structure.

Source:http://probaway.files.wordpress.com/2010/05/orly_airport_hangar_.jpg, accessed (16-11-2012)

La Ciudad de las Artes y las Ciencias

The City of Arts and Sciences building, developed by Santiago Calatrava, is a large-scale urban recreation centre for culture and science in Valencia, Spain. Calatrava's designs specified the use of pure white concrete and fragments of shattered tiles in the traditional Catalan style, as shown in fig. (1-13).

Fig. 1-13 La Ciudad De Las Artes, expressing the use of white concrete.

Source: http://www.viajesconpeques.com/wp-content/uploads/2008/10/ciudad-de-las-artes-y-las-c.jpg , accessed (16-11-2012)

The Museum of Modern Literature, David Chipperfield Architects, 2007

Winner of the 12th RIBA Stirling Prize and located in Germany. The construction materials reflect the museum's spaces and include fair-faced concrete, sandblasted reconstituted stone and limestone aggregate, as shown in fig. (1-14).

Fig. 1-14 The Museum of Modern Literature, expressing the use of fair-faced concrete.

Source:http://eliinbar.files.wordpress.com/2011/01/13633_image_3.jpg, accessed (16-11-2012)

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[8] Farrelly, L., (2009), Basics Architecture Construction + Materiality, 2nd Ed., Switzerland, AVA Publishing SA.

1.2.2.2 Glass and Steel

Glass and steel represent a manufactured form of architecture; these are materials that are used frequently in contemporary architecture to produce buildings that are both functional and practical.

1.2.2.2.1 Basics

Glass offers the architect the potential to create building forms that can be immediately associated with the properties of the material itself, producing structures that are transparent, light, open and clear.

Advances in the use of steel-frame forms brought with it a new conceptual way of thinking about structures. As steel has tensile strength, it allows new structural systems (such as cantilevers) and far-reaching aesthetic possibilities (such as gravity-defying skyscrapers) to be developed.

Historically, the application of glass in architecture has been limited by the manufacturing techniques used to produce it, as these controlled size of panels or piece made. Its fragility has also made it expensive to produce, transport and handle. Advances in manufacturing and construction technologies, however, have allowed glass to be used in innovative applications and for structural purposes in contemporary architecture.

1.2.2.2.2 Applications

Crystal Palace

Joseph Paxton (1851)

Using an iron frame and glass panels, Paxton’s Crystal Palace was the world’s first prefabricated glass building. It was constructed for The Great Exhibition, which was held in London’s Hyde Park in 1851. Fig. (1-15) expressing the use of large glass sheets in the building.

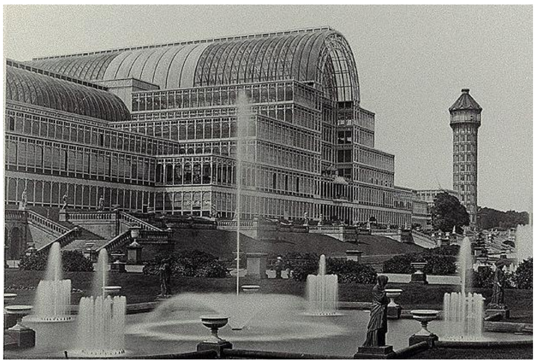

Fig. 1-15 Crystal Palace, the world’s first prefabricated glass building.

Source:http://www.expo2010italia.gov.it/public/SHA/681px_Crystal_Palace_Centre_transept_&_north_tower_from_south_wing%281%29.jpg , accessed (16-11-2012)

Louvre Pyramid

IM Pei (1989)

The Louvre in Paris was reinvented by the architecture of IM Pei. He used a platonic shape – a pyramid made of glass – to make a connection between the museum and La Défense (an office development on the edge of Paris). Pei’s pyramid is both architectural and culturally significant to Paris, as shown in fig. (1-16).

Fig. 1-16 Louvre Pyramid, expressing the platonic shape of the glass pyramid.

Source:http://spacecowboymodels.weebly.com/louvre-pyramid-paris.html, accessed (16-11-2012)

Swiss Re, Foster &Partners (2004)

Most of the tall buildings get their lateral stability from a rigid central core. However, with this tower the exoskeleton frame braces the structure through triangulation, as shown in fig. (1-17), as well as carrying the floor load- each floor rotates 5 degrees from the last. Despite its overall curved glass shape, there is only one piece of curved glass on the building- the lens-shaped cap at the very top – tapering into the crown, it reduces wind resistance.

Fig. 1-17 Swiss Re, expressing the use of exoskeleton frame braces and glass.

Source:http://www.eikongraphia.com/wordpress/wp-content/SwissRe.jpg, accessed (16-11-2012)

1.2.2.3 Composite Materials

Composite materials are those that are designed and produced from a range of other resources (natural, synthetic or manmade) to perform a particular function.[9]

Composites are engineered materials formed by combining two or more different elements with dissimilar properties. The properties of the newly designed composite are

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[9] Farrelly, L., (2009), Basics Architecture Construction + Materiality, 2nd Ed., Switzerland, AVA Publishing SA.

different from those of the original constituent materials acting independently; in fact, the new composite appears to have taken advantage of the different strengths and abilities of the elements from which it was formed.[10]

1.2.2.3.1 Basics

The properties of composite materials can be engineered to respond to particular design conditions; for example they may be especially durable, strong or waterproof depending on the requirements of the build. The key advantage of using composite materials in architectural design is that they are hugely flexible: by varying their composition and constituent parts different solutions for different projects can be found.

Composites consist of two elements: matrix and reinforcement. The matrix is the body constituent of a composite that completely surrounds the dispersed element and gives its bulk form. The reinforcements are harder and stronger than the matrix and enhance the properties of the matrix. The resulting composite consist of layers of reinforcements and matrix stacked in such away to achieve the desired properties.[11]

Green composites are similar to regular composites, but they designed with the lowest environmental footprint possible. The raw materials of green composites are not necessarily drived from renewable resources, because of financial reasons. Green composites are biodegradable, dependant on time, temperature, and local conditions. The biodegradability of the composite is desirable if it doesn’t harm the properties of the composite while in use.[12]

The evolution of composite materials is a critical part of the design palette for our future. In architecture, designs using composite materials have been the principal manner of making functional products for ages. For example, polyvinyl chloride (PVC) –coated polyester fabric or polytetrafluroethylene (PTFE)- coated glass fiber fabrics are commonly used to create tensile roofs on airport, warehouse and exhibition spaces because their properties make them very appropriate for covering large and open spans[13].

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[10] Daniel, I., Ishai, O., (2006), Engineering Mechanics of Composite Materials,2nd Ed., New York, Oxford University Press.

[11] Attmann, O., (2010), Green Architecture Advanced Technologies and Materials, United States of America, McGraw-Hill.

[12] Baillie, C., (2004), Green composites, Cambridge, woodhead Publishing Limited.

[13] Farrelly, L., (2009), Basics Architecture Construction + Materiality, 2nd Ed., Switzerland, AVA Publishing SA.

1.2.2.3.2 Types

Bio Composites: are renewable, recyclable, biodegradable, economical, nontoxic and require less energy to produce. These are used as adhesives, films, foams, rigid and flexible panels, coating, resins and elastomers. In architecture, bio composites are widely used for architectural applications in making building products (such as decking, roofing, doors and windows) and in structural and nonstructural assemblies.[14]

Ceramic Composites: have high temperature resistance but have limitations in structural applications because of their brittle composition using ceramic-fiber reinforcement improved this structural limitation. The average fracture toughness, is double with the ceramic composites[15]. These composites are mostly used in the aerospace industries, military technologies, auto industries, sports, electronics and building industry.

Polymer Composites: are used in a wide range of applications, especially where large and complex forms are required. They consist of high strength fibers (such as glass and carbon) in a thermoplastic resin. Polymer composites are strong, durable, and flexible and have very high resistance to weathering and corrosion which enables their use in marine, construction and infrastructure applications, including piping and storage tanks.[16]

Metal Composites: consist of metal alloy reinforced with continuous fiber. These composites have a high stiffness, durability and temperature resistance but they are heavier than many other composites. In architecture, metal composites provide a low maintenance, sturdy, durability and can be formed in to various shapes[17]. They can be used in building construction, aerospace and automotive applications.

Carbon Fiber Composites: are very strong, light weight material that composed of carbon atoms and ultra thin fibers. It’s used to reinforce composite materials, but it has limited use in metal matrix composite applications. Carbon fiber is much stronger and lighter than fiberglass and aluminum, 10 times stronger, and lighter than steel. They are used in automotive, aerospace, sports equipments fields and in construction industry.[18]

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[14] Attmann, O., (2010), Green Architecture Advanced Technologies and Materials, United States of America, McGraw-Hill.

[15] Chawla, K., (2003), Ceramic matrix composites, Norwell, Kluwer Academic Publisher.

[16] Attmann, O., (2010), Green Architecture Advanced Technologies and Materials, United States of America, McGraw-Hill.

[17] Schwartz, M., (1997), Composite Materials, vol. 1, United States, Prentice Hall.

[18] Attmann, O., (2010), Green Architecture Advanced Technologies and Materials, United States of America, McGraw-Hill.

Hybrid Composites: this category covers both the hybridizing of a composite material with other materials (either other composites or base unreinforced materials) and composites using reinforcements.[19]

Polytetrafluoroethylene (PTFE): PTFE (also known as Teflon) is very tough and commonly used to surface coat other materials in order to strengthen or protect them. PTFE is dirt-resistant because its properties prevent other particles from sticking to its surface, so is useful in areas where maintenance or cleaning access to a building may be limited.[20]

Polyvinyl Chloride (PVC): it's flexible, durable, require little maintenance and easily used with low cost. In the building industry, PVC is used in piping, siding, electrical insulation, roofing, door and window frames, wall coverings and flooring.[21]

Polymethyl methylacrylate (PMMA): PMMA (also known as acrylic) is a very hard material that is used to toughen various surfaces and also as an additive to finishes and paints. It is also used in place of glass for both interior and exterior conditions.[22]

Ethylene Tetrafluroethylene (ETFE): is a fluorocarbon-based polymer. It has a high strength, durability and its non-toxic and light weight. ETFE can bear 400 times its own weight, can be stretched three times its length without loss of elasticity and weight one percent of a comparable glass panel. Its surface is a corrosion and dirt resistant, self cleaning, has high resistance to heat, low smoke and flame characteristics. ETFE is not tear-resistant; so it’s used as roof material, if the material is torn, it can be replaced easily with other piece of ETFE. In most buildings applications it's used as ETFE bubbles, where multiple layers are pressurized to form a composite unit, sealed and held by metal composite strips such as aluminum.[23]

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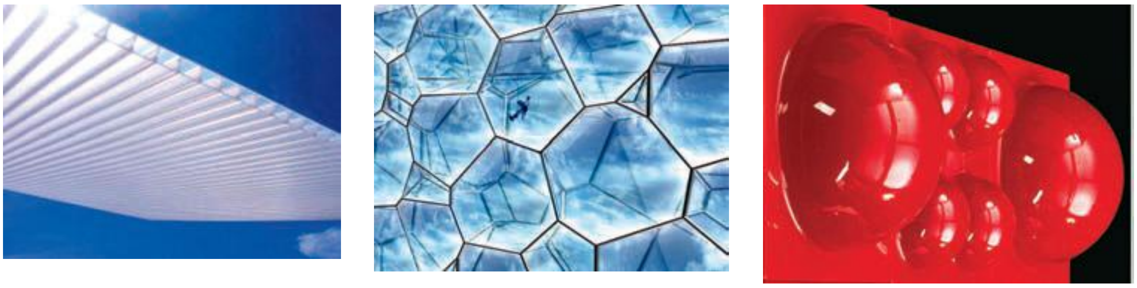
[19] Schwartz, M., (1997), Composite Materials, vol. 1, United States, Prentice Hall.

[20] Farrelly, L., (2009), Basics Architecture Construction + Materiality, 2nd Ed., Switzerland, AVA Publishing SA.

[21] Attmann, O., (2010), Green Architecture Advanced Technologies and Materials, United States of America, McGraw-Hill.

[22] Farrelly, L., (2009), Basics Architecture Construction + Materiality, 2nd Ed., Switzerland, AVA Publishing SA.

[23] Attmann, O., (2010), Green Architecture Advanced Technologies and Materials, United States of America, McGraw-Hill.



Corrugated plastic

Ethylene tetrafluoroethylene (ETFE)

Molded plastic

Rubber flooring

Titanium cladding

Kalzip AluPlusSolar solar panels

Fig. 1-18 Different sample panels of composite materials.

Source: Farrelly, L., (2009)

1.2.2.3.3 Applications

Guggenheim Museum, Frank Gehry (1997)

Located in Bilbao, Spain, the most distinctive and remarkable aspects of this building are its shape and its material application. Its sculptural dynamic shape is only possible because titanium, the material used for the building’s cladding panels, is incredibly flexible. Fig. (1-20) shows the using of titanium cladding in Guggenheim museum.

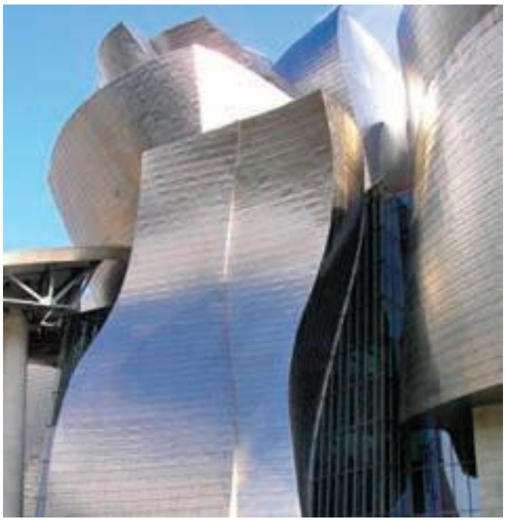


Fig. 1-19 Guggenheim Museum, expressing the titanium cladding.

Source: Farrelly, L., (2009)

The 02 Arena, Richard Rogers Partnership,(2000)

London’s O2 Arena (the ‘Dome’) is covered by a polytetrafluoroethylene (PTFE) plastic roof, as shown in fig. (1-19). The space within it is 50 meters high and the roof is supported by a series of masts and cables. The building has taken its popular name from its defining feature, its roof structure.

Fig. 1-20 The 02 Arena, expressing the use of PTFE plastic roof.

Source: http://mytravelinfodiary.com/wp-content/uploads/2012/04/o2-arena-03.jpg, accessed (9-10-2012)

Galleria shopping centre, UN Studio, (2004)

Located in Seoul, Korea, the façade of the Galleria shopping centre projects an ever-changing surface. In total, 4330 glass discs are mounted on the concrete skin of the building. The discs include special dichroic foil, generating a mother-of pearl effect during the day. At night each glass disc is lit by LED lights, which are programmed to create a multitude of aesthetic effects, as shown in fig (1-21).

Fig. 1-21 Galleria Shopping Centre, expressing the changing surface.

Source: http://english.chosun.com/site/data/html_dir/2007/01/25/2007012561009.html ,accessed (9-10-2012)

Water Cube , Arup and PTW Architects (2006)

Beijing’s National Aquatics Centre was constructed to house water events for the 2008 Olympic Games. The ‘Cube’s’ main structure is made of concrete and steel and the form is clad with ETFE plastic, which is molded to resemble bubbles, as shown in fig. (1-22). The material is transparent and fills the space with light.

Fig. 1-22 Wter Cube, expressing the clad with ETFE plastic

Source: http://www.englishexercises.org/makeagame/viewgame.asp?id=309 ,accessed (9-10-2012)

1.2.2.4 Smart Materials

For many centuries one had to accept and work with the properties of a standard material such as wood or stone, designing to accommodate the material's limitations, whereas during the 20th century one could begin to select or engineer the properties of a high performance material to meet a specifically defined need. Smart materials allow even a further specificity – their properties are changeable and thus responsive to transient needs. For example, photochromic materials change their color (the property of spectral transmissivity) when exposed to light: the more intense the incident light, the darker the surface.

Cost and availability have restricted widespread replacement of conventional building materials with smart materials, but the stages of implementation are tending to follow the model by which 'new' materials have traditionally been introduced into architecture.

Using smart materials can produce an architecture that is fluid and responsive to changing conditions. The designer needs to understand the enormous potential for the application of these materials and experiment with them to develop a new paradigm for architecture.

1.3 Classification Systems of Smart Materials and Traditional Materials

Classification systems are useful for simple categories and description purpose; they also can suggest fundamental constructs of a field. This is important in helping us to place smart materials with in a broader context. For this discussion, we will distinguish between three types of classification: traditional material classification systems, alternative classification systems, and classification systems for advanced and smart materials.

1.3.1 Traditional materials classification systems

There are a number of existing classification and descriptive systems used in connection with materials. One broad approach stems from a fairly basic materials science approach to the subject matter, which revolves around the internal structure of the material. Another approach commonly used in the engineering profession focuses on the performance characteristics of materials. In the design fields, a host of different loose categorizations are used, many of which are particular to individual fields.

In general, we will see that each material system adopts a particular point of view that is useful to a particular construct of the field and/or for a particular application. Hence, it is important to understand these points of view.

1.3.1.1 Material Science Classifications

The material science approach aims to understand the basic internal structure of materials. The most fundamental level of differentiation begins with the bonding forces between individual atoms, whether ionic, covalent, and metallic or Van der Waals, which will ultimately determine many of the intrinsic properties and major behavioral differences between materials. The next level of description hinges on the way these bonding forces produce different types of aggregation patterns between atoms to form various molecular and crystalline solid structures. These larger aggregation patterns can further be differentiated by how their molecular structures branch or link or, in crystalline solids, by different types of unit cell and related spatial lattice structures such as face-centered or body-centered.[24]

This way of classifying materials is extremely useful for many reasons. In particular, the understandings reflected in the classifications provide a way of describing the specific qualities or properties (e.g., hardness, electrical conductivity) that characterize different materials. Knowledge of properties at atomic and molecular levels. Consequently, it also provides a basis for developing a method for designing materials that possess different qualities or properties.

1.3.1.2 Engineering Classifications

Applied classification approaches are shown in Fig. (1-23) and (1-24). These types are primarily used in the mechanical engineering profession to distinguish between the fundamental problem-solving characteristics of the nearly 300 000 materials readily available to the engineer. The engineering classification enabling the engineer to mix and match properties and attributes to solve the problem at hand. Materials in these classifications are chosen based on what they can do, how they behave and what they can withstand. The final objective in all engineering applications is the optimization of a material property for a particular situation, regardless of the material type.[25]

STATE	solid, liquid, gas
STRUCTURE	amorphous, crystalline
ORIGIN	natural, synthetic
COMPOSITION	organic, inorganic, alloy
PROCESSING	cast, hardened, rolled
PROPERTY	emissivity, conductivity
ENVIRONMENT	corrosive, underwater
APPLICATION	adhesive, paint, fuel

Fig. 1-23 Basic organization of material categories in the engineering profession with a few examples in each category.

Source: Addington, M., Schodek, D., (2005)

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[24] Addington, M., Schodek, D., (2005), Smart Materials and New Technologies, Oxford, Architectural Press.

[25] Addington, M., Schodek, D., (2005), Ibid.

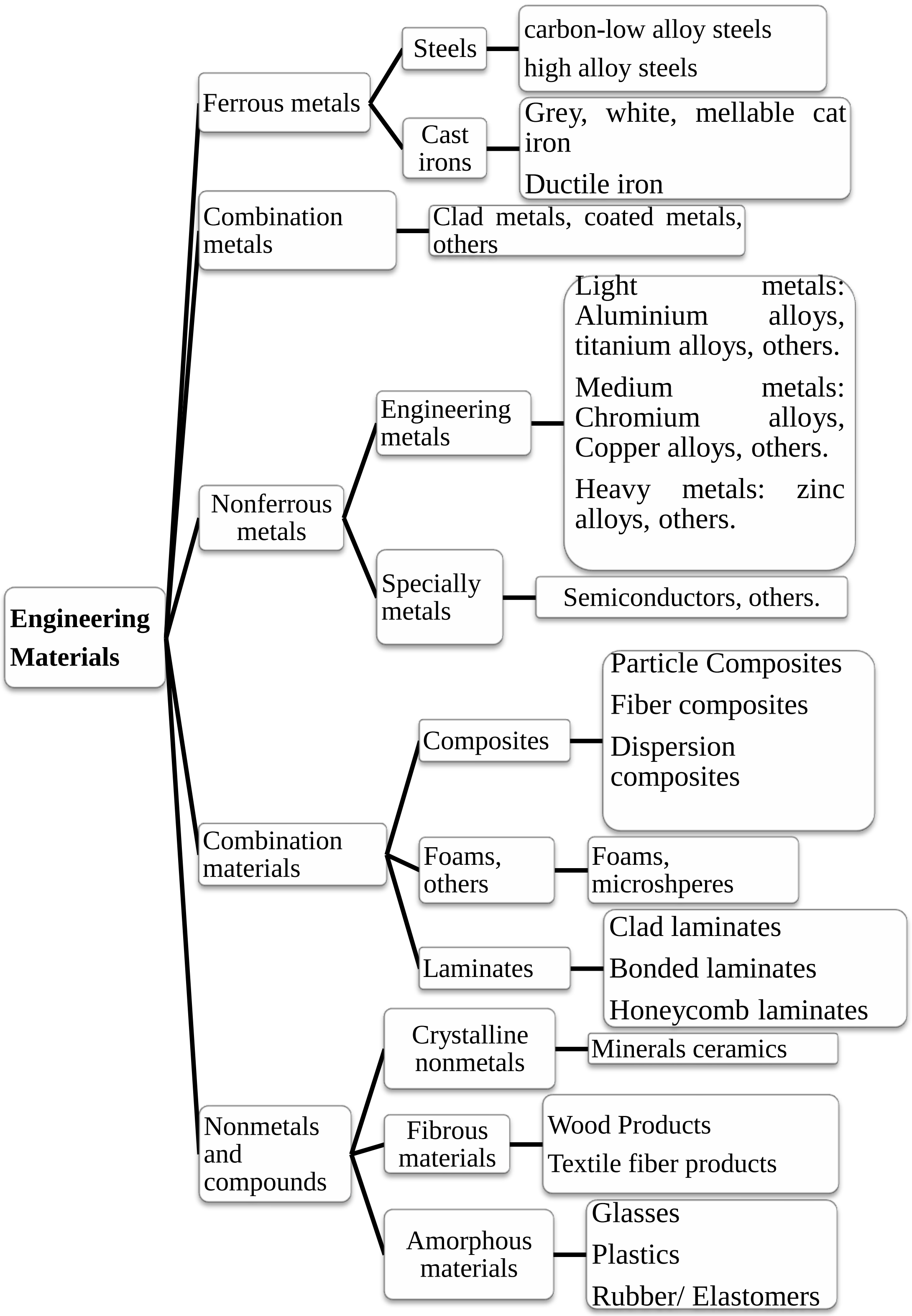

Fig. 1-24 This classification system mixes the form of material structures (e.g., laminates, amorphous) with properties (ferrous, nonferrous).

Source: Author, according to: Addington, M., Schodek, D., (2005)

1.3.1.3 Traditional Architectural Classifications

Architectural classifications tend to be more nominative – simply listing materials and uses in accordance with standard building requirements. These various requirements are codified in different ways.

In the United States, the Construction Specifications Institute has maintained a standardized classification system for over 50 years. This system, known as the CSI index, organizes materials in two ways. The first places the materials typically used in a building into broad classes. The second organizes by component or system. In the broad material classes, the properties, performance and behavior are largely presumed to be satisfactory as long as the chosen material fits within the normative uses defined by practice. The system or component classes focus on application as well. The CSI index also addresses the technologies typically used in buildings, grouping them into operational systems, such as heating, ventilating and air conditioning (HVAC), lighting and plumbing, and into constructional systems, such as structural, drainage and vertical circulation. Classification systems such as that of the CSI are practical templates for communication between architects, contractors, fabricators and suppliers, and result in the exclusion of new and unusual materials and technologies[26].

1.3.1.4 Comparison between Traditional materials classification systems

Table (1-2) shows a comparison between the three types of traditional materials classification systems based on their description, what they focus on, and the advantages of each classification system.

Points of comparison	Material science classification	Engineering classification	Traditional Architectural classification
Description	Describe how the material is composed and why one material is differentiated from another.	Describe what the material does and how it performs.	Describe the sequence by listing what a material is and where it is used.

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[26] Addington, M., Schodek, D., (2005), Smart Materials and New Technologies, Oxford, Architectural Press.

Focus on	Focus on the internal structure of materials through two levels of description : Bonding force between individual atoms that determine the intrinsic properties. The way these bonding forces produce different patterns between atoms to form various crystalline solid structure	Focus on mixes the form of material structures with properties. Materials are chosen based on what they can do, how they behave and what they understand.	Focus on listing materials and uses in accordance with standard building requirements. These requirements are codified in different ways, such as CSI index.
Advantages	Understanding reflected in the classifications provides a way of describing the specific qualities or properties. Know the properties at the atomic and molecular level. Provides basics for developing a method for designing materials that possess different qualities or properties.	Optimization of a material property for particular situation, regardless the material type. Development of new materials.	Result in the exclusion of new and unusual materials and technologies.

Table 1-2 Comparison between Types of Traditional Materials Classification Systems

Source: according to the author.

1.3.2 Alternative classification systems

There have been many attempts to introduce new materials to designers through alternative classification systems. Many are qualitive and readily mix approaches to description, but almost all invert the criteria driven process that characterize the material science and engineering systems.

The traditional engineering approach the material is understood as an array of physical behaviors, then in the traditional architectural and the engineering approach is little better as it is based on a specificity of performance optimized to a single state that inherently denies the mutability of the material and its interactions with its surroundings. As a result, many of the materials and technologies that we are interested in have not been suitably categorized by other systems, including those of the engineering field.

1.3.3 Classification systems for advanced and smart materials

The information necessary for the implementation of new materials may be available, but there is as yet no method for its application in the design fields. Staying with the current method and treating smart materials as artifacts in a classification system is clearly problematic. Even if a smart material could be considered as a replacement for a conventional material in many components and applications, its inherent ‘active’ behavior makes it also potentially applicable as a technology.. Furthermore, many of the new technologies are unprecedented in application, and thus have no place-holder in conventional descriptions.

The most fitting for smart material classifications is to be multi-layered – with one layer characterizing the material according to its physical behavior (what it does) and another layer characterizing the material according to its phenomenological behavior (the results of the physical behavior). The smart materials that we use can produce direct effects on the energy environments (luminous, thermal and acoustic), or they can produce indirect effects on systems (energy generation, mechanical equipment). This approach is operationally very useful to the designer in evaluating the use of smart materials and systems in relation to the design of environments. This is essentially a functions/systems approach.[27]

This layer enables us to meet and confront related new initiatives and technologies that shape larger devices and environments. As a way of structuring subsequent inquiries and discussions, a working classification approach based on function/system overlay is shown in Fig. (1-25). The figure describes a proposed organization that establishes a sequential relationship between materials, technologies and environments.

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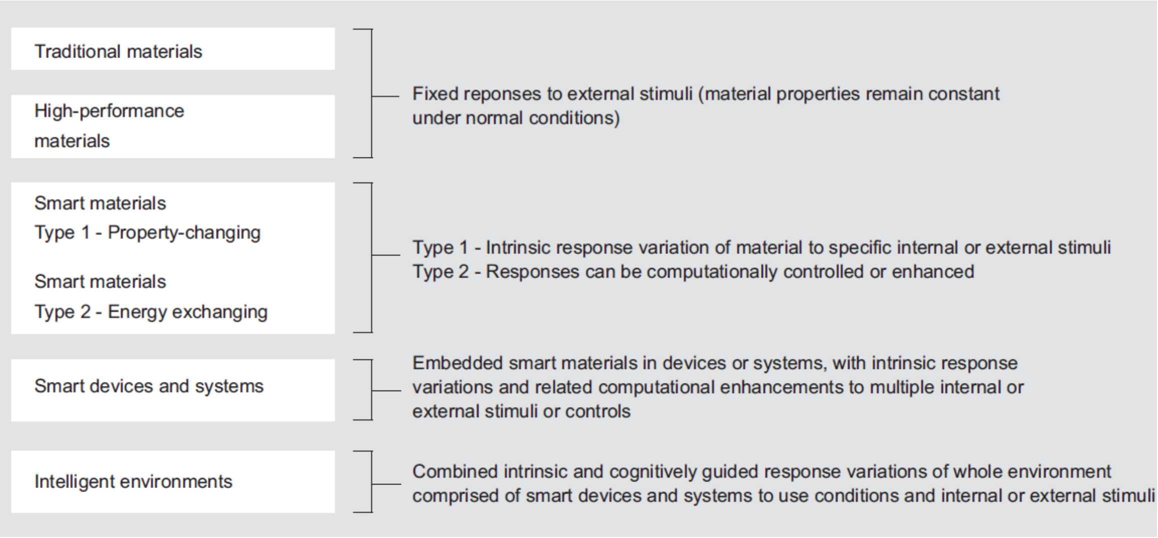
[27] Addington, M., Schodek, D., (2005), Smart Materials and New Technologies, Oxford, Architectural Press.



Traditional materials High-performance materials	Fixed reponses to external stimuli (material properties remain constant under normal conditions)
Smart materials Type 1 - Property-changing Smart materials Type 2 - Energy exchanging	Type 1 - Intrinsic response variation of material to specific internal or external stimuli Type 2 - Responses can be computationally controlled or enhanced
Smart devices and systems	Embedded smart materials in devices or systems, with intrinsic response variations and related computational enhancements to multiple internal or external stimuli or controls
Intelligent environments	Combined intrinsic and cognitively guided response variations of whole environment comprised of smart devices and systems to use conditions and internal or external stimuli

Fig. 1-25 Distinguishing smart and intelligent systems and environments.

Source: Addington, M., Schodek, D., (2005)

1.4 Conclusions

The building materials have been developed with time. Starting from natural materials such as Stone and timber, and the man-made materials such as concrete, glass, steel, composite materials, and smart materials.

There are three types of classification systems for smart and traditional material which are: traditional materials classification systems (which include three types of classifications: material science classifications, engineering classifications, and traditional architectural classifications), alternative classification systems, and classification systems for advanced and smart materials.

SMART MATERIALS, THEIR TYPES, AND CHARACTERISTICS

2.1 Introduction

There is an increasing awareness of the benefits to be derived from the development of smart materials and structures in applications ranging from hydrospace to aerospace. With the ability to respond to changes in their environment, smart systems can offer a simplified approach to various material and system characteristics control such as light transmission, viscosity, strain, noise and vibration etc. depending on the smart materials used.

Smart materials sense changes in the environment around them and respond in a predictable manner. Smart systems also sense their environment and respond, but are not constructed from a single material. They may incorporate smart materials, but can also be constructed using traditional materials that evolve smart technology.

Smart materials and systems open up new possibilities, such as clothes that can interact with a mobile phone or structures that can repair themselves. They also allow existing technology to be improved. Using a smart material instead of conventional mechanisms to sense and respond, can simplify devices, reducing weight and the chance of failure.

This chapter is divided into two main parts ;the first part will begin to layout the definitions that are necessary for understanding smart materials, then it will provide the basic fundamental characteristics that distinguish smart materials from the traditional ones. The second part will provide the different types of characterization of smart materials based on their different criteria.

2.2 Smart Materials Definitions and Characteristics

Smart materials represent a radical departure from the more normative building materials, whereas standard building materials are static in that they are intended to withstand building forces, smart materials are dynamic in that they behave in response to energy fields. This part will provide the necessary overview of the smart materials definitions and their fundamental characteristics.

2.2.1 Smart Materials Definitions

The term smart materials has been used without defining what it means. Creating a definition, however is very difficult. The term is already in wide use, but there is no general agreement about it really means. So there are many definitions that defines smart materials.

NASA defines smart materials as ‘materials that ‘‘remember’’ configurations and can conform to them when given a specific stimulus’[1].

Smart materials is a relatively new term for materials and products that have changeable properties and are able to reversibly change their shape or color in response to physical and/or chemical influences, e.g. light, temperature or the application of an electric field[2].

Smart materials are engineered materials that sense react to environmental conditions, and /or have one or more properties that can be significantly altered in a controlled fashion by external stimuli. These stimuli may include light, temperature, moisture, mechanical force and/or electric or magnetic fields[3].

Smart materials and structures are those objects that sense environmental events, process that sensory information, and then act on the environment[4].

These definitions seem to be referring to the same type of behavior, that they sense react to environmental conditions.

2.2.2 Fundamental characteristics

The five fundamental characteristics that were defined as distinguishing a smart material from the more traditional materials used in architecture were transiency, selectivity, immediacy, self actuation and directness. By applying these characteristics to the organization of these materials they can be grouped into: Property change capability, Energy exchange capability, Discrete size/location, Reversibility[5].

2.2.2.1 Reversibility/Directionality

Materials with bi-directional property change or energy exchange behaviors can often allow further exploitation of their transient change rather than only of the input and output energies and/or properties. The energy absorption characteristics of phase

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[1] Addington, M., Schodek, D., (2005), Smart Materials and New Technologies, Oxford, Architectural Press.

[2] Ritter, A., (2007), Smart materials in architecture, interior architecture and design, Basel, Switzerland, Birkhäuser.

[3] Addington, M., Schodek, D., (2005), Smart Materials and New Technologies, Oxford, Architectural Press.

[4] Korschwitz, J., (1992), Encyclopedia of Chemical Technology, Newyork, John Wiley and sons.

[5] Addington, M., Schodek, D., (2005), Smart Materials and New Technologies, Oxford, Architectural Press.

changing materials can be used either to stabilize an environment or to release energy to the environment depending on in which direction the phase change is taking place.

2.2.2.2 Property change

These materials undergo a change in a property or properties – chemical, thermal, mechanical, magnetic, optical or electrical – in response to a change in the conditions of the environment of the material. Included in this class are all color changing materials, such as thermochromics, electrochromics, photochromics, etc., in which the intrinsic surface or molecular spectral absorptive of visible electromagnetic radiation is modified through an environmental change (incident solar radiation, surface temperature) or a direct energy input to the material (current, voltage). Fig. (2-1) shows the change in photochromic lens color as illumination and uv light increase.

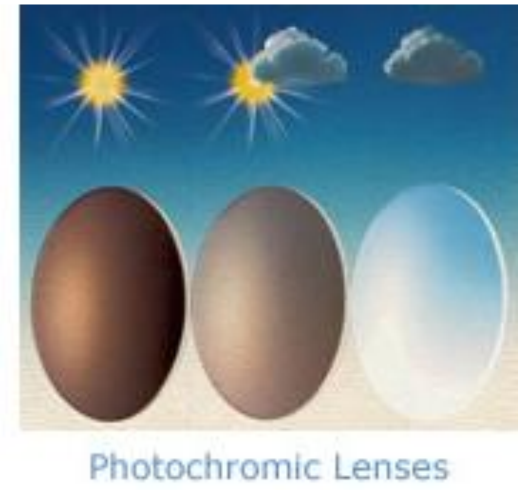

Fig. 2-1 Photochromic lenses darken as illumination and UV light increase.

Source:http://www.katzandklein.com/katzandklein.asp?pageid=2579&parentpageid=617, (accessed 11-3-2013)

2.2.2.3 Energy Exchange

These materials, which can also be called ‘First Law’ materials, change an input energy into another form to produce an output energy in accordance with the First Law of Thermodynamics. Although the energy conversion efficiency for smart materials such as photovoltaics and thermoelectric, as shown in fig. (2-2) the potential utility of the energy is much greater. For example, the direct relationship between input energy and output energy renders many of the energy exchanging smart materials, including piezoelectrics, pyroelectrics and photovoltaics, as excellent environmental sensors. The form of the output energy can further add direct actuation capabilities such as those currently demonstrated by electrostrictives, chemoluminescents and conducting polymers.

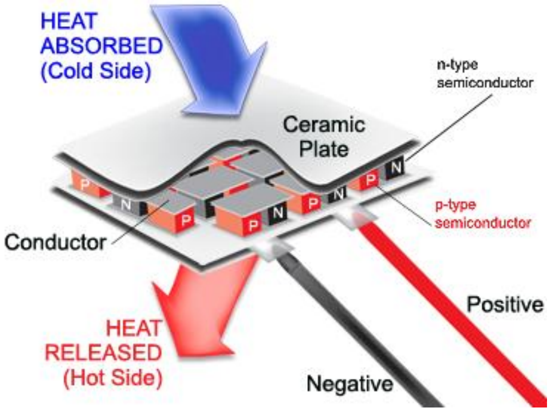

Fig. 2-2 Fig. (2-2) Thermoelectric: Based on the Peltier effect, current flow in one direction causes heat to be transferred from Surface A to Surface B.

Source: http://www.teamwavelength.com/info/temperaturecontrollers.php, (accessed 11-3-2013)

2.2.2.4 Size/location

One of the most fundamental characteristics that differentiate them from traditional materials is the discrete size and direct action of the material. The elimination or reduction in secondary transduction networks, additional components, and, in some cases, even packaging and power connections allows the minimization in size of the active part of the material. A component or element composed of a smart material will not only be much smaller than a similar construction using more traditional materials but will also require less infrastructural support. The resulting component can then be deployed in the most efficacious location. The smaller size coupled with the directness of the property change or energy exchange renders these materials to be particularly effective as sensors: they are less likely to interfere with the environment that they are measuring, and they are less likely to require calibration adjustments.

2.3 Types Characterization of Smart Materials

In comparison to conventional materials, smart materials are functional, that is, they are required to undergo purposeful and reversible changes, playing an active part in the way the structure or device works. Their classification is based on the relationship between the stimulus and response[6]. The following table shows the relation between response and stimulus in electrical, magnetic, optical, thermal, mechanical fields, and the effect of each field on the other.

Response **Stimuli**	**Mechanical**
Electrical	Piezoelectric Electrostrictive ER Fluids
Magnetic	MR Fluids (fluids that in the absence of a Magnetic Field are liquid and in the presence of a Magnetic Field are solid.)
Optical	
Thermal	Shape Memory
Mechanical	Negative Poisson Ratio

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[6] Rivera, A., Types of Smart Materials, http://academic.uprm.edu/pcaceres/Undergrad/Smart-Alessandra/id18.htm , [accessed 15-2-2013].

Electrical	**Thermal**	**Optical**	**Magnetic**
	Thermoelectric	Electrochromic Electroluminescent Electro-optic	
		Magnto-Optic	
Photoconductor		Photochromic	
		Thermochromic Thermoluminescent	
Piezoelectric & Electrostrictive		Mechanochromic	Magnetostrictive

Table 2-1 Smart materials classification based on the relationship between the stimulus and response.

Source: Author, according to: http://academic.uprm.edu/pcaceres/Undergrad/Smart-Alessandra/id18.htm (accessed : 15-2-2013)

2.3.1 First classification

The different types of smart materials have been differentiated on a case basis from the point of view of their importance in the context of realized or future architectural applications. The materials chosen offer a overview of the smart materials most suitable at the current time for use in architecture, interior architecture, and design[7].

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[7] Ritter, A., (2007), Smart materials in architecture, interior architecture and design, Basel, Switzerland, Birkhäuser.

2.3.1.1 Shape- Changing Smart Materials

They include materials and products that are able to reversibly change their shape and/or dimensions in response to one or more stimuli through external influences, the effect of light, temperature, pressure, an electric or magnetic field, or a chemical stimulus. Among these, there are materials and products that are able to change their shape without changing their dimensions, and other materials and products that retain their shape but change their dimensions. Some are also able to change both parameters at the same time. The currently available shape-changing materials can be differentiated according to their triggering stimuli as follows:[8]

Photostrictive Smart Materials: Excited by the effect of light (electromagnetic energy).

Thermostrictive Smart Materials: Excited by the effect of temperature (thermal energy).

Piezoelectric Smart Materials: Excited by the effect of pressure or tension (mechanical energy).

Electroactive Smart Materials: Excited by the effect of an electric field (electrical energy).

Magnetostrictive Smart Materials: Excited by the effect of a magnetic field (magnetic energy).

Chemostrictive Smart Materials: Excited by the effect of a chemical environment (chemical energy).

Thermostrictive, piezoelectric, electroactive and chemostrictive smart materials are those that are currently of the greatest interest in the field of architecture, due to their availability, predicted long-term stability and other factors.

2.3.1.2 Color and Optically Changing Smart Materials

They include materials and products that are able to reversibly change their color and/or optical properties in response to one or more stimuli through the external influence of light, temperature, compression, an electrical or magnetic field and/or a chemical stimulus. The currently available color- and optically changing smart materials can be differentiated according to their triggering stimuli as follows[9]:

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[8] Ritter, A., (2007), Smart materials in architecture, interior architecture and design, Basel, Switzerland, Birkhäuser.

[9] Ritter, A., (2007),Ibid.

Photochromic Smart Materials: These materials change their color when excited by the effect of light (electromagnetic energy).

Thermochromic, Thermotropic Smart Materials: These materials change their color and/or optical properties when excited by the effect of temperature (thermal energy).

Mechanochromic Smart Materials: These materials change their color when excited by the effect of compression, tension or friction (mechanical energy), e.g. Piezochromic, and Tribochromic.

Electrochromic, Electrooptic Smart Materials: These materials change their color and/or optical properties when excited by the effect of electrical fields, electrons or ions (electrical energy), e.g. Ionochromic.

Chemochromic Smart Materials: These materials change their color and/or optical properties when excited by the effect of a chemical environment (chemical energy), e.g. hydrogen, oxygen, salt content (pH value), a solution or water.

2.3.1.3 Adhesion-Changing Smart Materials

They include materials and products that are able to change reversibly the attraction forces of adsorption or absorption of an atom or molecule of a solid, liquid or gaseous component in response to a stimulus. This may take place due to the effect of light, temperature, an electrical field or a liquid and/or biological component. Depending on the stimulus involved adhesion-changing smart materials can be differentiated as[10]:

Photoadhesive Smart Materials: Change the attraction forces of adsorption or absorption of atoms or molecules of solid, liquid or gaseous components in response to light.

Thermoadhesive Smart Materials: Change the attraction forces of adsorption or absorption of atoms or molecules of solid, liquid or gaseous components in response to temperature.

Electroadhesive Smart Materials: Change the attraction forces of adsorption or absorption of atoms or molecules of solid, liquid or gaseous components in response to an electrical field.

Hydroadhesive Smart Materials: Change the attraction forces of adsorption or absorption of atoms or molecules of solid, liquid or gaseous components in response to liquid components (e.g. water).

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[10] Ritter, A., (2007), Smart materials in architecture, interior architecture and design, Basel, Switzerland, Birkhäuser.

Bioadhesive Smart Materials: Change the attraction forces of adsorption or absorption of atoms or molecules of solid, liquid or gaseous components in response to biological components (e.g. bacteria).

Thermoplastic plastics are one example of smart materials that have strong thermoadhesive properties. They create a temperature-dependent bond between different components. Electroadhesive smart materials are able to generate an electrostatic field in response to a stimulus and reversibly bond with ionised particles floating in the air, to give an example. Bioadhesive smart materials can be considered to include living bacteria on a nutrient and carrier layer (e.g. agar), which secrete adhesive substances, e.g. in the form of polysaccharide fibers in response to light or nutrients.

2.3.1.4 Light-Emitting Smart Materials

They include materials or products with molecules that become excited by the effects of light or an electrical field, to emit light. This happens as a result of the molecules taking up a temporary state of higher energy before leaving it again, at which time part of the energy taken up is emitted in the form of visible electromagnetic radiation, without the simultaneous emission of considerable thermal radiation. This phenomenon is called luminescence. In general terms luminescence can be differentiated as[11]:

Photoluminescence: An optical phenomenon in which a molecule is excited and emits light due to the effect of light.

Electroluminescence: An optical phenomenon in which a molecule is excited and emits light due to the effect of an electrical field.

Bioluminescence: An optical phenomenon in which a chemical reaction occurs to excite a molecule in a living organism to emit light.

Chemoluminescence: An optical phenomenon in which a chemical reaction occurs to excite a molecule to emit light.

Crystalloluminescence: An optical phenomenon in which a molecule is excited due to crystallization and emits light.

Radioluminescence : An optical phenomenon in which a molecule is excited by the effect of radioactive radiation and emits light.

Radiophotoluminescence (Thermoluminescence): An optical phenomenon in which a molecule is excited by the effect of radioactive radiation followed by thermal radiation to emit cold light.

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[11] Ritter, A., (2007), Smart materials in architecture, interior architecture and design, Basel, Switzerland, Birkhäuser.

Triboluminescence: An optical phenomenon in which a molecule is excited by a mechanical effect to emit light.

2.3.1.5 Electricity-Generating Smart Materials

They include materials and products that are able to generate an electric current with a connected consumer (e.g. a resistance load) in response to one or more stimuli from outside influences, the effect of light, or changes in temperature and/or pressure. The currently available electricity-generating smart materials can be differentiated according to their triggering stimuli as follows[12]:

Photoelectric Smart Materials: After the connection of a consumer these materials generate an electric current when excited by the effect of light (electromagnetic energy).

Thermoelectric Smart Materials: After the connection of a consumer these materials generate an electric current when excited by the effect of temperature (thermal energy).

Piezoelectric Smart Materials: After the connection of a consumer these materials generate an electric current when excited by the effect of compression or tension (mechanical energy).

Chemoelectric Smart Materials: After the connection of a consumer these materials generate an electric current when excited by the effect of a chemical environment (chemical energy).

2.3.1.6 Energy-Exchanging Smart Materials

They including energy-storing smart materials, are materials and products that are able to store energy, both sensible and latent energy, e.g. in the form of light, heat, electricity or hydrogen, and exhibit at least some reversibility. The energy-storing smart materials available on today‘s market can be differentiated as follows[13]:

Light-Storing Smart Materials: These materials have inherent properties that enable them to store energy in the form of light.

Heat-Storing Smart Materials: These materials have inherent properties that enable them to store energy in the form of heat and cold (negative heat).

Electricity-Storing Smart Materials: These materials have inherent properties that enable them to store energy in the form of electricity.

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[12] Ritter, A., (2007), Smart materials in architecture, interior architecture and design, Basel, Switzerland, Birkhäuser.

[13] Ritter, A., (2007), Ibid.

Hydrogen-Storing Smart Materials: These materials have inherent properties that enable them to store energy in the form of hydrogen.

2.3.1.7 Matter-Exchanging Smart Materials

They including matter-storing smart materials, are materials and products that are able to reversibly take up and/or in, to bind and release matter either in the form of molecules, as gaseous, liquid or solid components by various physical and/or chemical processes. The matter-storing smart materials currently available on the market can be differentiated on the basis of the type of matter stored, which can also be the triggering stimulus[14].

Gas/Water-Storing Smart Materials: They are excited by gas and/or water to adsorb or absorb them. Through contact with another medium such as air, and in certain situations through other influences (e.g. increased temperatures), they can become excited and desorbs the stored matter.

Particle-Storing Smart Materials: They are excited for example by ionized, electrical or electromagnetic fields to absorb particles. When the field is removed, they are excited and desorbs the stored matter.

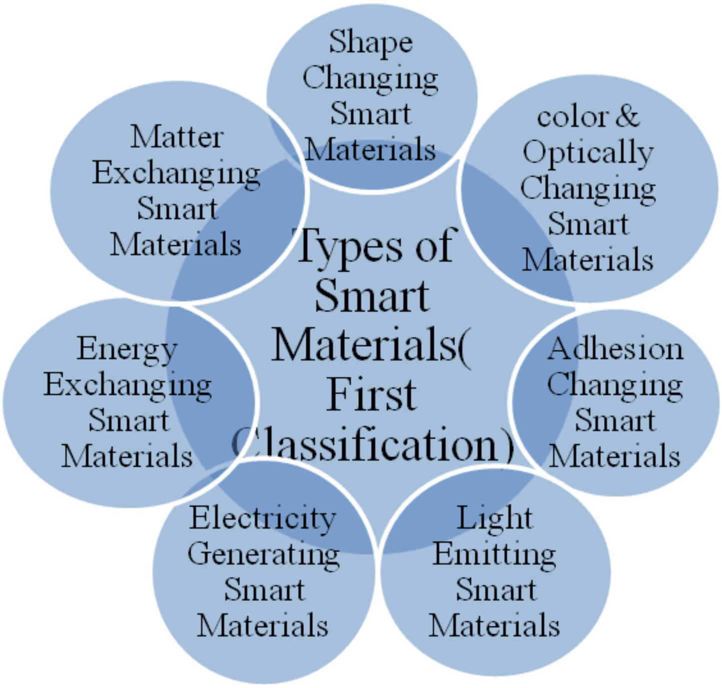

Fig. 2-3 Smart material types (First classification).

Source: Author, according to: Ritter, A., (2007).

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[14] Ritter, A., (2007), Smart materials in architecture, interior architecture and design, Basel, Switzerland, Birkhäuser.

2.3.2 Second classification:

The types of smart materials are classified based on their inherent properties, molecular alterations, and the embedded control systems. Accordingly, there are three types of smart materials: thermo-responsive materials; light-responsive materials; stimulus (force) –responsive materials[15].

2.3.2.1 Thermo-Responsive Materials (TRMs)

They are smart materials that transform due to a change in temperature.

2.3.2.1.1 Thermochromic Materials

They change color in response to temperature differences. When a thermochromic materials absorb heat, its molecular structure and the consequent light reflection of the material also change. This result in reversible color reflection. There are two general types: thermochromic liquid crystals and leucodyes. When accurate temperatures are needed, thermochromic liquid crystals are used. A temperature change triggers the molecular change on the crystal, which affects its color reflection from light. Leucodyes paints or inks work on the same principal and are used in circumstances where precise temperature readings are not necessary. In architecture, these materials are used for interactive visual effects.

Thermochromic windows: in response to temperature change, new thermochromic window films alter their color structures as well as reduce solar heat transmission by blocking UV radiation Fig.(2-4). These thin plastic films are quite practical and can be incorporated into almost any window assembly.

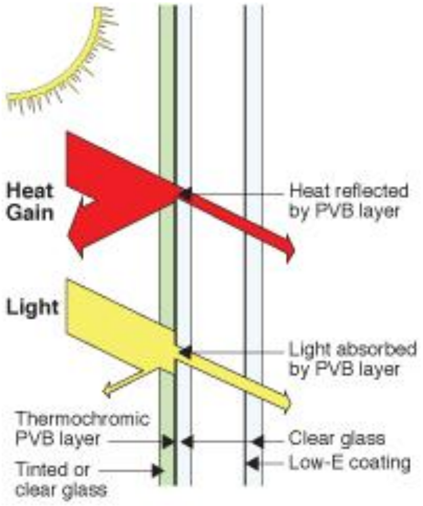

Fig. 2-4 Thermochromic Window, used to reduce solar heat transmission.

Source: http://www.commercialwindows.org/thermochromic.php, (accessed 10-2-2013)

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[15] Attmann, O., (2010), Green Architecture Advanced Technologies and Materials, United States of America, McGraw-Hill.

2.3.2.1.2 Thermotropic materials

In response to heat and temperature changes, thermotropic materials undergo various property transformation, including: conductivity, transmissivity, volumetric expansion, and solubility[16].

There are different thermotropic systems, including casting resins, polymer films, hydrogels, and liquid crystals. Transparent casting resins are used in diverse types of glazing, such as windows, façade elements, and roofs. Thermoplastic polymers are used for existing windows, roof structures, or as laminates for greenhouses and solar panels. Hydrogels are particularly ideal for energy-efficient windows, as they may be used over a wide temperature range[17]. Thermotropic liquid crystals are similar to liquids and crystalline solids. They are used for smart, efficient windows as they can provide privacy without sacrificing incoming light.

Thermotropic windows: window's visibility is directly controlled by climatic temperature changes. If the material's temperature exceeds a certain limit, the thermotropic layer becomes milky white, reflecting a large proportion of the incident light. There are no visual changes to the window at low temperatures.

2.3.2.1.3 Thermoelectric Materials

Thermoelectric is the conversion of electrical energy into thermal energy, which is based on principle called the "Peltier'' effect[18]. Thermoelectric materials are constructed from a series of connected metals. When an electrical current passes through the connections, heat is transferred. In fact, these materials are capable of transferring a large quantity of heat when connected to a heat absorbing device on one side and a heat-dissipating device on the other.

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[16] Addington, M., Schodek, D., (2005), Smart Materials and New Technologies, Oxford, Architectural Press.

[17] Schwartz, M., (2008), Smart Materials, Boca Raton, FL: CRC Press.

[18] Ohta, H., (2007), Thermoelectrics based on strontium titanate, Materials Today, Vol. 10, 10, PP. 44-49.

There are three physical properties that thermoelectric materials need to efficiently turn thermal energy into electric current: low thermal conductivity; high electrical conductivity; large thermo electromotive force[19].

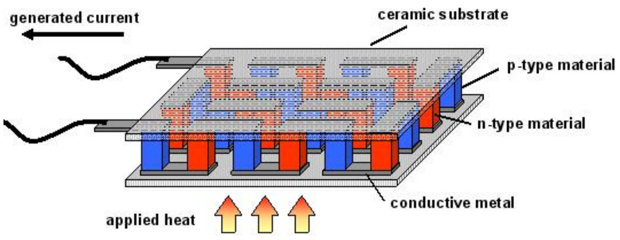

Fig. 2-5 Thermoelectric Modules, used to convert thermal energy into electrical energy.

Source: http://www.ferrotec.com/technology/thermoelectric/, (accessed 10-2-2013)

Thermo electric modules are durable, reliable, silent, lightweight, and compact green materials; they don't include compressed gasses, chemicals, or toxic agents, fig (2-5) shows the thermo electric modules and their components. Currently, because of their relatively high cost and low efficiency, thermoelectric devices are limited to applications in which portability, reliability, and/or small size are more important than their cost such as for the military or aerospace industry.

2.3.2.1.4 Shape Memory Materials

They change their shapes from a rigid form to an elastic state when thermal energy is applied fig.(2-4). When a thermal stimulus is removed, the material reverts back to its original rigid state without degradation. These effects are called "thermal shape memory'' and "superelasticity''[20].

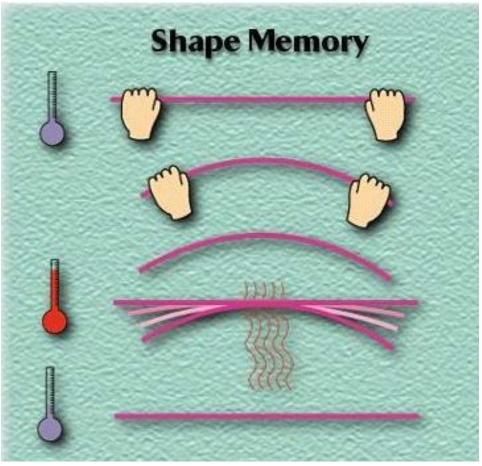

Fig. 2-6 Shape Memory Materials, expressing how can they change their shape when thermal energy is applied.

Source: http://www.talkingelectronics.com/projects/Nitinol/Nitinol-1.html, (accessed 10-2-2013)

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[19] Attmann, O., (2010), Green Architecture Advanced Technologies and Materials, United States of America, McGraw-Hill.

[20] Lagoudas, D., (2008), Shape Memory Alloys, New York, NY: Springer.

There are two classes of shape memory materials, each different shape-changing characteristics: shape memory polymers (SMP) and shape memory alloys (SMA). When exposed to a temperature change, SMPs exhibit a mechanical property loss, as seen in releasable fasteners. By contrast, materials with SMAs provide force[21]. As such, they can become a lightweight, solid-state alternative to conventional actuators, such as hydraulic, pneumatic, and motor-based systems.

The application of shape memory materials spans a wide variety of sectors where their superelastic properties or the shape memory effect can be utilized. In architecture , there are many application, such as shape memory foams that expands when exposed to higher temperature to seal window frames.

Self- accommodating Ventilation Systems : shape memory alloys are used in a self-accommodating ventilation system. Changes in temperature within or outside the building activate the SMAs, operating a louver ventilation system.

Deployable Structures: a new structure system has been developed using shape memory composites that can be temporarily softened, reshaped, and hardened to function as deployable, flexible structures. These materials can be easily stowed for space efficiency, and then later developed to its operational shape[22].

Flexible Surface materials: in their living glass project, David Benjamine and Soo-In Yang used a shape memory alloy to open and close surface[23]. Wire embedded within cast silicone contrast when subjected to an electrical stimulus, casing the surface to open and close.

2.3.2.2 Light-Responsive Materials (LRMs)

They are smart materials that transform due to a change in light[24].

2.3.2.2.1 Photochromic Materials

These materials change their ability to reflect color when exposed to light, and the color change is proportional to its level of UV light absorption. When a photochromic material absorbs UV light, the chemical structure of its molecules changes. This result in reversible color reflections. When the light source is terminated, the material changes

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[21] Attmann, O., (2010), Green Architecture Advanced Technologies and Materials, United States of America, McGraw-Hill.

[22] Attmann, O., (2010), Ibid.

[23] Manfra, L., (2006), Living Breathing Building: Envisioning architecture that performs like natural organisms, Metropolis, 5, PP. 52-54.

[24] Attmann, O., (2010), Green Architecture Advanced Technologies and Materials, United States of America, McGraw-Hill.

back to a clear state. Photochromic materials can also change from one color to another when it is combined with a base color[25].

2.3.2.2.2 Photoluminescent Materials

They absorb radiation from light and convert it into visible light[26]. Photoluminescent Materials are especially used for fluorescent lighting, whose tubes include both electroluminescent (mercury) and photoluminescent (fluorescent coating) components. They are used widely for exist signs and other self-luminous emergency egress indicators as they don’t rely on external sources and require minimal maintenance.

2.3.2.2.3 Photovoltaic (PV)

A photovoltaic system is the process of producing an electrical current in a solid material[27]. It’s used to convert sunlight into electricity. There are two types of solar cell technologies: thin film materials, and crystalline materials. Thin films photovoltaic materials produce solar cells with lower conversion efficiencies. They need less direct sunlight and use less material than crystalline silicon cells[28].

Single crystal silicon cells are made of thin silicon wafers, which are cut from a single silicon crystal. These are the most efficient types of silicon cells and have a long life expectancy. Multicrystal silicon cells are also extremely thin wafer of silicon but are cut from multiple crystals with similar life expectancy and fragility attributes. Multicrystal silicons are slightly less efficient and require more space to produce than single crystal cells. Fig. (2-7) shows the photovoltaic cells.

Fig. 2-7 Photovoltaic cells, used to produce electricity.

Source: <u>http://www.mathematicsmagazine.com/energy/what_are_photovoltaics.htm</u>, (accessed 10-2-2013)

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[25] Attmann, O., (2010), <u>Green Architecture Advanced Technologies and Materials</u>, United States of America, McGraw-Hill.

[26] Addington, M., Schodek, D., (2005), <u>Smart Materials and New Technologies</u>, Oxford, Architectural Press.

[27] Attmann, O., (2010), <u>Green Architecture Advanced Technologies and Materials</u>, United States of America, McGraw-Hill.

[28] Bube, R., (1998), <u>Photovoltaic Materials: Imperial College Press</u>; London, NJ: Distributed by world Scientific Publishing Company, River Edge.

2.3.2.3 Stimulus (Force)-Responsive Materials (SRMs)

They are smart materials that transform due to a change in external stimulants, such as electricity, mechanical force, and kinetic energy[29].

2.3.2.3.1 Electrochromic Materials

Electrochromic is the ability of a material to transmit light due to a change in electrical current[30]. The optical properties are reversible, and the material reverts to its original state once thecurrent is removed. As such, electrochromic materials are the primary choice for visual devices, such as smart windows, light shutters, information displays, reflectance mirrors, and thermal radiators[31].

In architecture this material used in smart windows for its energy efficiency and thermal comfort. The transparency/ opacity level is adjusted by an applied voltage. Fig. (2-8) shows the electrochromic window and how it convert light into electric current.

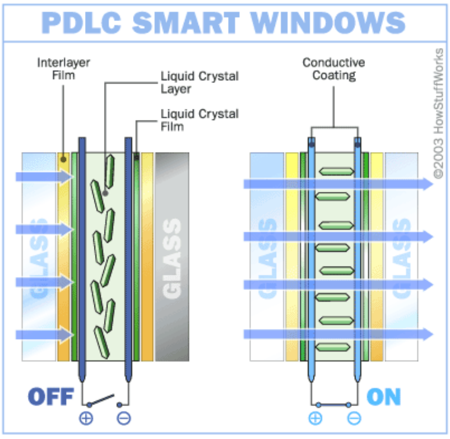

Fig. 2-8 Electrochromic Window, used to transmit light during electric current change.

Source: http://cantilever.wordpress.com/about innovation/switchable-glazing-on-the-verge/, (accessed 10-2-2013)

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[29] Attmann, O., (2010), Green Architecture Advanced Technologies and Materials, United States of America, McGraw-Hill.

[30] Attmann, O., (2010), Ibid.

[31] Granqvist, C., (1995), Handbook of Inorganic electrochromic materials, Amesterdam; New York, Ny: Elsevier.

2.3.2.3.2 Electrostrictive Materials

They change in size in response to an electric field and produce electricity when stretched[32]. These materials are primarily used as precision control systems such: as vibration control, and dynamic loading in building construction. They are also used as transducers for a variety of electric power generation applications, such as acoustic actuators for smart skins and micro-actuators for micro-pumps and valves.

2.3.2.3.3 Piezoelectric Materials

They generate an electrical current in response to an applied mechanical stress. Piezoelectric are bidirectional, meaning an applied input produces a deformation[33]. They are used in electromechanical devices such as: microphone transducers, speakers, ceramic tweeters, buzzers, medical ultrasound imaging, and underwater sonar devices.

Smart Materials Types (Second Classification)	**Thermo-Responsive Materials**	**Light-Responsive Materials**	**Stimulus (force) Responsive Materials**
Definition	Materials undergo transformations due to the changes in temperature.	Materials respond to change in uv light.	These materials undergo transformations due to external stimulants such as electricity, mechanical force, magnetic force, and kinetic force.
Types	Thermo-Chromic Thermotropic Thermoelectric Shape memory	Photochromic Photovoltaic photoluminescent	Electrochromic Electrostrictive Piezoelectric

Table 2-2 Smart Materials Types (Second Classification).

Source: Author, according to: Attmann, O., (2010)

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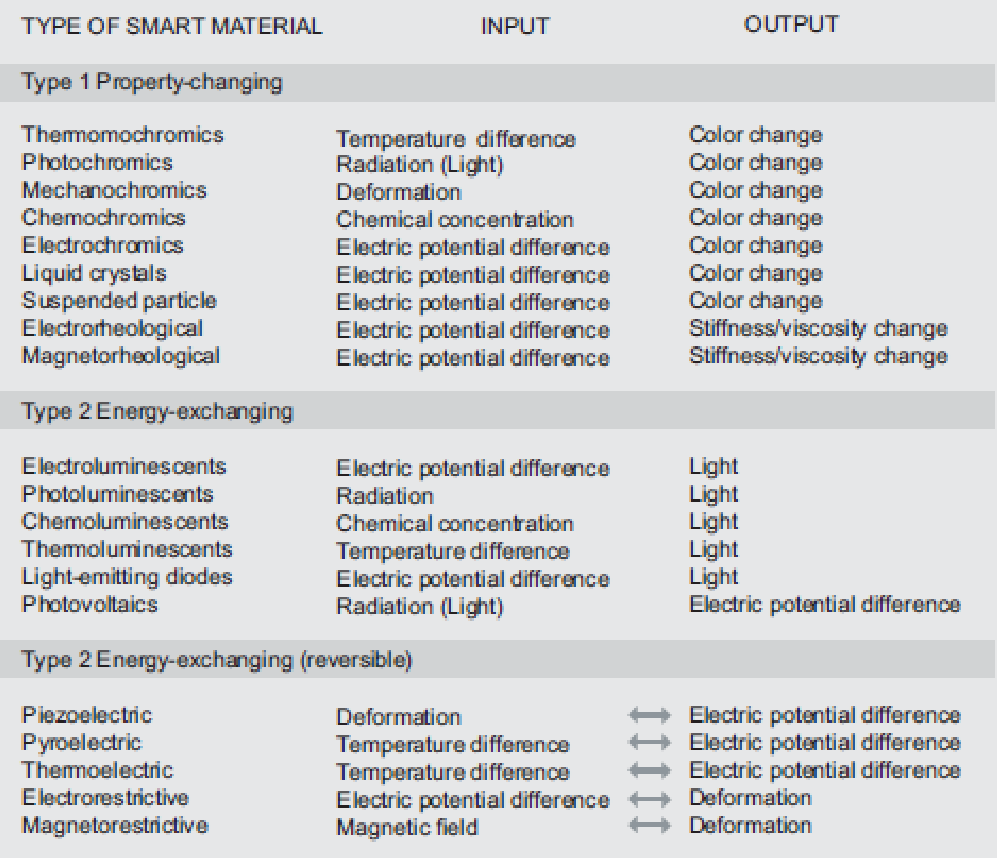
[32] Attmann, O., (2010), Green Architecture Advanced Technologies and Materials, United States of America, McGraw-Hill.

[33] Addington, M., Schodek, D., (2005), Smart Materials and New Technologies, Oxford, Architectural Press.

2.3.3 Third classification:

categorize them in relation to their actions and their energy stimulus. The physical characteristics of smart materials are determined by the energy fields (chemical, electrical, mechanical, thermal, …) and the mechanism through which this energy input to a material is converted. If the mechanism affects the internal energy of the material by altering either the material's molecular structure or microstructure then the input results in a property change of the material. If the mechanism changes the energy state of the material, but does not alter the material itself, then the input results in an exchange of energy from one form to another. Based on this approach, smart materials can be classified in two basic ways, Type 1 smart materials property-changing materials, and Type 2 smart materials energy-exchanging[34]. Fig. (2-9) shows different types of Type1 and Type2 in relation to input and output stimuli.



TYPE OF SMART MATERIAL	INPUT		OUTPUT
Type 1 Property-changing			
Thermomochromics	Temperature difference		Color change
Photochromics	Radiation (Light)		Color change
Mechanochromics	Deformation		Color change
Chemochromics	Chemical concentration		Color change
Electrochromics	Electric potential difference		Color change
Liquid crystals	Electric potential difference		Color change
Suspended particle	Electric potential difference		Color change
Electrorheological	Electric potential difference		Stiffness/viscosity change
Magnetorheological	Electric potential difference		Stiffness/viscosity change
Type 2 Energy-exchanging			
Electroluminescents	Electric potential difference		Light
Photoluminescents	Radiation		Light
Chemoluminescents	Chemical concentration		Light
Thermoluminescents	Temperature difference		Light
Light-emitting diodes	Electric potential difference		Light
Photovoltaics	Radiation (Light)		Electric potential difference
Type 2 Energy-exchanging (reversible)			
Piezoelectric	Deformation	⟷	Electric potential difference
Pyroelectric	Temperature difference	⟷	Electric potential difference
Thermoelectric	Temperature difference	⟷	Electric potential difference
Electrorestrictive	Electric potential difference	⟷	Deformation
Magnetorestrictive	Magnetic field	⟷	Deformation

Fig. 2-9 Sampling of different Type 1 and Type 2 smart materials in relation to input and output stimuli.

Source: Addington, M., Schodek, D., (2005)

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[34] Addington, M., Schodek, D., (2005), Smart Materials and New Technologies, Oxford, Architectural Press.

2.3.3.1 Type 1 Smart Materials-Property-Changing

a material that changes one of its properties (chemical, mechanical, optical, electrical, magnetic or thermal) in response to a change in the conditions of its environment and does so without the need of external control[35].

2.3.3.1.1 Chromics or 'Color-Changing' Smart Materials

color-changing materials change color. They change their optical properties under different external stimuli (e.g., heat, light or a chemical environment), which we often perceive as a color change. The main classes of color-changing smart materials are described by the nature of the input energy that causes the property change, and include photochromics, electrochromics, thermochromics, mechanochromics, and chemochromics.

Mechanochromics: materials that change color due to imposed stresses and/or deformations.

Chemochromics: materials that change color when exposed to specific chemical environments.

Photochromics: materials that change color when exposed to light[36]. Its intensity depends upon the directness of exposure. It reverts to its original colorless state in the dark when there is no sunlight. In architecture, they have been used in various window as shown in fig. (2-10) or facade treatments, to control solar gain and reduce glare.

Fig. 2-10 Photochromic Window, used to change color when exposed to light.

Source :http://www.glassonweb.com/articles/article/520/, (accessed 17-1-2013)

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[35] Addington, M., Schodek, D., (2005), Smart Materials and New Technologies, Oxford, Architectural Press.

[36] Addington, M., Schodek, D., (2005), Smart Materials and New Technologies, Oxford, Architectural Press.

Thermochromic Materials: They have properties that undergo reversible changes when the surrounding temperature is changed. Thermochromic materials come in many forms, including liquid crystal forms used in thermochromic films and the leucodyes used in many other applications. Films are used in applications such as battery testers, thermometers. Fig. (2-11) shows the memories of touch via thermochromic materials.

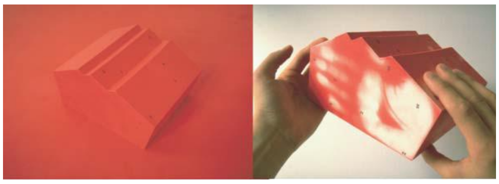

Fig. 2-11 Memories of touch via thermochromic materials.

Source: Addington, M., Schodek, D., (2005)

Electrochromic Materials: materials that change color when a voltage is applied. There are three main classes of materials that change color when electrically activated: electrochromics, liquid crystals and suspended particles[37]. Fig. (2-12) shows how the color of electrochromic glass changes when a voltage applied.

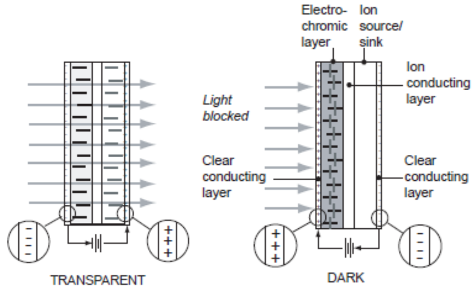

Fig. 2-12 Electrochromic Glass, expressing how color change when a voltage applied.

Source: Addington, M., Schodek, D., (2005)

2.3.3.1.2 Phase Changing Materials

Phase change processes invariably involve the absorbing, storing or releasing of large amounts of energy in the form of latent heat. A phase change from a solid to a liquid, or liquid to a gas, and vice versa, occurs at precise temperatures. These processes are reversible and phase-changing materials can undergo an unlimited number of cycles without degradation. Fig. (2-13) express the different phases of phase change transformation.

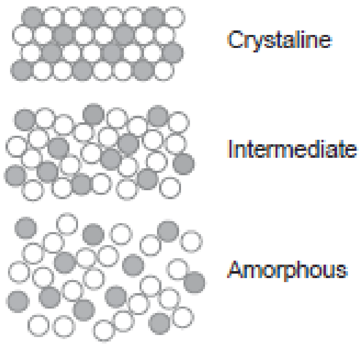

Fig. 2-13 Phase change transformation, expressing their different phases.

Source: Addington, M., Schodek, D., (2005)

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[37] Addington, M., Schodek, D., (2005), Smart Materials and New Technologies, Oxford, Architectural Press.

2.3.3.1.3 Conducting Polymers and other Smart Conductors

Polymers can be made conductive by the direct addition of conductive materials (e.g., graphite, metal oxide particles) into the material. There are other polymers whose electrical conductivity is intrinsic. Electroactive polymers change their electrical conductivity in response to a change in the strength of an electrical field applied to the material. Some polymers exhibit semiconductor behavior and can be light-emitting. Electrochemical polymers exhibit a change in response to the strength of the chemical environment .

Other smart conductors include photoconductors and photoresistors that exhibit changes in their electrical conductivity when exposed to a light source. Pyroconductors are materials whose conductivities are temperature-dependent, and can have minimal conductivity near certain critical low temperatures. Magnetoconductors have conductivities responsive to the strength of an applied magnetic field.

2.3.3.1.4 Liquid Crystal Technologies

Liquid crystals are an intermediate phase between crystalline solids and isotropic liquids. They are orientationally ordered liquids with anisotropic properties that are sensitive to electrical fields, and therefore are particularly applicable for optical displays. Liquid crystal displays utilize two sheets of polarizing material with a liquid crystal solution between them, as shown in fig. (2-14). An electric current passed through the liquid causes the crystals to align so that light cannot pass through them. Each crystal is like a shutter, either allowing light to pass through or blocking the light.

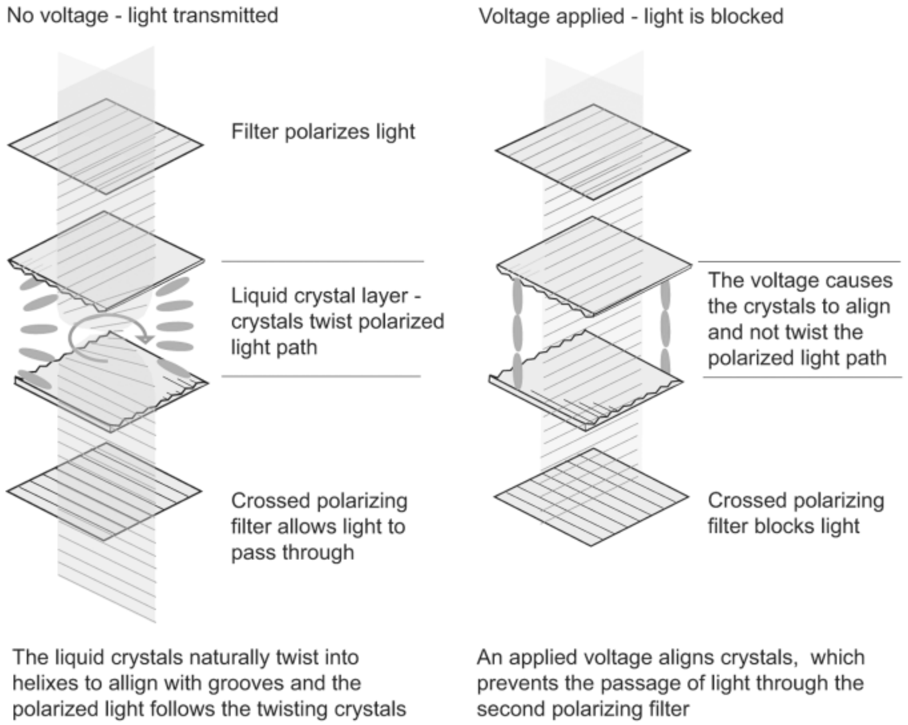
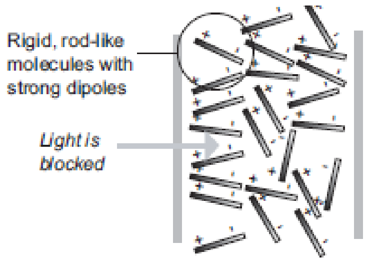


Fig. 2-14 A liquid crystal display (LCD) uses two sheets of polarizing material and a liquid crystal solution sandwiched in between them.

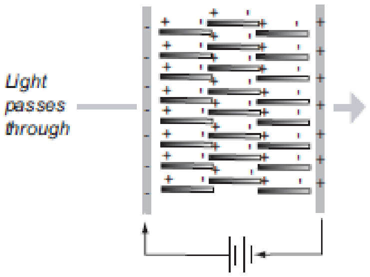
Source: Addington, M., Schodek, D., (2005)

2.3.3.1.5 Suspended Particle Displays

These displays are electrically activated and can change from an opaque to a clear color instantly and vice-versa. A typical suspended particle device consists of multiple layers of different materials. The active layer associated with color change has needle-shaped particles suspended in a liquid. This active layer is sandwiched between two parallel conducting sheets, as shown in fig. (2-15). When no voltage is applied, the particles are randomly positioned and absorb light. An applied voltage causes the particles to align with the field. When aligned, light transmission is greatly increased through the composite layers. the color or transparency level remains at the last setting when voltage was applied or turned off. A constant voltage need not be applied for the state to remain.



Particles suspended in film between two clear conducting layers align randomly in the absence of an electric field, absorbing light



Application of an electric field causes individual molecules to orient similarly, thus allowing light to pass through

Fig. 2-15 Suspended particle display, expressing changing color from opaque to clear and vice versa.

Source: Addington, M., Schodek, D., (2005)

2.3.3.1.6 Rheological Property-Changing Materials

The term ‘rheological’ generally refers to the properties of flowing matter, notably fluids and viscous materials. Many of these materials are termed ‘field dependent’. Specifically, they change their properties in response to electric or magnetic fields. Most of these fluids are so-called ‘structured fluids’’ with colloidal dispersions that change phase when subjected to an electric or magnetic field. Accompanying the phase change is a change in the properties of the fluid[38]. When an external electric field is applied to an electrorheological.

Fluid, the viscosity of the fluid increases remarkably. When the electric field is removed, the viscosity of the fluid reverts to its original state. Magnetorheological fluids behave similarly in response to a magnetic field.

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[38] Addington, M., Schodek, D., (2005), Smart Materials and New Technologies, Oxford, Architectural Press.

2.3.3.2 Type 2 Smart Materials-Energy-Exchanging

a material or device that transforms energy from one form to another to effect a desired final state. Many of the energy-exchanging materials are also bidirectional– the input energy and output energy can be switched. the energy-exchange materials are almost always composite materials – exceptions include magnetostrictive iron and naturally occurring piezoelectric quartz[39].

2.3.3.2.1 Light-Emitting Materials (Luminescence, fluorescence and phosphorescence)

A definition of luminescence: is the emitted light that is not caused by incandescence, but rather by some other means, such as chemical action. Luminescence is the general term used to describe different phenomena based on emitted light. If the emission occurs more or less instantaneously, the term fluorescent is used. If the emission is slower or delayed to several microseconds or milliseconds, the term phosphorescence is used[40].

Photoluminescence: generally refers to a kind of luminescence that occurs when incident energy associated with an external light source acts upon a material that then re-emits light at a lower energy level.

Chemoluminescence: the excitation comes from a chemical action of one type or another.

Electroluminescence: With electroluminescent materials the source of excitation is an applied voltage or an electric field. Electroluminescent materials are widely used for light strips and panels of all descriptions. Electroluminescent lamps are becoming widely used. They draw little power and generate no heat.

2.3.3.2.2 Basic Semiconductor Phenomena

Basic semiconductor materials, such as silicon, are neither good conductors nor good insulators, but, with the addition of small impurities called dopants, they can be made to possess many fascinating electrical properties. The addition of these dopants or impurities allows electron movements to be precisely controlled. Exploitation of the resultant properties has allowed a semiconductor to serve the same functions as complicated multipart electronic circuitries.

Basic semiconducting materials exhibit interesting properties when surrounding temperatures are varied. Unlike most metals wherein increases in temperatures cause

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[39] Addington, M., Schodek, D., (2005), Smart Materials and New Technologies, Oxford, Architectural Press.

[40] Addington, M., Schodek, D., (2005), Ibid.

increases in resistance, the conductivity of semiconducting materials increases with increasing temperatures.

2.3.3.2.3 Photovoltaic, Led, Transistors, Thermoelectric

A photovoltaic device: consists primarily of a p and n junction. There is an incident energy (typically solar) that acts on the junction and provides the external energy input, as shown in fig. (2-16). In typical solar cells, the n layer is formed on top of the p layer. Incident energy impinges on the n layer. This incident energy causes a change in electron levels that in turn causes adjacent electrons to move because of electrostatic forces. This movement of electrons produces a current flow. Phototransistors are similar in that they convert radiant energy from light into a current.

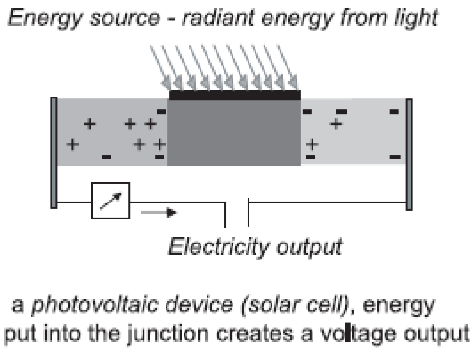

Fig. 2-16 Photovoltaic Device, expressing changing solar energy into electric energy.

Source: Addington, M., Schodek, D., (2005)

Common LEDs (light-emitting diodes): are based essentially on the converse of photovoltaic effects. An LED is a semiconductor that luminance when a current passes through it, as shown in fig. (2-17). It is basically the opposite of a photovoltaic cell.

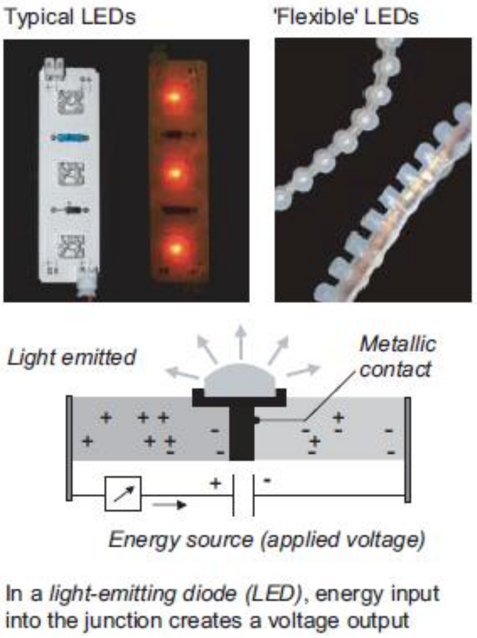

Fig. 2-17 Light emitting diodes (LED) are based on semiconductor technologies.

Source: Addington, M., Schodek, D., (2005)

Transistors: are similarly based on semiconductor technologies. Fundamentally, a transistor can be used as a signal amplification device, or as a switching device.

Thermoelectrics or Peltier devices: are an electronic form of heat pump. A typical Peltier device uses a voltage input to create hot and cold junctions, hence they can be used for heating or cooling. They are found in computers as cooling devices, and in common automotive and household goods as small heaters or coolers.

2.3.3.2.4 Piezoelectric Effects and Materials

When an applied mechanical force produces a deformation that in turn produces an electric voltage, or, conversely, an applied voltage that causes a mechanical deformation in the material that can be used to produce a force. This general phenomenon is called the piezoelectric effect[41].

The phenomenon is based upon a reversible energy conversion between electrical and mechanical forms that occurs naturally in permanently polarized materials in which parts of molecules are positively charged and other parts are negatively charged. Fig. (2-18) shows the deformation produced by piezoelectric behavior when an electric voltage applied.

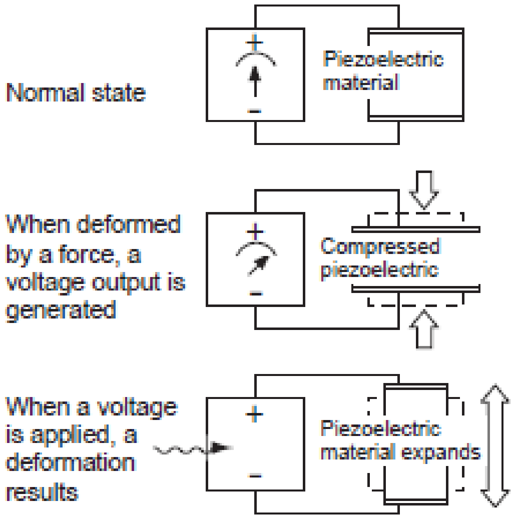

Fig. 2-18 Piezoelectric behavior, produce deformation when applying electric voltage.

Source: Addington, M., Schodek, D., (2005)

In piezoelectric materials, each cell or molecule is a dipole with a positive and negative charges onto either end. There is an alignment of the internal electric dipoles. This alignment can result in a surface charge, but this charge is neutralized by free charges present in the surrounding atmosphere. A force is applied to the piezoelectric material that causes deformations to take place, which in turn alters the neutralized state of the surface by changing the orientation of the dipoles.

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[41] Addington, M., Schodek, D., (2005), Smart Materials and New Technologies, Oxford, Architectural Press.

2.3.3.2.5 Shape Memory Alloys

Shape memory effect refers to the ability of a particular kind of alloy material to revert, or remember, a previously memorized or preset shape[42]. The characteristic derives from the phase-transformation characteristics of the material. A solid state phase change – a molecular rearrangement – occurs in the shape memory alloy that is temperature-dependent and reversible. The phenomenon of superelasticity – the ability of a material to undergo enormous elastic or reversible deformations – is also related to the shape memory effect.

Nickel–titanium (NiTi) alloys are commonly used in shape memory applications, although many other kinds of alloys also exhibit shape memory effects. These alloys can exist in final product form in two different temperature-dependent crystalline states or phases. The primary and higher temperature phase is called the austenite state. The lower temperature phase is called the martensite state. The physical properties of the material in the austenite and martensite phases are quite different. The material in the austenite state is strong and hard, while it is soft and ductile in the martensite phase. The

Austenite crystal structure is a simple body-centered cubic structure, while martensite has a more complex rhombic structure.

The thermally induced shape memory effect is associated with these different phases. In the primary high temperature environment, the material is in the austenite phase. Upon cooling the material becomes martensitic. No obvious shape change occurs upon cooling, but now the material can be mechanically deformed. It will remain deformed while it is cool. Upon heating, the austenitic structure again appears and the material returns to its initial shape. A related mechanically induced phenomenon called superelasticity can also take place. The application of a stress to a shape memory alloy being deformed induces a phase transformation from the austenite phase to the martensite phase (which is highly deformable). The stress causes martensite to form at temperatures higher than previously and there is high ductility associated with the martensite. The associated strains or deformations are reversible when the applied stress level is removed and the material reverts back to austenite.

2.3.3.2.6 Shape Memory Polymers

Alloys are not the only materials to exhibit shape memory effects. A major effort has been recently directed with considerable success to engineering polymers to have the same effects. Applications are enormous, since polymers can be easily fabricated in a number of different forms. Medical applications, for example, include the development of shape memory polymeric strands to be used in surgical operations as self-tying knots.

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[42] Addington, M., Schodek, D., (2005), Smart Materials and New Technologies, Oxford, Architectural Press.

Smart Materials Types (Third Classification)	**Type 1 Smart Materials-Property-Changing**	**Type 2 Smart Materials-Energy-Exchanging**
Definition	Materials that change one of their properties (chemical, mechanical, optical, electrical, magnetic or thermal) in response to a change in the conditions of their environment and does so without the need of external control.	Materials or devices that transform energy from one form to another to effect a desired final state.
Types	Chromics or 'Color-Changing' Smart Materials. Conducting Polymers and other Smart Conductors. Rheological Property-Changing Materials. Suspended Particle Displays. Liquid Crystal Technologies. Phase Changing Materials.	Light-Emitting Materials. Basic Semiconductor Phenomena. Photovoltaic, Thermoelectric Transistors, Led. Piezoelectric Effects and Materials. Shape Memory Alloys. Shape Memory Polymers.

Table 2-3 Smart Materials Types (Third Classification).

Source: Author, according to: Addington, M., Schodek, D., (2005)

2.3.4 Comparison between the Three Types of Classifications

This table shows a comparison between different types characterization of smart materials that were mentioned previously, according to what their classification based on, and the types of each classification. From this comparison we can come to a conclusion that the first type of classification is more specialized from architectural point of view as it helps the architects to recognize the different types of smart materials as its more detailed.

Points of Comparison	**First Classification**	**Second classification**	**Third classification**
Classifications based on	Based on the point of view of their importance in the context of realized or future architectural applications.	Based on their inherent properties, molecular alterations, and the embedded control systems.	Based on their relation to their actions and their energy stimulus.
Types	Shape changing smart materials Color and optically smart materials Adhesion changing smart materials Light emitting smart materials Electricity generating smart materials Energy exchanging smart materials Matter exchanging smart materials	Thermo-Responsive materials Light-Responsive materials Stimulus (Force) Responsive materials	Type 1 Smart Materials-Property-Changing Type 2 Smart Materials-Energy-Exchanging

Table 2-4 Comparison between different Classification of smart materials

Source: Author

2.4 Conclusions

From smart materials definitions we can conclude those materials can sense and respond to the surrounding environment, they also have a changeable properties and these changes can be reversible.

Smart materials have four main fundamental characteristics: property change capability, energy exchange capability, discrete size/location, and reversibility.

Smart materials have three types characterization, the first classification based on the point of view of their importance in the context of architectural applications, second classification which based on their inherent properties, molecular alterations, and the embedded control systems, and the third classification that based on smart materials in relation to their actions and their energy stimulus.

APPLICATIONS OF SMART MATERIALS IN BUILDINGS IN ARID REGIONS

3.1 Introduction

Since the beginning of time, man has been affected by climate and its influence over the earth. The first humans built shelters and lived in caves to protect themselves from the weather elements.

In general, a building usually designed to withstand a portable combination of climatic extremes and to make indoor conditions comfortable and healthful regardless of weather conditions outside. With the help of new climate technology, many developing countries are making use of climate-responsive architecture and its benefits in helping to keep humans comfortable. Each region of the world employs its own techniques and designs in its buildings that are better suited to that particular region and that encompass the region’s cultural patterns.

Hot climate-responsive architecture uses special techniques and designs to help get the most benefit out of the natural environment. Architects who use climate-responsive architecture builds their creations with the intent on taking advantage of the surrounding environment and the average climate conditions of the region. Around the world architects are continuously expanding and inventing new ideas that make use of the natural environment and its extraordinary effects on the way humans live comfortably in their homes and workplaces.

Today, there are new materials and new knowledge about the interaction between the indoor climate and the outdoor environment. These new developments provide architectural solutions which can yield more comfortable indoor and outdoor climate than the experienced in traditional buildings.

This chapter analyzed the outdoor condition in hot arid climate, to understand the problems of overheating and discomfort due to high temperature and solar radiation. In arid climates, the main problems are the dry air with a large diurnal temperature variation, the low relative humidity and precipitation, and the high solar radiation which leads to a very high risk of overheating, and show how can smart products, components, systems solve the arid problems. The second part of this chapter focuses on identifying the actions and effects of smart materials and their products, components, and systems, and showing how they can solve building Problems in arid regions.

3.2 Effect of Climate on Buildings

Climate produces observed effects on architectural forms. For example, the proportion of window area to wall area becomes less as one moves toward the equator. In warm areas, people shun the glare and heat of the sun, as demonstrated by the decreasing size of the windows. In the subtropical and tropical zones, more distractive changes in architectural from occur to meet the problems caused by excessive heat.

The gabled roof decreases as the rate of precipitation decrease. In Northern Europe and most districts subjected to heavy snow, the gables are steep, while in the sunny lands of the south, the pitch steadily decreases[1]. Fig. (3-1) shows the using of steep roofs in cold regions.

Fig. 3-1 shows the using of steep roofs in building in cold regions.

Source:http://featured.matternetwork.com/2009/10/cool-energys-solarheart-brings-solar.cfm , accessed (24-4-2013)

Roofs in Hot Dry Climates: As rainwater run-off is no major requirement, flat roofs are most common. Vaults and dome shaped roofs are also common, providing good thermal comfort. Fig. (3-2) shows the different types of roofs that can be used in hot regions.

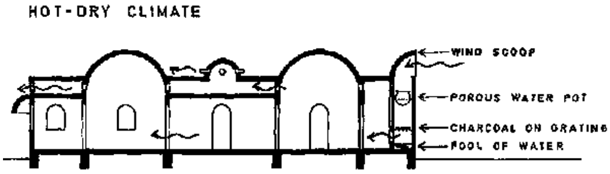

Fig. 3-2 shows the using of vaults, domes, and flat roofs in buildings in hot regions.

Source:http://collections.infocollections.org/ukedu/en/d/Jsk01ae/4.4.html, accessed (24-4-2013)

3.2.1 Climate Classification and Climatic Regions of the World

The Köppen Climate Classification System is the most widely used system for classifying the world's climates. Its categories are based on the annual and monthly averages of temperature and precipitation. The Köppen system recognizes five major climatic type[2] as shown in fig. (3-3):

A - Tropical Moist Climates: all months have average temperatures above 18° Celsius.

B - Dry Climates: with deficient precipitation during most of the year.

C - Moist Mid-latitude Climates with Mild Winters.

D - Moist Mid-Latitude Climates with Cold Winters.

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[1] Fathy, H., (1986), Natural Energy and Vernacular Architecture: Principles and Examples with Reference to Hot Arid Climate, London, the University of Chicago Press.

[2] Pidwirny, M.,(2006), Fundamentals of Physical Geography, 2nd Edition, http://www.physicalgeography.net/fundamentals/7v.html , (accessed: 21-4-2013).

E - Polar Climates: with extremely cold winters and summers.

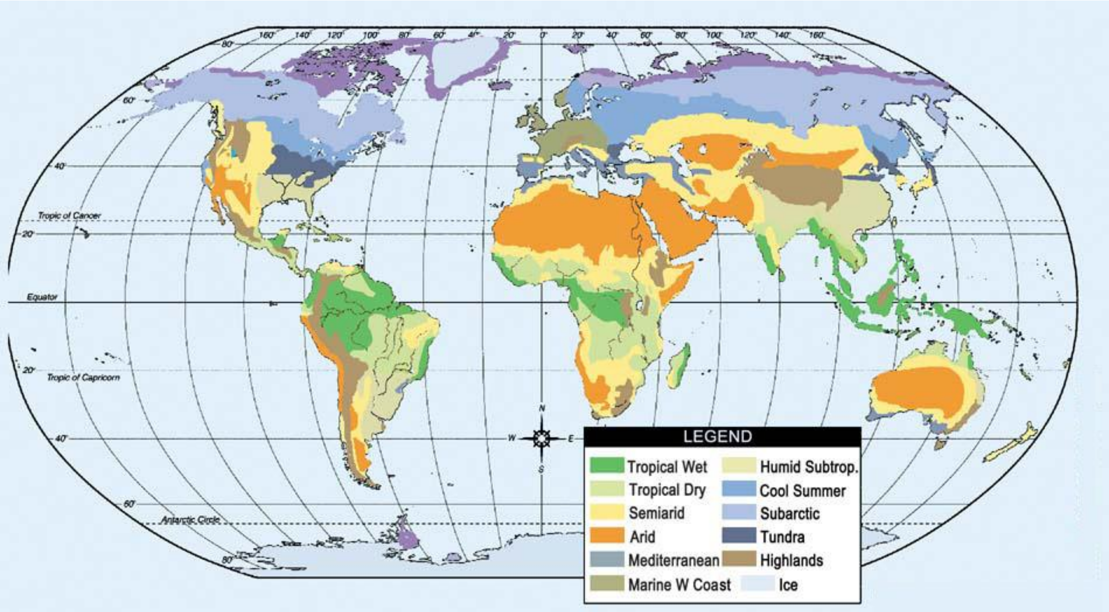

Fig. 3-3 World Climate Zones, expressing the different climatic zones.

Source: http://www.dessertseed.com/Our%20Climatic%20Zone%20Map%20Section.htm, accessed (19-7-2013)

3.2.1.1 Tropical Moist Climates (A)

Tropical moist climates extend northward and southward from the equator to about 15 to 25° of latitude. In these climates all months have average temperatures greater than 18° Celsius. Annual precipitation is greater than 1500 mm. Three minor Köppen climate types exist in the A group, and their designation is based on seasonal distribution of rainfall. Af or tropical wet is a tropical climate where precipitation occurs all year long. Monthly temperature variations in this climate are less than 3° Celsius. Because of intense surface heating and high humidity, cumulus and cumulonimbus clouds form early in the afternoons almost every day. Daily highs are about 32° Celsius, while night time temperatures average 22° Celsius. Am is a tropical monsoon climate. Annual rainfall is equal to or greater than Af, but most of the precipitation falls in the 7 to 9 hottest months. During the dry season very little rainfall occurs. The *tropical wet and dry* or savanna (Aw) has an extended dry season during winter. Precipitation during the wet season is usually less than 1000 millimeters, and only during the summer season[3].

3.2.1.2 Dry Climates (B)

The most obvious climatic feature of this climate is that potential evaporation and transpiration exceed precipitation. These climates extend from 20 - 35° North and

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[3] Pidwirny, M.,(2006), Fundamentals of Physical Geography, 2nd Edition, http://www.physicalgeography.net/fundamentals/7v.html , (accessed: 21-4-2013).

South of the equator and in large continental regions of the mid-latitudes often surrounded by mountains. Minor types of this climate include:BW - dry arid (desert) is a true desert climate. It covers 12% of the Earth's land surface and is dominated by xerophytic vegetation. The additional letters h and k are used generally to distinguish whether the dry arid climate is found in the subtropics or in the mid-latitudes, respectively. BS - dry semiarid (steppe). Is a grassland climate that covers 14% of the Earth's land surface. It receives more precipitation than the BW either from the intertropical convergence zone or from mid-latitude cyclones. Once again, the additional letters h and k are used generally to distinguish whether the dry semiarid climate is found in the subtropics or in the mid-latitudes, respectively[4].

3.2.1.3 Moist Subtropical Mid-Latitude Climates (C)

This climate generally has warm and humid summers with mild winters. Its extent is from 30 to 50° of latitude mainly on the eastern and western borders of most continents. During the winter, the main weather feature is the mid-latitude cyclone. Convective thunderstorms dominate summer months. Three minor types exist: Cfa - humid subtropical; Cs - Mediterranean; and Cfb - marine. The humid subtropical climate (Cfa) has hot muggy summers and frequent thunderstorms. Winters are mild and precipitation during this season comes from mid-latitude cyclones. A good example of a Cfa climate is the southeastern USA. Cfb marine climates are found on the western coasts of continents. They have a humid climate with short dry summer. Heavy precipitation occurs during the mild winters because of the continuous presence of mid-latitude cyclones. Mediterranean climates (Cs) receive rain primarily during winter season from the mid-latitude cyclone. Extreme summer aridity is caused by the sinking air of the subtropical highs and may exist for up to 5 months. Locations in North America are from Portland, Oregon to all of California[5].

3.2.1.4 Moist Continental Mid-latitude Climates (D)

Moist continental mid-latitude climates have warm to cool summers and cold winters. The location of these climates is pole ward of the C climates. The average temperature of the warmest month is greater than 10° Celsius, while the coldest month is less than -3° Celsius. Winters are severe with snowstorms, strong winds, and bitter cold from Continental Polar or Arctic air masses. Like the C climates there are three minor types: Dw - dry winters; Ds - dry summers; and Df - wet all seasons[6].

3.2.1.5 Polar Climates (E)

Polar climates have year-round cold temperatures with the warmest month less than 10° Celsius. Polar climates are found on the northern coastal areas of North

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[4] Pidwirny, M.,(2006), Fundamentals of Physical Geography, 2nd Edition, http://www.physicalgeography.net/fundamentals/7v.html , (accessed: 21-4-2013).

[5] Pidwirny, M.,(2006),Ibid.

[6] Pidwirny, M.,(2006), *Ibid.*

America, Europe, Asia, and on the landmasses of Greenland and Antarctica. Two minor climate types exist. ET or polar tundra is a climate where the soil is permanently frozen to depths of hundreds of meters, a condition known as permafrost. Vegetation is dominated by mosses, lichens, dwarf trees and scattered woody shrubs. EF or polar ice caps has a surface that is permanently covered with snow and ice[7].

3.2.2 The Arid Environments

Arid ecosystems occur in regions less than 254 mm of annual rainfall, or sometimes in hot regions where there is more rainfall but where it is unevenly distributed in the annual cycle. The arid zone has a common characteristic in that the climate everywhere is too dry[8].

3.2.2.1 Meaning of aridity

The term Arid is defined in the Webster's New World Dictionary as dry and barren. Aridity is defined as an expression of water deficiency is also influenced by factors such as soil moisture and permeability, evaporation, transpiration by plants, and the intensity and duration of sunlight and wind[9].

Aridity is usually expressed as a function of rainfall and temperature. A useful "representation" of aridity is the following climatic aridity index: p/ETP, where P = precipitation ETP = potential evapotranspiration, calculated by method of Penman, taking into account atmospheric humidity, solar radiation, and wind[10].

Arid lands are part of dry lands. Dry lands are areas with limited water resources[11].

3.2.2.2 Aridity Zones Distribution

Aridity zones cover almost 61 million square kilometers of the globe. These aridity zones spread across all continents, but are found most predominantly in Asia and Africa[12]. As shown in fig. (3-4) there are three arid zones can be delineated by this

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[7] Pidwirny, M.,(2006), Fundamentals of Physical Geography, 2nd Edition, http://www.physicalgeography.net/fundamentals/7v.html , (accessed: 21-4-2013).

[8] Hamed, S., (2002), Landscape Planning For the Arid Middle East: An approach to Setting Environmental Objectives, Lewiston, Edwin Mellen Press.

[9] Hamed, S., (2002), Ibid.

[10] Food and Agriculture Organization of the United Nations, (1989), Arid zone forestry: A guide for field technicians, Rome, Food and Agriculture Organization of the United Nations.

[11] White, P., (2002), An Ecosystem Approach to Drylands: Building Support for New Development Policies, Washington, World Resource Institute.

[12] Mohamed Abd-Elaal, M., (2008), Renewable Energy And Sustainable Urban Development In Hot Rid Regions: Case of Egypt, Ph.D, university of Stuttgart.

index: namely, hyper-arid, arid and semi-arid. Of the total land area of the world, the hyper-arid zone covers 4.2 percent, the arid zone 14.6 percent, and the semiarid zone 12.2 percent. Therefore, almost one-third of the total area of the world is arid land[13].

3.2.2.2.1 The hyper-arid zone

Its arid index 0.03, comprises dry land areas without vegetation, with the exception of a few scattered shrubs. True nomadic pastoralism is frequently practiced. Annual rainfall is low, rarely exceeding 100 millimeters. The rains are infrequent and irregular, sometimes with no rain during long periods of several years[14].

3.2.2.2.2 The arid zone

Its arid index 0.03-0.20, is characterized by pastoralism and no farming except with irrigation. For the most part, the native vegetation is sparse, being comprised of annual and perennial grasses and other herbaceous vegetation, and shrubs and small trees. There is high rainfall variability, with annual amounts ranging between 100 and 300 millimeters[15].

3.2.2.2.3 The semi-arid zone

Its arid index 0.20-0.50 can support rain-fed agriculture with more or less sustained levels of production. Sedentary livestock production also occurs. Native vegetation is represented by a variety of species, such as grasses and grass-like plants, fortes and half-shrubs, and shrubs and trees. Annual precipitation varies from 300-600 to 700-800 millimeters, with summer rains, and from 200-250 to 450-500 millimeters with winter rains[16].

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[13] Food and Agriculture Organization of the United Nations, (1989), Arid zone forestry: A guide for field technicians, Rome, Food and Agriculture Organization of the United Nations.

[14] Food and Agriculture Organization of the United Nations, (1989), Ibid.

[15] Food and Agriculture Organization of the United Nations, (1989), Ibid.

[16] Food and Agriculture Organization of the United Nations, (1989), Ibid..

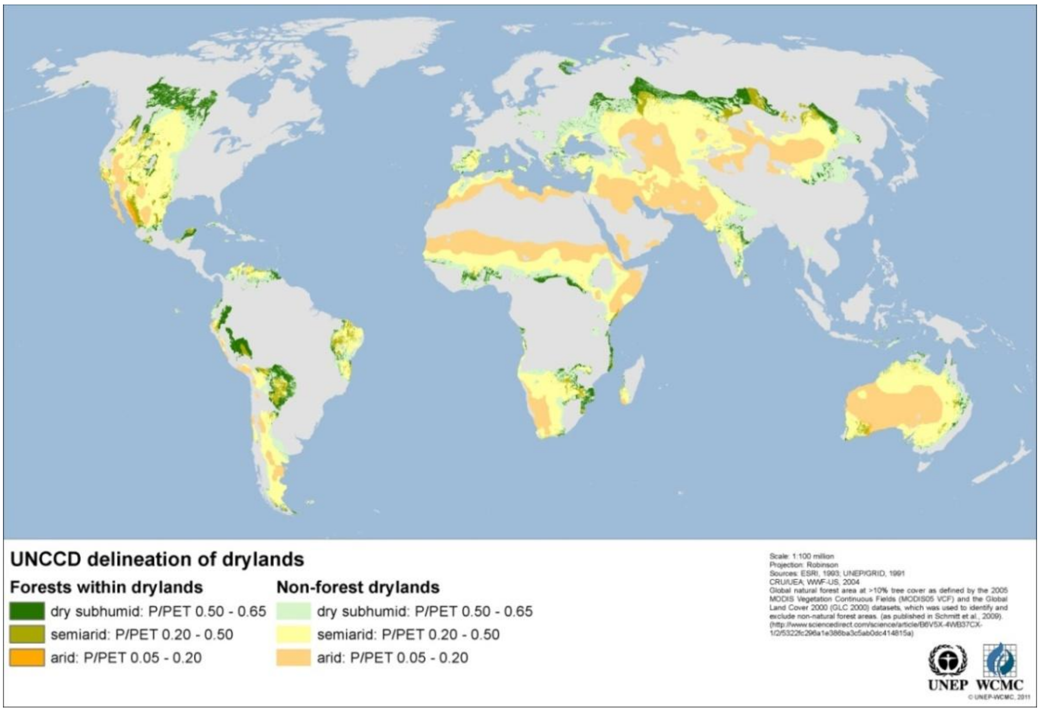

Fig. 3-4 Aridity Climate Zones, expressing the different arid zones.

Source: http://www.unccd.int/en/programmes/Event-and-campaigns/WDCD/2011/Pages/default.aspx, accessed (25-4-2013)

3.2.2.3 Arid Climate

The properties of matter and energy must considered in order to fully understand climatic phenomena. Heat, radiation pressure, humidity, and wind, among other factors, interact mutually to establish climate conditions near the Earth’s surface.

The climate of arid regions is the main factors that affect such regions. The climate is varying between the different types of arid regions. This part summarizes the main environmental characters of the three types of arid zones: hyper-arid, arid, and semi-arid zones. Their climatic characters can be summarized in the following[17]:

3.2.2.3.1 Temperature

The climatic pattern in the arid zones is frequently characterized by a relatively "cool" dry season, followed by a relatively "hot" dry season, and ultimately by a "moderate" rainy season. In general, there are significant diurnal temperature fluctuations within these seasons. Arid regions are characterize by a mean maximum day temperature in shade around 45°C during summer (sometimes, shade temperatures of over 50°C may be reached) and between 20°-30° in winter. At night, it is around 25°C during summer, and between 10°-20°C in the cool seasons. Diurnal range of 20°C is uncommon.

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[17] Mohamed Abd-Elaal, M., (2008), Renewable Energy And Sustainable Urban Development In Hot Rid Regions: Case of Egypt, Ph.D, university of Stuttgart.

3.2.2.3.2 Humidity

It's generally low. The real humidity (RH) fluctuates with air temperature. It can range between below 20% in afternoon to over 40% at night. However, maritime areas of the arid regions experience high humidity between 50% and 90%.

3.2.2.3.3 Rain Fall

Rains are few and they are ranged between the types of the arid zones, as shown in fig. (3-5). In addition, they sometimes start at high altitudes, but evaporate before it reaches the ground. Unlike conditions in temperate regions, the rainfall distribution in arid zones varies between summer and winter. For example, Rabat, Morocco, receives rain during the cold winter period, while the warm summer months are almost devoid of rainfall. On the other hand, Sennar, Sudan, has a long dry season during the winter, while the rains fall during the summer months. Although Rabat and Sennar receive about the same amount of rainfall, the variation in rainfall is considerable. Winter rains in Rabat can penetrate the soil to underground storage, while the summer rains in Sennar fall on a hot soil surface and are lost to evaporation, particularly when rain falls in the form of light showers[18].

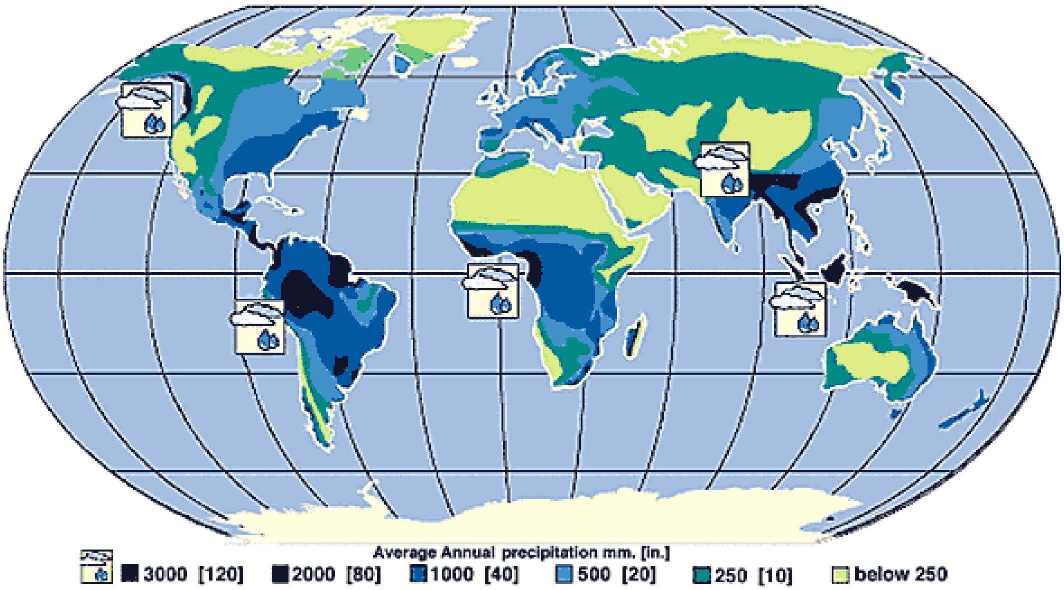

Fig. 3-5 Rain Fall Map, expressing the average annual precipitation.

Source: http://ga.water.usgs.gov/edu/watercycleprecipitation.html, accessed (25-4-2013)

3.2.2.3.4 Sky Conditions and Solar Radiation

The sky is without cloud for the greater part of the year, but dust haze and storms are frequent, mainly in the afternoon. Direct solar radiation is intense and is augmented by radiation reflected from the barren, light-colored terrain.

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[18] Food and Agriculture Organization of the United Nations, (1989), Arid zone forestry: A guide for field technicians, Rome, Food and Agriculture Organization of the United Nations.

3.2.2.3.5 Wind

They are usually local. They are generally low in morning increasing towards noon to reach its maximum in the afternoon, and they frequently accompanied by dust. Prevailing wind axis lies in E-W direction. Highest wind velocities, which can be utilize in spring and fall, occur at afternoons. Night winds follow topography, with cool air drainage from the mountains. Day winds com from S, SE and SW; westerly directions prevail at afternoons, and ore more pronounced in summer[19].

3.2.3 Arid Region Problems

The climate of hot-dry zones are in general characterized by high temperatures, with sharp variations in both diurnal (day / night) and seasonal (summer-/ winter) temperatures; and precipitation (rainfall, snow) which is scarce, irregular and unreliable, but may nevertheless cause severe floods. Cold winds and dust/sandstorms prevail in winter. The solar radiation intensity is high and enhanced by the radiation reflected from the ground. All these characteristics help in causing any problems to buildings in arid regions such as: overheating and high energy consumption, solar radiations through the building envelope, lighting problems (such as glare), and dust penetration. Figure (3-6) shows the characteristics of arid regions and building problems there.

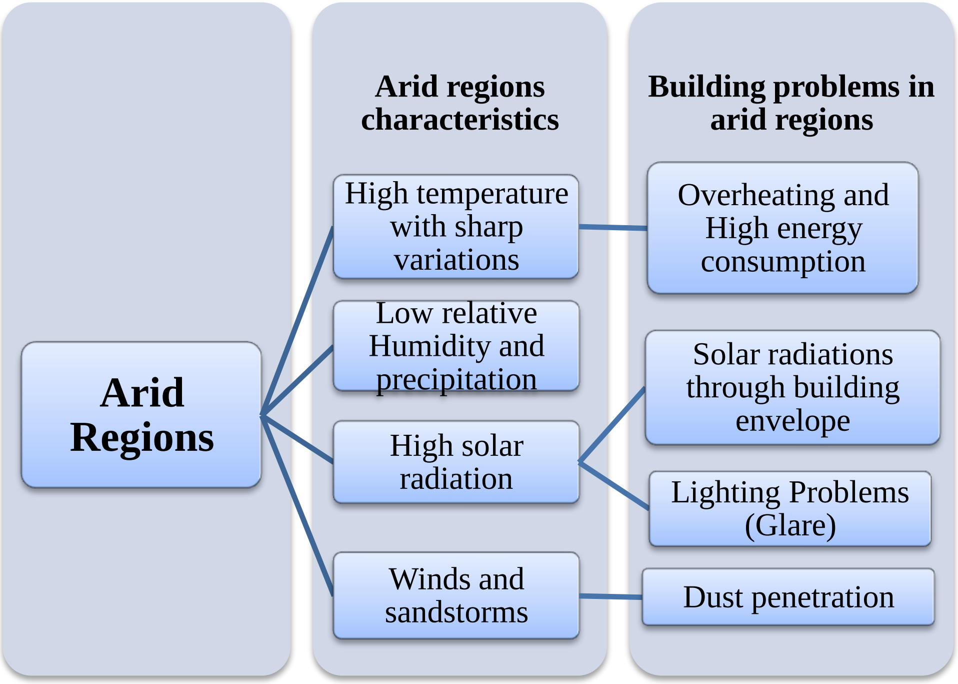

Fig. 3-6 expressing the main Problems of Arid Regions.

Source: Author

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[19] Olgyay, V., (1973), Design With Climate: Bioclimatic Approach to Architectural Regionalism, Princeton, N.J . , Princeton University Press.

3.2.4 Hot-Arid Climate Strategies for buildings form, and elements

A main aspect in designing a climatic responsive building is its comfort criteria, in hot-arid climate, four main climatic factors that need interrelated and integrated treatments to attain comfort dealing with solar radiation through appropriate orientation, building shape, shading of walls and openings, roof treatments special kinds of glazing and using landscape for evaporative cooling, the temperature can be treated for cooling or heating by thermal mass, insulation, partial or total embedding of the building in earth treatments of walls and shading. Ventilation can be attained through enhancement of air movement and cross ventilation, wind catchers, courtyards and day lighting can be abundant through proper positions and sizes of openings and shading. These factors dictate certain climatic strategies related to the building design at three levels, the first level of strategies relates to general building and environmental control characteristics such as mass/materials, plan shape and section, the second level relates to the specific aspects of building form such as plan orientation, landscaping and courtyards, and the third level of climate strategies is related to the main building elements the roof, the walls and the floor[20], where:

3.2.4.1 General building and environmental control characteristics

Mass/materials: Thermal mass can be used to absorb heat from a room during the day and then be cooled at night with ventilation. Materials vary greatly in their capacity for storing heat. Among the more interesting developments is the use of phase-change materials such as Glauber’s salt, these materials absorb a large amount of heat in passing from a solid to a liquid state and then release it when they reverse the change and return to the solid state, they are packaged in tubes and bags[21].

Plan and section shape: Buildings can be shaped to allow for maximum exposure to summer breezes and induce air movement.

3.2.4.2 Specific Aspects of Building Form

Plan orientation: Buildings can be oriented to allow for maximum exposure to summer breezes and cross ventilation can be enhanced by facing the building at an oblique angle to the prevailing wind.

Courtyards and atrium: Cool night air can be captured in enclosed external spaces such as courtyards. It is most effective in high mass well insulated buildings.

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[20] Kamel, S., Climate Responsive Practices in Local Architecture, http://www.cpasegypt.com/pdf/Shaima/Researches/002%20%20%20CLIMATE%20RESPONSIVE%20PRACTICES%20IN%20LOCAL%20ARCHITECTURE.pdf .

[21] Kamel, S., Climate Responsive Practices in Local Architecture, Ibid.

During the day the court remains more comfortable than exposed outdoor areas because its surfaces and the ambient air are relatively cool[22].

Landscape: Evaporative cooling involves placing a body of water such as a fountain, pool or saturated membrane in the path of a breeze. Planting trees provide shade and a cooling effect caused by the evaporation of the water released by the leaves.

3.2.4.3 Main Building Elements

Roof: Design features like mirror-tube skylights, light wells, light shelves and up lighter glazing panels are used to distribute light further into internal spaces by reflecting daylight off the ceiling. Phase change cooling system draws daytime warm external air by fan over an array of fluid-filled heat pipes. The pipes conduct heat to storage modules containing a solid phase change material which, located in the ceiling void, absorb the heat as they slowly melt during the day providing cool ventilation air, during the night the opposite occurs[23].

Walls: Walls and window placement are important for efficient circulation of summer breezes, sizing the inlet area equal to the outlet area and horizontally shaped windows work best for ventilation. An internal shading layer behind the window or an in-between shading layer separating two glazing panels can reduce solar heat gain. An important consideration with insulation is its placement with respect to the two areas to be thermally separated, the insulation, insulation curtains or panels would function more effectively on the outside. Double skin materials should be selected to reflect solar heat gain and avoid transmitting heat to the inner layer; this can be attained through absorptivity of outer skin, emissivity of cavity and rate of ventilation in it. Thermochromic glass depends on “clear gel” which is a clear film which when heated above room temperature reflects sunlight by turning an opaque white, turning clear again when cooled. Electrochromic glass depends on certain compounds that undergo reversible color changes when a small voltage is applied across a thin layer causing a change in the oxidation state. It changes color from clear to blue when a current is passed across it. Prizamtic glazing are designed to optimize day lighting by high precision coated plastic components fitted to glazing; they act to redirect light from window areas that are too bright further into a room through calculation of light angle. Other types can be used to reject excess sunlight through the same mechanism. Low contrast between the window frame and adjacent walls will reduce glare and improve vision[24].

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[22] Brown, G., Kekey, M., (2001), Sun, Wind & Light, Canada, John Wiley & Sons.

[23] Kamel, S., Climate Responsive Practices in Local Architecture, http://www.cpasegypt.com/pdf/Shaima/Researches/002%20%20%20CLIMATE%20RESPONSIVE%20PRACTICES%20IN%20LOCAL%20ARCHITECTURE.pdf .

[24] Kamel, S., Climate Responsive Practices in Local Architecture, Ibid.

3.2.4.4 Design objectives and response

The main goal of climatic design, on a macro (settlement) and micro (building) level, is hence to reduce uncomfortable conditions created by extremes of heat and dryness. Buildings must be adapted to extreme summer / winter and day / night conditions to achieve a well balanced indoor climate. Not only cooling is needed; passive heating may also be needed in winter and during cold nights. Protection is required from the intense radiation from the sun, ground and surrounding buildings, from dust, sandstorms and insects (flies). Glare has to be reduced and dust penetration prevented. Settlements and buildings, therefore, have to be compact, providing shade and controllable ventilation. From the previous problems we can put some basics steps in the design approach in hot arid regions:

- Minimize heat gain during daytime and maximize heat loss at night in hot seasons, and reverse in cold seasons.
- Minimize internal heat gain in the hot season.
- Select the site according to microclimatic criteria
- Optimize the building structure (especially regarding thermal storage and time lag).
- Control solar radiation.
- Regulate air circulation.
- Reduce internal heat production and conduction gain in hot seasons.
- Promote evaporation and heat loss by radiation.

3.3 Using Smart Products to Solve Arid Problems

This part focuses on identifying the actions and effects that are possible via smart materials and then on the technologies that allow them to be implemented, and how they can solve arid problems.

3.3.1 Phenomenological perspective

We can categorize these effects in terms of their arena of action (what do we want the materials to do). The smart materials can produce direct effects on the energy environments (luminous, thermal and acoustics), or they can produce indirect effects on systems (energy generation, mechanical equipments).

The following categories organize smart materials according to their effects. Some smart materials can be deployed to have multiple effects depending on the energy input.

3.3.1.1 Luminous Environment

3.3.1.1.1 Transparency and Color Change

This is one of the largest classes of smart materials, as many different mechanisms give rise to a wide variety of color conditions. Translucent materials may change their total transmissivity, whether from opaque to transparent. Suspended particle and electrochromic technologies do this, as well as photochromics and thermotropics. Alternatively, they may selectively change the color that is being transmitted (liquid crystal, chemochromic). Reflectivity may also be changed, from one color to another (also photochromic and chemochromic) or through several colors depending on the environmental inputs (thermochromic). In glasses and films, reflected or transmitted colors may change according to the angle of view (diochroic effects). Various light control objectives, e.g., glare reduction; can also be achieved through various high performance optical materials.

3.3.1.1.2 Light Emission

Light can be produced of any color (electroluminescent, light-emitting diodes), of any size, intensity or shape (also electroluminescent). Light can be produced in direct response to environmental conditions (chemoluminescent, photoluminescent) and light can also be stored and re-released at a later time (photoluminescent).

3.3.1.2 Thermal Environment

3.3.1.2.1 Heat transfer

The most efficient heat exchange takes place in a heat engine, which essentially cycles between a low temperature and high temperature reservoir. A heat engine can be established across a junction in a semiconductor, producing an enormous temperature difference (thermoelectric). This temperature difference can be used as a sink (for cooling) or as a source (for heating).

3.3.1.2.2 Heat absorption

Rather than removing heat from a space (heat transfer), we can convert it into internal energy (which involves a molecular or microstructure change). Thermal energy can be absorbed and inertial swings dampened by material property changes (phase change materials, polymer gels, thermotropics).

3.3.1.3 Acoustic Environment

3.3.1.3.1 Sound absorption

Energy-exchanging materials allow for more controllable and much more efficient exchange of elastic energy to another form. Elastic energy can be converted to electricity, thus reducing the amplitude of the acoustic vibrations (piezoelectric).

3.3.1.4 Kinetic Environment

3.3.1.4.1 Energy production

Although all of the energy-exchanging materials could be considered as energy producers in that they output some form of energy, we can distinguish this category according to the purpose of that energy. If the output energy is intended for some other function, such as sensing, then we do not consider the material typologically to be an energy-producing smart material (light emission is an exception as it has its own distinct category). The materials in this category are those that we can consider as 'generators' – they directly produce useful energy. The energy can be in many forms: generated electricity (photovoltaic and thermo-photovoltaic), heat pump or engine (thermoelectric) as well as elastic energy (piezoelectric).

3.3.1.4.2 Energy absorption (mechanical dampening)

The intention of energy-absorbing materials is to dissipate or counteract the input energy. Vibrations can be dissipated by conversion to electricity (piezoelectric) or dampened by absorption produced by a material property change (magnetorheological, electrorheological, shape memory alloy). Column buckling can be counteracted by an applied strain (piezoelectric) and other types of deformations can also be counteracted by selectively applied strains (electrostrictive, magnetostrictive, shape memory alloys).

3.3.1.4.3 Shape change

Unlike color change, which can take place over a large area of material, shape change tends to be confined to a much smaller scale (typically meso-scale). The shape-changing smart materials are differentiated by not only their ability to be reversible, but also by the relative magnitude of the shape change. Most shape changing materials move from one position to another – the movement may be produced by a strain, or it may be due to a microstructural change – but the result is a displacement. A material may bend or straighten (shape memory alloys, electrostrictive, piezoelectric), or twist and untwist (shape memory alloys), or constrict and loosen (magnetostrictive), or swell and shrink (polymer gels).

3.3.2 Smart Materials Product Forms

This part will look at general smart product forms available to the designer, e.g., paints, films, glasses, dyes.

3.3.2.1 Polymer Films

They are designed to have many different properties and exhibit a wide variety of different behaviors. Particularly interesting are developments in the area of multi-player laminates. These products can be relatively low cost. Several are described below. Many are actually high-performance materials, while others exhibit true smart behaviors.

3.3.2.1.1 Radiant color and mirror film

The mirror film is advertised as secularly reflecting 98% of visible light. The opaque mirror film consists of multiple layers of polymeric film, each with differing reflective properties, and a polyester surface. It can be embossed, cut, coated to be UV resistant and given an adhesive backing or laminated to other surfaces. It is metal free (hence non-corrosive) and thermally stable. Radiant color film also consists of multiple layers of film with different reflective properties, but is transparent. It possesses remarkable reflective and transmissive qualities. The color of the reflection perceived depends on the angle that light strikes it. The color of the film when looking through it depends on the exact angle of the viewer to the film surface[25] as shown in fig. (3-7).

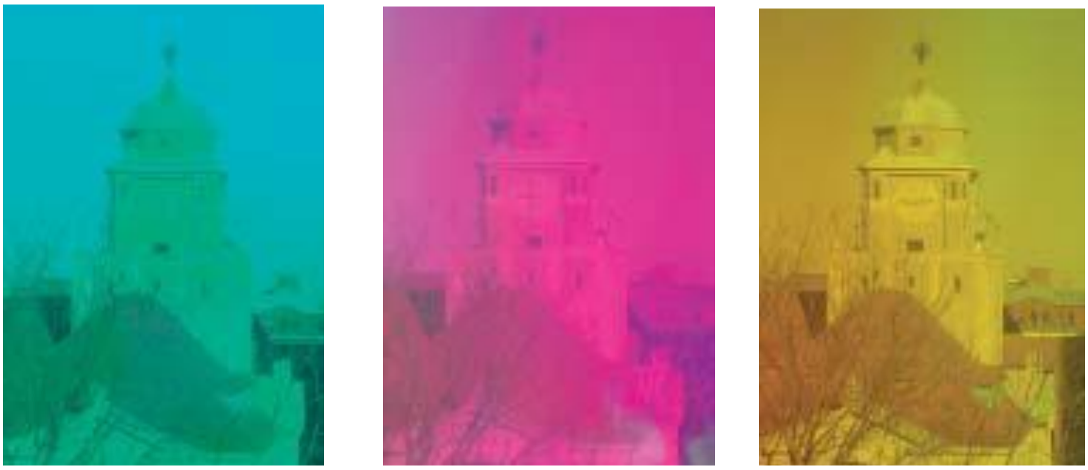

Fig. 3-7 Radiant mirror film. The color of the transparent film depends on the angle of the viewer with respect to the film.

Source: Addington, M., Schodek, D., (2005)

3.3.2.1.2 View directional films

Fig. 3-8 View control film (privacy film) allows the viewer to see an object clearly only from a specified direction.

Source: Addington, M., Schodek, D., (2005)

Often called light control film or privacy film, this polymeric material is embossed with very small specially shaped grooves or micro-louvers. Depending on how the micro-louvers are organized, a viewer can see through the film only in specified directions as shown in fig. (3-8). The observer perceives an object through the film only under certain conditions. This same film can also be effectively used to control light coming in through it, and thus it finds wide

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[25] Addington, M., Schodek, D., (2005), Smart Materials and New Technologies, Oxford Architectural Press.

application as a glare-reducer for computer displays and other applications[26].

3.3.2.1.3 Image redirection films

While seemingly similar to view directional films, these view redirection films have the curious property of acting somewhat like a periscope in that one can look around corners to a certain extent. They are made from embossing specially shaped grooves onto polymer sheets. Fig. (3-9) shows how these films work.

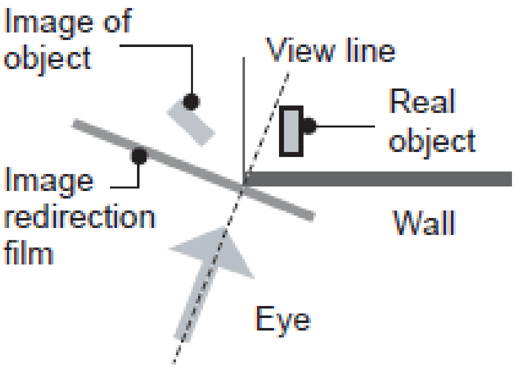

Fig. 3-9 Image redirection film

Source: Addington, M., Schodek, D., (2005)

3.3.2.1.4 Fresnel lens films

The Fresnel lens has the ability to focus parallel light rays on a point, or to be a highly effective means of projecting bright parallel rays from a point source. They are now widely used in many applications, ranging from overhead projectors to campers' solar cook stoves. Figure (3-10) shows how a light source hits the lens, which has different shaped prisms to refract the light and direct it forwards[27].

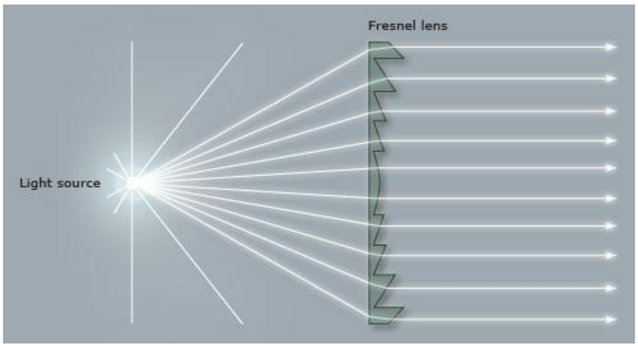

Fig. 3-10 Fresnel lens, it can project bright parallel rays from a point source.

Source:http://www.teara.govt.nz/en/diagram/6675/fresnel-lens, accessed (30-4-2013)

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[26] Addington, M., Schodek, D., (2005), Smart Materials and New Technologies, Oxford Architectural Press.

[27] Beaglehole, H., (2012), 'Lighthouses - Lights: from oil to electricity', http://www.teara.govt.nz/en/diagram/6675/fresnel-lens (accessed 30-4-2013).

3.3.2.1.5 Polarizing films

Many kinds of polarized films are used in computer or kiosk displays to reduce glare. A circularly polarized film assembly consisting of linear and circular polarizing filters can be particularly effective. Fig. (3-11) shows how the sliding sheets of polarized film can used to modify a view.

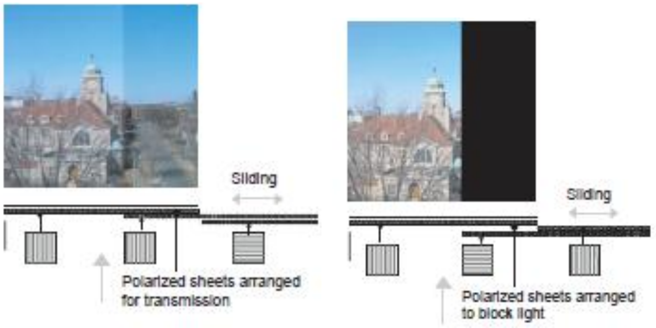

Fig. 3-11 Use of sliding sheets of polarized film to modify a view.

Source: Addington, M., Schodek, D., (2005)

3.3.2.1.6 Light pipes

Many kinds of polymer films with special surface properties are shaped into tubes to be used as devices for transmitting light. Some are designed to 'leak' light along their lengths to create glowing tubes as shown in fig. (3-12). Others are designed to carry light with as little loss as possible from one end of a tube to another as shown in fig. (3-13). The basic system includes a pipe with a highly reflective interior, a light directing cap (which ensures that a maximum amount of light gets pushed into the tube) and a diffuse lens or mirror at the base of the tube, to spread the light within the interior[28].

Fig. 3-12 Light Pipes

Source: Addington, M., Schodek, D., (2005)

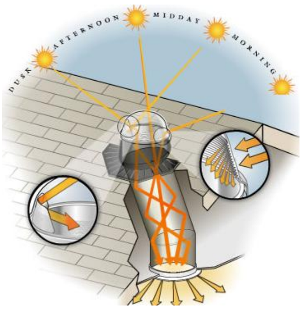

Fig. 3-13 Light pipes work by reflecting light along the inside of a tube.

Source:http://www.ecogeek.org/content/view/356/ , accessed (30-4-2013)

3.3.2.1.7 Photochromic films

Photochromic materials change color when subjected to light. Many photochromic films are available that change from a clear state to a transparent colored state. These

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[28] Green, H., (2006), Light Pipes, http://www.ecogeek.org/component/content/article/356 (accessed 30-4-2013).

polymeric films can be relatively inexpensive as compared to photochromic glasses. Normally, their color-changing response is relatively slow and the color quality less controlled than obtainable in photochromic glasses.

3.3.2.1.8 Thermochromic films

Thermochromic materials change color with temperature. Special thermochromic films, based on a form of liquid crystal behavior, can exhibit controlled responses to temperature changes. They can be designed to be calibrated to specific temperature ranges.

3.3.2.1.9 Electroluminescent films

Electroluminescent materials, produce illumination when their phosphor materials are charged as shown in fig.(3-14). This phosphorescent material can be put on a film layer, as can metallic charge carriers. This technology is directed towards thin low-voltage displays with low power consumption. It is largely compatible with a number of low-cost fabrication techniques for applying it to substrates (e.g., spin coatings) and other printer-based fabrication techniques.

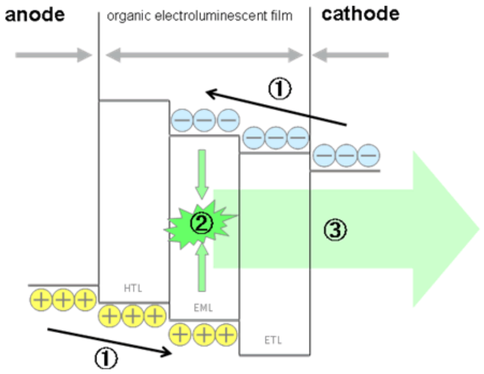

Fig. 3-14 Electroluminescent films, expressing how it can produce illumination when their phosphor materials are charged

Source:http://www.sony.net/SonyInfo/technology/technology/theme/oel_01.html#tmpl_header, accessed (1-5-2013)

3.3.2.1.10 Conductive polymeric films

These conducting polymers are sensitive to radiation, which can change the color and the conductivity of polyaniline. These materials are widely used in organic light-emitting polymer (OLEP) films. Additionally, different electronic components like resistors, capacitors, diodes and transistors can be made by combining different types of conducting polymers. These electroactive polymers can also be used as sensors, actuators and even artificial muscles. An applied voltage can cause the polymer to expand, contract or bend. Until recently, electroactive polymers have presented practical problems. They consumed too much energy. They couldn't generate enough force[29].

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[29] Addington, M., Schodek, D., (2005), Smart Materials and New Technologies, Oxford Architectural Press.

3.3.2.1.11 Light-emitting polymers

There are several technologies based on polymeric materials that emit light. There has been great interest in this area because of the potential for low costs, their ability to cover large areas and their potential for material flexibility. A polymer LED can be divided into three different components as shown in fig.(3-15): Anode: the hole supplier, made of metal of high working function. Examples of the common anode are indium tin oxide (ITO), gold etc. The anode is usually transparent so that light can be emitted through. Cathode: the electron supplier made of metal of low working function. Examples of the common cathode are aluminum or calcium. Polymer: made of conjugated polymer film with thickness of 100 nm[30]. An applied voltage causes the sandwiched emissive polymer to emit light. The chemical structure of the polymer can be varied so that the color of the light can be changed.

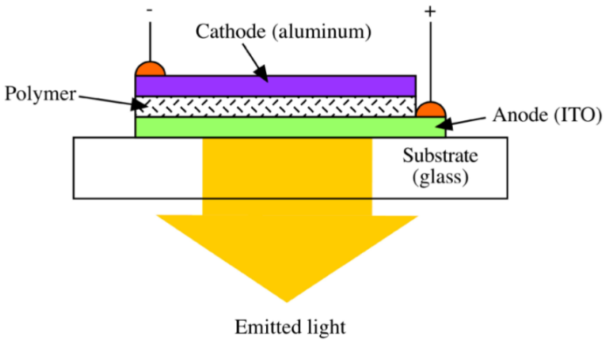

Fig. 3-15 Light Emitting Polymers, expressing their contents.

Source: http://cnx.org/content/m25670/latest/, accessed (30-4-2013)

3.3.2.1.12 Chemically sensitive color- and shape-changing films

Films have been developed that are sensitized to respond to different chemical substances that act as external stimuli. Exposed films may changes shape, color or other properties. Interest in these films has been widespread because of their potential in acting as simple sensors that detect the presence of chemicals in surrounding atmospheres or fluids[31].

3.3.2.1.13 Piezoelectric films

Piezoelectric materials convert mechanical energy (via deformations) to electrical energy and vice-versa[32]. Piezoelectric Film is an enabling transducer technology with unique capabilities. Piezo Film produces voltage in proportion to compressive or tensile

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[30] Barron, A., (2009), Polymer Light Emitting Diodes, http://cnx.org/content/m25670/latest/ (accessed 30-4-2013).

[31] Addington, M., Schodek, D., (2005), Smart Materials and New Technologies, Oxford Architectural Press.

[32] Addington, M., Schodek, D., (2005), Ibid.

mechanical stress or strain, making it an ideal dynamic strain gage. It makes a highly reliable, low-cost vibration sensor, accelerometer or dynamic switch element. Piezo Film is also ideally suited for high fidelity transducers operating throughout the high audio (>1kHz) and ultrasonic (up to 100MHz) ranges[33]. Fig. (3-17) shows different shapes of piezoelectric sensors.

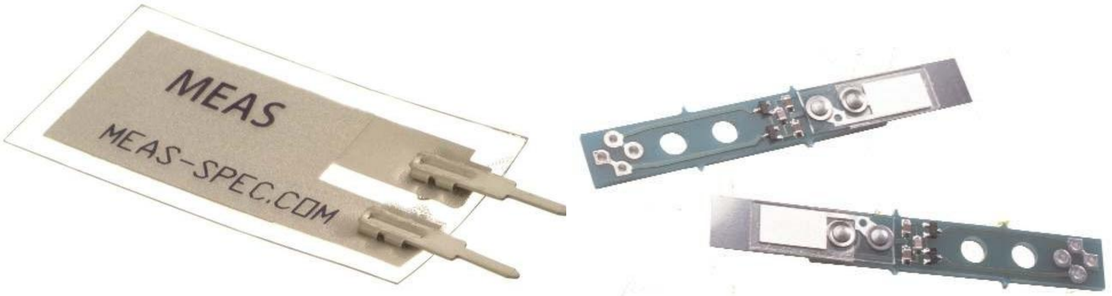

Fig. 3-16 Piezo Electric Sensors, expressing their different shapes.

Source: http://www.imagesco.com/piezoelectric/index.html, accessed (1-5-2013)

3.3.2.1.14 Photovoltaic films

The interest here is that flexible polymeric films of exhibiting photovoltaic effects have been made as a result of advances in laminating multi-layered films, as shown in fig. (3-16). The objectives often stated by developers are to create thin and flexible solar cells that can be applied to large surfaces, and which could be made in different transparencies and colors so that they could be used in windows and other similar places. Problems of low efficiency, including those generated by not being able to control solar angles in these applications, remain. There have been, however, many successful applications in the product and industrial design worlds for smaller and more contained products, ranging from clocks to battery chargers.

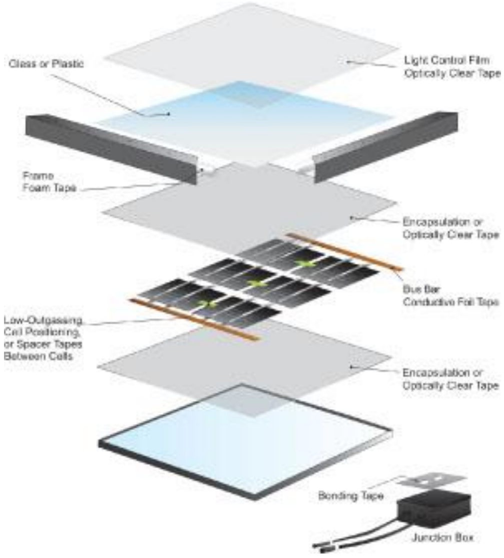

Fig. 3-17 Photovoltaic films, expressing their contents.

Source:http://www.onlinetes.com/tes-0710-photovoltaic-cells-evolve-pressure-sensitive-adhesives.aspx, accessed (1-5-2013)

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[33] Measurement Specialties company, (2012), Piezo Film Sensors, http://www.meas-spec.com/piezo-film-sensors.aspx (accessed 1-5-2013).

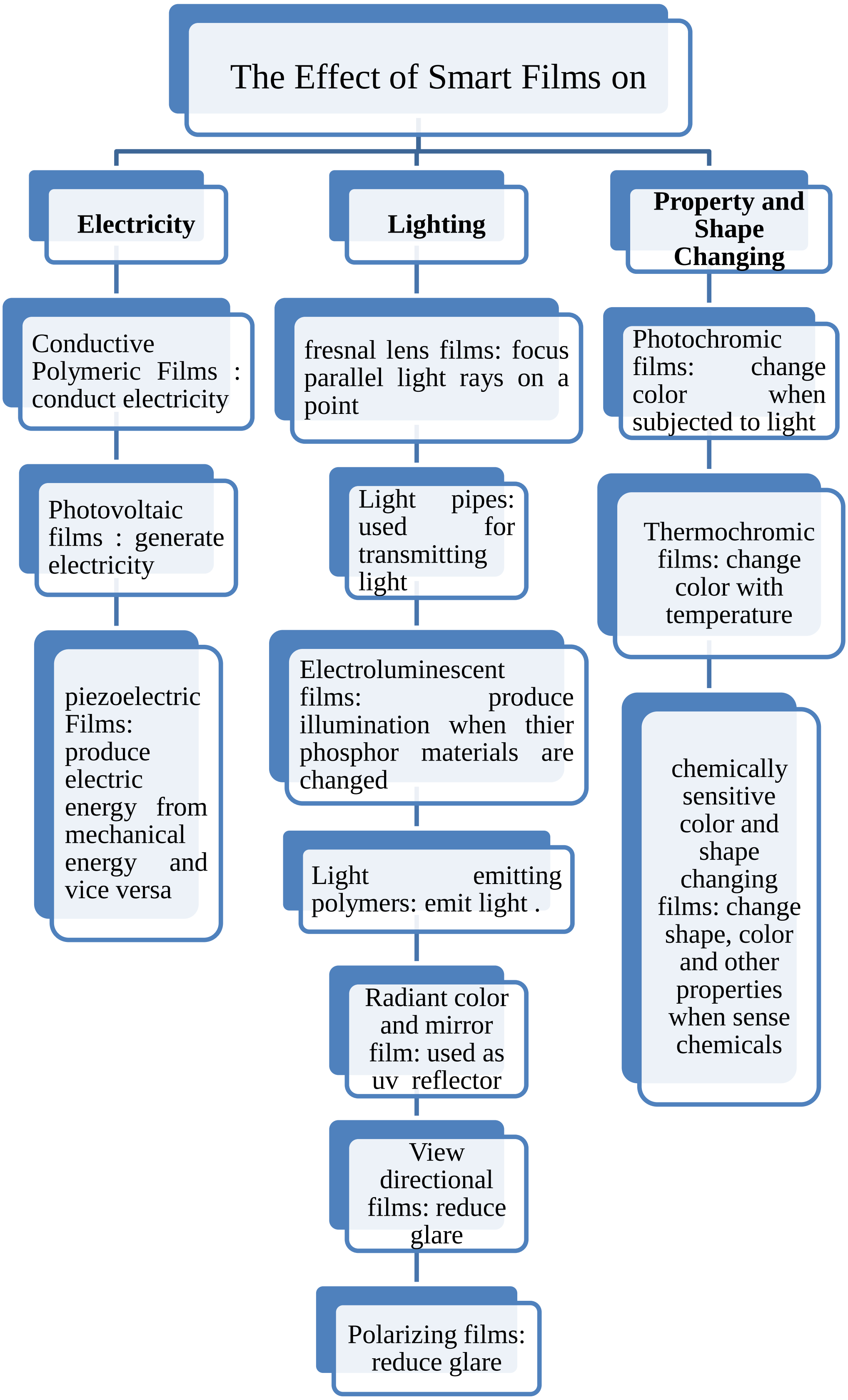

Fig. 3-18 This figure shows the applications of different types of smart films

Source: Author, according to: Addington, M., Schodek, D., (2005)

3.3.2.2 Polymer Rods and Strands

3.3.2.2.1 Optical Carriers

Optical cables can be made in many different ways. At the most basic level, simple long flexible plastic strands or rods find uses in many simple applications that involve simple light distribution via internal reflection. These same rods can be encased or jacketed in an opaque material to improve their light transmission. Diameters can vary greatly, but even large diameters suitable for lighting installations can be relatively inexpensive.

3.3.2.2.2 Shape-changing polymer strands

Polymers that shrink or expand due to changes in the thermal environment. Fig. (3-19) shows different types of polymer rods and strands.

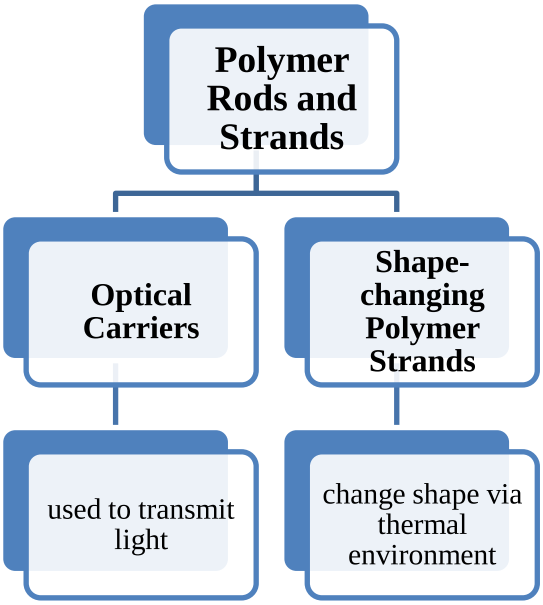

Fig. 3-19 Types of polymer rods and strands

Source: Author, according to: Addington, M., Schodek, D., (2005)

3.3.2.3 Inks and Dyes

Smart dyes and inks are fundamental to the making of many types of smart products, including papers, cloths and others. Normal paper, for example, can be made into thermochromic paper by the use of leucodyes. When cool, leucodyes exhibit color and become clearer upon heating or can be made to change to another color. Photochromic dyes can be used to make photochromic cloths. Color-changing printing can be done via thermochromic or photochromic inks.

3.3.2.4 Smart Paints and Coatings

Smart paints and coatings can be generally classified into (a) high-performance materials, (b) property-changing materials and (c) energy-exchanging Materials. High-performance paints and coatings – particularly those that are the result of the burgeoning field of polymer science[34].

Many of the basic property-changing materials can be manufactured in the form of fine particles that can be used as pigment materials in paints. Thus, there are many variations of thermochromic and photochromic paints or coatings. Thermochromic paints are widely used to provide a color change indicator of the temperature level of a product. Some phase-changing materials, could be directly used in coatings or embedded as microcapsules.

Energy-exchanging materials used in paint or coating form there are many direct applications. There are many natural and synthetic luminescent materials that can be made in paint or coating form. These paints or coatings absorb energy from light, chemical or thermal sources and reemit photons to cause fluorescence, phosphorescence or afterglow lighting.

Many paints and coatings are devised to conduct electricity, such as the coatings used on glass substrates to make the surface electrically conductive and thus have the capability of ‘heating up’.

Polymeric materials can also be used as hosts for many other energy-exchanging materials, including piezoelectric particles (recall that piezoelectric materials produce an electrical charge when subjected to a force, or can produce a force when subjected to a voltage). In these smart piezoelectric paints, piezoelectric ceramic particles made of PZT (lead ziconate titanate) or barium titanates (BaTIO3) are frequently used. They are dispersed in an epoxy, acrylic, or alkyd base. The paint itself is electrically insulating and, in order for the paint to work as described, an electrode must be present (on the film surface) to detect a voltage output.

3.3.2.5 Smart Glasses

3.3.2.5.1 Electro-Optical Glass

Glass is well known for use as an electrical insulator. Electro-optical glass consists of a glass substrate that has been covered – via a chemical deposition process – by a thin and transparent coating of an electrically conductive material. The most frequently used product uses a chemical vapor deposition system to apply a thin coating of tin oxide to a glass substrate. The chemical deposition process yields a coating that is extremely thin and visually transparent, but which is still electrically conductive. In architecture, this technology can be used to create ‘heated glasses. Strip connectors are applied to either edge of a glass sheet and a voltage applied. The thin conductive deposition layer essentially becomes a resistor that heats up. The whole glass sheet can become warm[35].

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[34] Addington, M., Schodek, D., (2005), Smart Materials and New Technologies, Oxford Architectural Press.

[35] Addington, M., Schodek, D., (2005), Ibid.

3.3.2.5.2 Holographically patterned glass

This glass is currently used for optical and related lighting purposes. The desired optical effects (normally in the form of light patterns) are inscribed beforehand in the microstructure of the surface of the material and are essentially replayed when a light is transmitted through the material. They allow the light to be directed into particular patterns. These particular luminous distributions are recorded a priori holographically on a reflective metalized coating that has been applied to a glass substrate. These materials are finding increasing use as diffusers in lighting applications. These diffusers are also transparent and provide relatively distortion-free images at certain viewing distances.

3.3.2.5.3 Dichroic Glass

A dichroic material exhibits color changes to the viewer as a function of either the angle of incident light or the angle of the viewer. The varying color changes can be very striking and unexpected, as shown in fig. (3-20) & (3-21). Dichroic Glass is a multi layer coating placed on glass by using a highly technical vacuum deposition process. Quartz Crystal and Metal Oxides are Vaporized with an electron beam gun in an airless vacuum chamber and the vapor then floats upward and attaches then condenses on the surface of the glass in the form of a crystal structure[36].

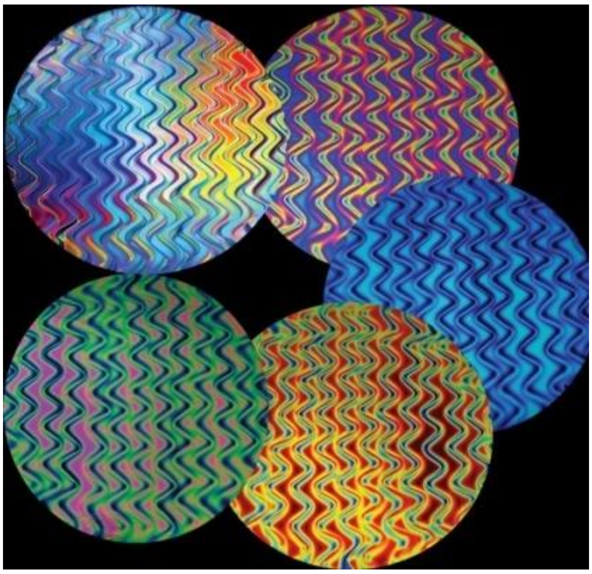

Fig. 3-20 Dichroic Glass, expressing how it can exhibits color changes to the viewer as a function of either the angle of incident light or the angle of the viewer.

Source:http://www.cbs-dichroic.com/whatsnew1.asp, accessed (1-5-2013)

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[36] CBS, Coatings by Sandberg, (2009), What is Dichroic Glass?, http://cbs-dichroic.com/dichroicglass.asp#whatisdichroic (accessed 1-5-2013).

In new dichroic glass, a glass substrate is coated with multiple layers of very thin transparent metal oxide coatings, each with different optical properties. When light impinges upon or is passed through these layers, various complex optical effects occur. Dichroic glass has been effectively used in many design situations. The coatings that produce the dichroic effect are subject to abrasion; hence a protective glass layer is typically used as a protection.

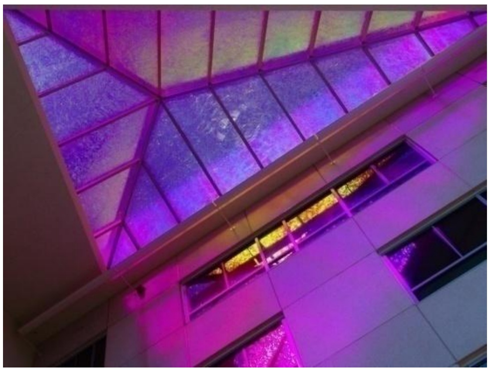

Fig. 3-21 Using dichroic glass in skylight

Source: <u>http://www.johnblazydesigns.com/</u>, accessed (1-5-2013)

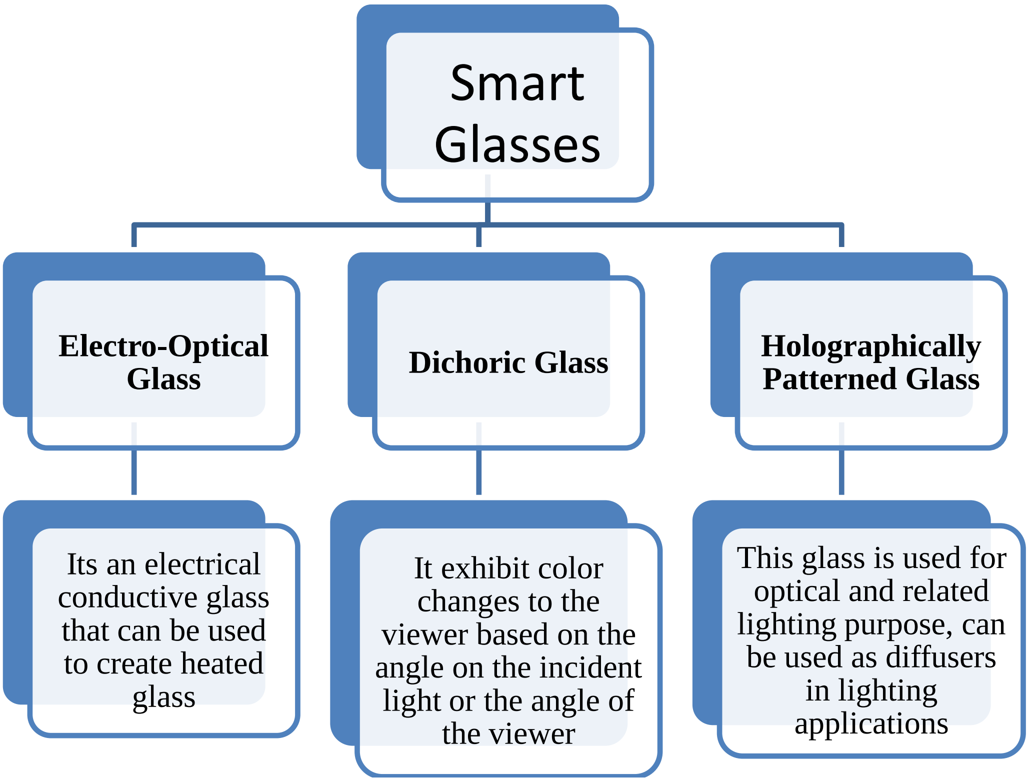

Fig. 3-22 Types of smart glasses

Source: Author, according to: Addington, M., Schodek, D., (2005)

3.3.2.6 Smart Fabrics

The term ‘fabric’ refers to a material that in some way resembles or shares some of the properties of cloth. Several primary types of smart fabrics exist[37]:

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[37] Addington, M., Schodek, D., (2005), <u>Smart Materials and New Technologies</u>, Oxford Architectural Press.

High-performance fabrics with materials or weaves designed to accomplish some specific objective.

Fabrics that exhibit some form of property change.

Fabrics that provide energy exchange function.

Fabrics that in some way are specifically intended to act as sensors, energy distribution, or communication networks.

3.3.2.6.1 Light and color

There are many fabrics that deal in one way or another with light and color. Fabrics may be made of materials with different optical qualities, and thus reflect light from only certain angles. Fabrics can also be made of layers of transparent materials with different refractive indices. Depending on the layering and the materials used, these fabrics can reflect light within certain wavelengths and absorb light not within this range. A 'mirror' material can be made that reflects light in all directions with little absorption. In addition to the use of these fabrics in displays or as special wall surfaces, these fabrics deal with light or radiation reflection and transmission.

3.3.2.6.2 Fiber-optic and electroluminescent weaves

The use of optical fiber-optic strands to make fabrics exhibit remarkable visual characteristics. They have remarkable visual appeal. One approach uses two layers of optical fiber weaves sandwiched between an outer reflective Mylar layer and an outer transparent diffuse layer. The fiber-optic weaves are in turn connected to a light source, typically an LED. Light is emitted from abraded surface areas in the fiber-optic weave. Other approaches use optical fibers in one direction only, with neutral fabrics running perpendicular to them. Other fabrics incorporate fiber-optic strands for use as sensors. A similar weaving strategy can be used in connection with electroluminescent materials[38] as shown in fig. (3-23).

Fig. 3-23 Fiber-optic and electroluminescent weaves

Source:<u>http://www.talk2myshirt.com/blog/wp-content/uploads/2012/04/Fiber-Optic-Tapestry.jpg</u>, accessed (1-5-2013)

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[38] Addington, M., Schodek, D., (2005), <u>Smart Materials and New Technologies</u>, Oxford Architectural Press.

3.3.2.6.3 Breathable fabrics

Another class of high-performance fabrics deals with material porosity or permeability. Products of this type are normally based on polytetrafluoroethylene. The material is stretched into a porous form to form the 'breathable' membranes widely used today under brand names such as Gore-Tex[39]. They allow a range of medical and industrial applications (e.g., filters, vents, gaskets, sensor covers, pressure venting).

3.3.2.6.4 Property-changing fabrics – thermochromic and photochromic cloths

The second class of smart fabrics contains those that exhibit some form of property change when subjected to an external stimulus. The most common applications are for fabrics that have color change properties, as shown in fig. (3-24) & (3-25). These are typically traditional fabrics that are either impregnated with thermochromic or photochromic materials in dye form, or are layered with similar materials in the form of coatings or paints.

Fig. 3-24 The patented product line indicates temperature changes visually, through color change.

Source:http://fabricarchitecturemag.com/articles/0509_np2_film.html , accessed (1-5-2013)

Fig. 3-25 This green to yellow color changing fabric will appear green when cool but will change to yellow when touched or heated at the point of contact.

Source:http://www.bodyfaders.com/shopping/pc/viewPrd.asp?idproduct=4748&idcategory=29, accessed (1-5-2013)

3.3.2.6.5 Phase-changing fabrics

A number of highly interesting property-changing fabrics have been developed for controlling thermal environments. These fabrics normally incorporate phase change materials. Phase change processes invariably involve absorbing, storing or releasing of large amounts of energy in the form of latent heat; and can thus be very useful in controlling thermal environments. Fig. (3-26) shows the encapsulated phase-changing materials that used in outdoor clothing applications.

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[39] Addington, M., Schodek, D., (2005), Smart Materials and New Technologies, Oxford Architectural Press.

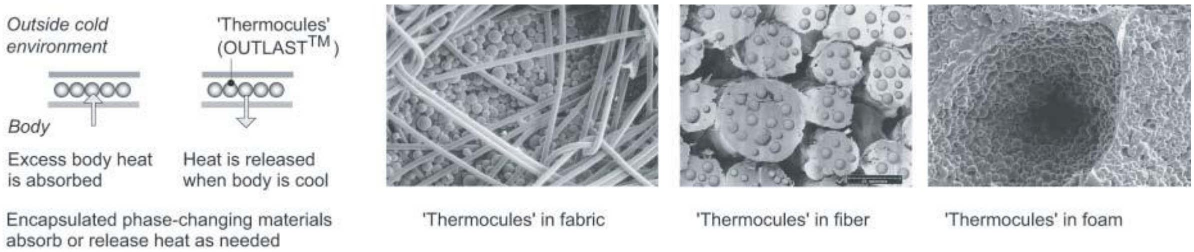

Fig. 3-26 The encapsulated phase-changing materials shown are used in outdoor clothing applications.

Source: Addington, M., Schodek, D., (2005)

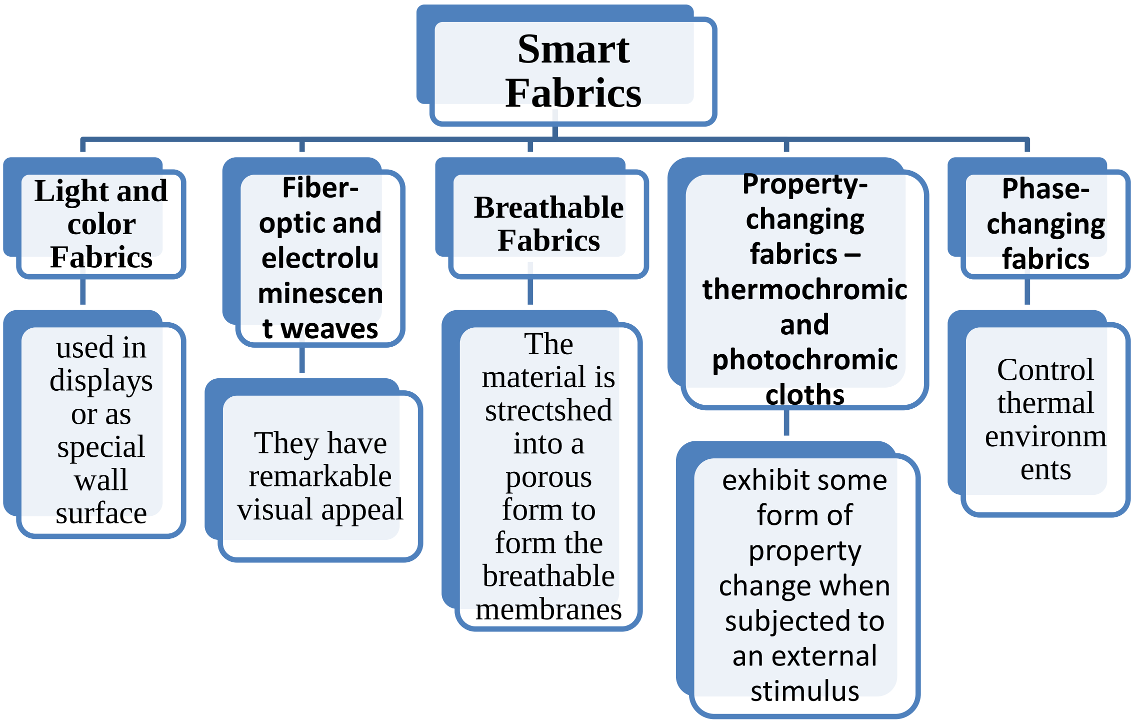

Fig. 3-27 This figure shows different smart fabrics and their applications

Source: Author, according to: Addington, M., Schodek, D., (2005)

3.3.3 Smart Components, assemblies and systems

These systems are often embedded within the building's infrastructure; many of the smart materials tend to be 'hidden'. Window and façade systems are the most visible category for smart application. Lighting systems perhaps have the most impact on the user's perception of the building. Energy systems have steadily become more important as concerns regarding the global environment have mounted[40].

3.3.3.1 Façade Systems

Smart materials were envisioned as the ideal technology for providing all of the functions of the super facade, yet would do so simply and seamlessly. Visions of Mike Davies' 'Polyvalent Wall' – a thin skin that combined layers of electrochromics, photovoltaics, conductive glass, thermal radiators, micro pore gas-flow sheets and more – served as the model of the ultimate façade, as shown in fig. (3-28). His prediction was not far off, as an entire field devoted to the development of smart windows and facades has been premised on their contribution to energy efficiency[41].

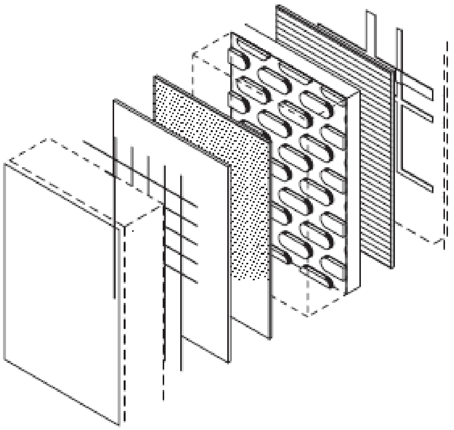

Fig. 3-28 Schematic representation of Mike Davies' polyvalent wall. He proposed that the exterior wall could be a thin system with layers of weather skin, sensors and actuators, and photoelectrics

Source: Addington, M., Schodek, D., (2005)

3.3.3.1.1 THE SMART WINDOW

This part will concentrate the discussion on exterior glazing and interior partitions. Fig. (3-29) shows a comparison of smart window features. 'Smart' windows will typically possess one or more of the following functions[42]:

<u>Control of optical transmittance:</u> to manage the incident solar radiation, particularly in the visual and near ultraviolet wavelengths. The window would vary from high density (opaque or translucent) for the prevention of direct sun penetration and its associated glare to low density (transparent) as incident light loses intensity.

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[40] Addington, M., Schodek, D., (2005), <u>Smart Materials and New Technologies</u>, Oxford Architectural Press.

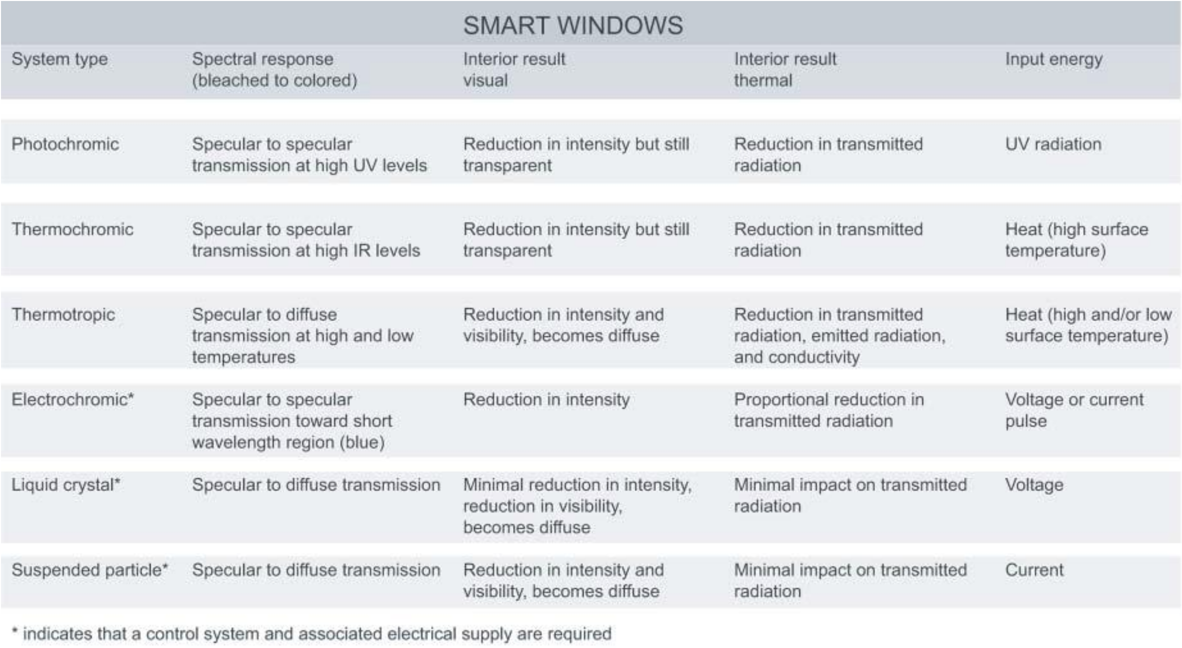
[41] Banham, R., (1984), <u>Architecture of the Well-Tempered Environment</u>, 2nd Ed., Chicago, The University of Chicago Press.

[42] Addington, M., Schodek, D., (2005), <u>Smart Materials and New Technologies</u>, Oxford Architectural Press.

Control of thermal transmittance: This is a similar function to that above. Heat transmission by radiation can be minimized when appropriate (summer) and maximized for other conditions.

Control of thermal absorption: Whenever the inside temperature is higher than the outside temperature, a bidirectional heat flow is established: radiant energy transfers in, while thermal energy transfers out. Altering the absorption of the glazing will ultimately affect the net conductivity, and thus can shift the balance in favor of one or the other direction.

Control of view: Interior panels and partitions that switch from transparent to translucent allow light to transmit, but are able to moderate the view by altering the secularity of the material A specular material will transmit intact images, whereas a diffuse material will obscure the image.



SMART WINDOWS

System type	Spectral response (bleached to colored)	Interior result visual	Interior result thermal	Input energy
Photochromic	Specular to specular transmission at high UV levels	Reduction in intensity but still transparent	Reduction in transmitted radiation	UV radiation
Thermochromic	Specular to specular transmission at high IR levels	Reduction in intensity but still transparent	Reduction in transmitted radiation	Heat (high surface temperature)
Thermotropic	Specular to diffuse transmission at high and low temperatures	Reduction in intensity and visibility, becomes diffuse	Reduction in transmitted radiation, emitted radiation, and conductivity	Heat (high and/or low surface temperature)
Electrochromic*	Specular to specular transmission toward short wavelength region (blue)	Reduction in intensity	Proportional reduction in transmitted radiation	Voltage or current pulse
Liquid crystal*	Specular to diffuse transmission	Minimal reduction in intensity, reduction in visibility, becomes diffuse	Minimal impact on transmitted radiation	Voltage
Suspended particle*	Specular to diffuse transmission	Reduction in intensity and visibility, becomes diffuse	Minimal impact on transmitted radiation	Current

* indicates that a control system and associated electrical supply are required

Fig. 3-29 Comparison of smart window features.

Source: Addington, M., Schodek, D., (2005)

3.3.3.2 Lighting systems

Smart materials can have a major impact on energy use, even insofar as they are not that much more efficient at producing light than are conventional systems. The fundamental savings will come from the lighting systems that smart materials enable, rather than from any single illumination source.

3.3.3.2.1 SOLID STATE

Solid state lighting is a large category that refers to any type of device that uses semi-conducting materials to convert electricity into light. In this category some of the most innovative new smart technologies can be found, including organic light-emitting diodes (OLEDs) and light-emitting polymers (OLPs)[43].

LEDs might consider as the ‘smart’ version of fiber optics, as, in addition to being discrete and direct, they are also self-actuating, immediate and transient. Besides their small dimensions which allow their deployment in spaces unable to be illuminated with any other means, the spectral qualities of the light can be precisely controlled.

Organic LEDs or OLED can be split into two types: SMOLED (Small Molecular OLED) and PLED, or (Polymer OLED, also referred to as POLED). The great advantage of the organic types is that they are based on thin film technology. Conventional LED systems are inherently constructed from point sources, and color change requires the right combination of the individual diodes in a particular region that then must be covered with a diffusing layer for homogeneity. The thin films, in contrast, can provide any type of color and light distribution, regardless of how the individual pixels are arrayed[44].

3.3.4 Mapping of Building Systems Needs in Arid Regions in Relation to Applicable Smart Materials

Figure (3-30) and Table (3-1) show the building system needs in arid regions and ‘map’ smart materials and their relevant property characteristics to current and/or defined architectural applications. With the exception of some of the glazing technologies, most of the current applications tend to be pragmatic and confined to the standard building systems: structural, mechanical and electrical, most of these systems are embedded within the infrastructure. Many smart materials are deployed as sensors. Sensing plays an extremely important role in the performance of building systems. Even the most routine operation of an HVAC system requires the precise determination of several environmental variables, particularly air temperature and relative humidity. The most visible category for smart material application is in the window and facade systems area, in which these materials are perhaps used as much for their cache as for their performance.

3.3.4.1 Control of Solar Gain and Heat Transfer through the Building Envelope

The envelope of a building constitutes the interface between outside and indoor climatic conditions. Incorporate solar controls on the building exterior to reduce heat gain. Radiant gains can have a significant impact on heating and cooling loads. A surface that is highly reflective of solar radiation will gain much less heat than one that is adsorptive. In general, light colors decrease solar gain while dark ones increase it. Specify construction materials and details that reduce heat transfer. Heat transfer across

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[43] Addington, M., Schodek, D., (2005), Smart Materials and New Technologies, Oxford Architectural Press.

[44] Addington, M., Schodek, D., (2005), Ibid.

the building envelope occurs as either conductive, radiant, or convective losses or gains. Building materials conduct heat at different rates. Smart materials can use in control solar radiation transmitting though the building envelope by using photochromic, electrochromics. They also can used to control conductive heat transfer by using thermo-tropics, and phase changing materials.

3.3.4.2 Energy Consumption

Due to the climatic conditions in arid regions, buildings are suffering high energy consumption. Approximately 50 percent of the energy use in buildings is devoted to producing an artificial indoor climate through heating, cooling, ventilation, and lighting[45].

3.3.4.3 Optimizing of Lighting Systems

Day lighting significantly reduces energy consumption and operating costs. Energy used for lighting in buildings can account for 40 to 50 percent of total energy consumption. In addition, the added space-cooling loads that result from waste heat generated by lights can amount to three to five percent of total energy use. Properly designed and implemented day lighting strategies can save 50 to 80 percent of lighting energy46. Smart materials can also help in optimizing of lighting systems by using some smart materials such as photovoltaics, LEDS, or electroluminescent.

3.3.4.4 Optimization of HVAC Systems

HVAC system requirements increased dramatically in the twentieth century in response to changes in other design practices, such as greater use of glazing, sealed buildings, alternate envelope systems with greater thermal loads, and more extensive use of artificial lighting and occupant equipment. As a result, buildings have become more dependent on fossil-fuel energy sources instead of natural energy flows such as climate, temperature, and solar conditions. The goal of environmentally sound HVAC system design is to meet occupant needs through the most efficient and environmentally positive means at the lowest initial and life-cycle costs. Solutions that have evolved provide environmental comfort while accounting for climatic conditions, use of space, and building technology. These green system designs take into consideration factors such as solar orientation, thermal mass, and insulation, selection of architectural materials, placement and type of doors and windows, and natural ventilation. Using smart materials can help on optimizing HVAC systems by using materials such as optical MEMS, biosensors, thermoelectric, and phase changing materials.

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[45] Public Technology Inc., (1996), Sustainable Building technical manual: Green Building Design, Construction, and Operations, United States of America, Public Technology, Inc.

[46] Public Technology Inc., (1996), Ibid.

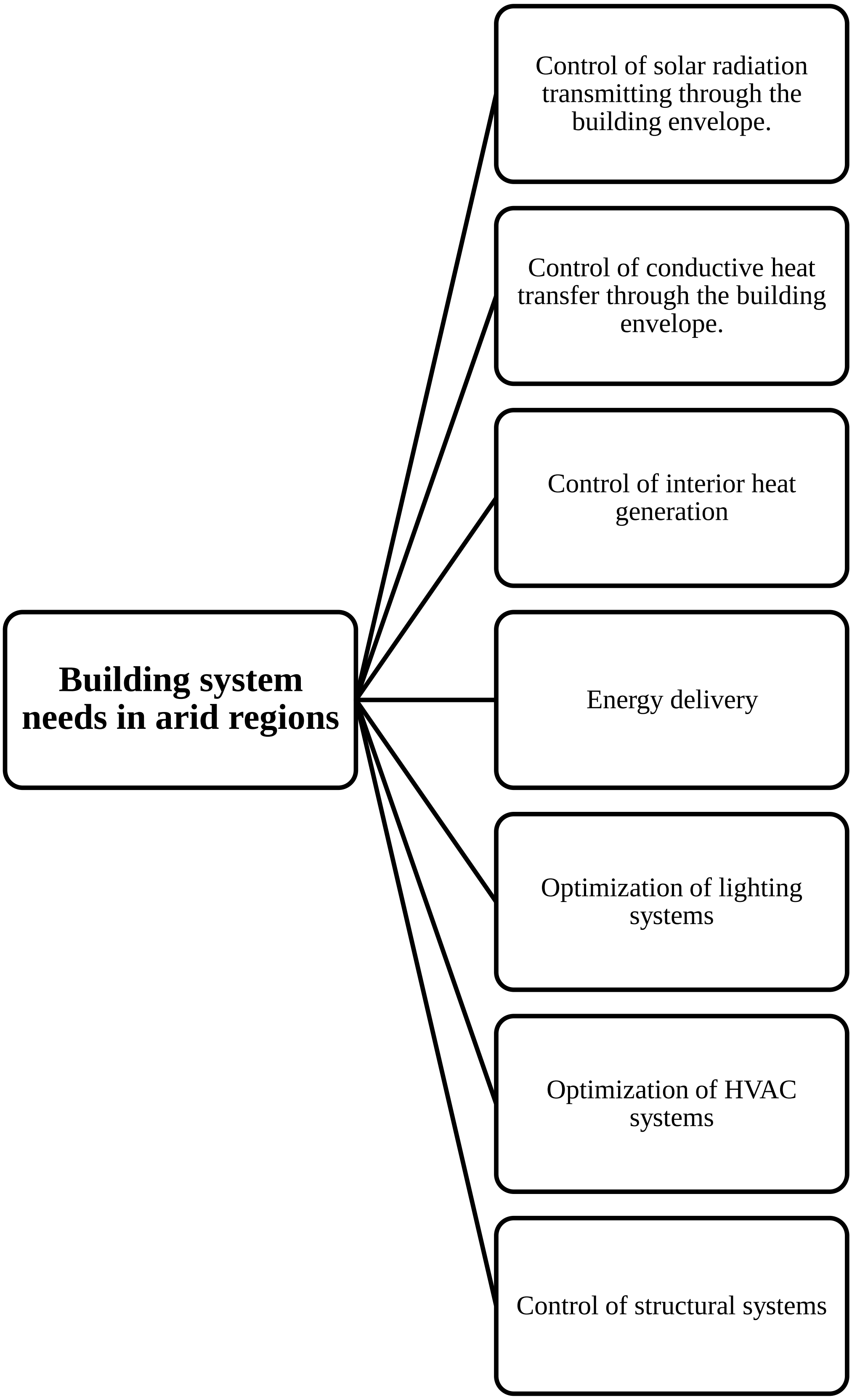

Fig. 3-30 shows the building systems needs in arid regions.
Source: Author, according to: Addington, M., Schodek, D., (2005)

Building System Needs	**Relevant Material or System Characteristics**	**Representative Applicable Smart Materials**
Control of solar radiation transmitting through the building envelope	Spectral absorptvity/ transmission of envelope materials	Suspended particle panels Liquid crystal panels Photochromics Electrochromics
	Relative position of envelope material	Louver or panel systems - exterior and exterior radiation (light) sensors : photovoltaics, photoelectrics - controls/actuators: shape memory alloys, electro and magnetorestrictive
Control of conductive heat transfer through the building envelope.	Thermal conductivity of envelope materials	Thermo-tropics, phase change materials
Control of interior heat generation	Heat capacity of interior material	Phase-change materials
	Relative location of heat source	Thermoelectrics
	Lumen/watt energy conversion	Photoluminescents, electroluminescents, light-emitting diodes
Energy delivery	Conversion of ambient energy to electrical energy	Photovoltaics, micro- and mesoenergy systems (thermoelectrics, fuel cells)
Optimization of lighting systems	Daylight sensing, Iluminance measurements, occupancy sensing	Photovoltaics, photoelectrics, pyroelectrics
	Relative size, location and color of source	Light-emitting diodes, electroluminescents

Optimization of HVAC systems	Temperature sensing, humidity sensing, occupancy sensing CO2 and chemical detection	Thermoelectrics, pyroelectrics, biosensors, chemical sensors, optical MEMS
	Relative location of source and/or sink	Thermoelectrics, phase-change materials
Control of structural systems	Stress and deformation monitoring Crack monitoring Stress and deformation control Vibration monitoring and control Euler buckling control	Fiber-optics, piezoelectrics, electrorheologicals (ERs), magnetorheologicals, shape memory alloys

Table 3-1 mapping of typical building systems designs needs in relation to potentially applicable smart materials

Source: Author, according to: Addington, M., Schodek, D., (2005)

3.4 Conclusions

Arid regions have many climatic characteristics such as: high temperature, low relative humidity and precipitation, high solar radiation, and wind. These characteristics cause many building problems such as overheating and high energy consumption, high solar radiation through the building envelope, lighting problems, and dust penetration.

Smart materials have many available product forms such as: paints, films, glasses, and dyes. Smart films have many different properties and exhibit a wide variety of different behaviors; they have different products such as: radiant color and mirror films, view directional films, image redirection films, Fresnel lens films, polarizing films, light pipes, photochromic films, thermochromic films, electroluminescent films, conductive polymer films, light-emitting polymers, photovoltaic films, and chemically sensitive color and shape-changing films. Smart glasses have many products such as: electro-optical glass, dichoric glass, and holographically patterned glass. Also smart fabrics have many products such as: light and color fabrics, fiber optic and electroluminescent weaves, breathable fabrics, property changing fabrics-thermochromic and photochromic cloths, and phase changing fabrics. Smart materials have many components, assemblies, and systems such as façade systems, lighting systems, and the smart window.

Based on the climatic characteristics and problems of arid regions, buildings in arid regions have many needs such as control of solar radiation transmitting through the building envelope, control of conductive heat transfer through the building envelope, control of interior heat generation, energy delivery, optimization of lighting systems, optimization of HVAC systems, and control of structural systems.

CASE STUDIES ANALYSIS

4.1 Introduction

Different examples will be presented in this chapter, demonstrating different applications of smart materials techniques and defining their features in each of them. Studying these examples will supply the research with a vision of where the usage of smart materials in building design stands in Egypt and the surrounding world.

In this chapter, the main objective is to drive the relation between using smart materials in buildings and its effect on solving building problems in hot arid regions by raising the building performance and decreasing the energy consumption. This will be studied through case studies.

4.2 Case Studies Methodology and Analysis Criteria

This part will analyze eight different case studies which are: DAR Headquarters Smart Village, Spiraling Triple Towered Eco Skyscraper for Cairo, Rotating Tower Dubai, Kempinski Hotel and Residences Sail Tower, World's Highest LED Screen in Dubai, Masdar City, Council House 2, and National Renewable Energy Laboratory's Research Support Facility.

The selected buildings use smart materials and have a significant effect in buildings' design either for being famous for their architectural concept as in case of Rotating Tower Dubai, and the World's Highest LED Screen in Dubai, or for their environmental impact as in the case of Council House 2, National Renewable Energy Laboratory's Research Support Facility, DAR Headquarters Smart Village, and Masdar City.

All of the selected case studies will be analyzed according to the following points: their basic information (such as location, architect, building type, and smart materials used), and the environmental treatments used (either the traditional treatments or treatments by using smart materials) in solving the building problems and achieving the different building system needs.

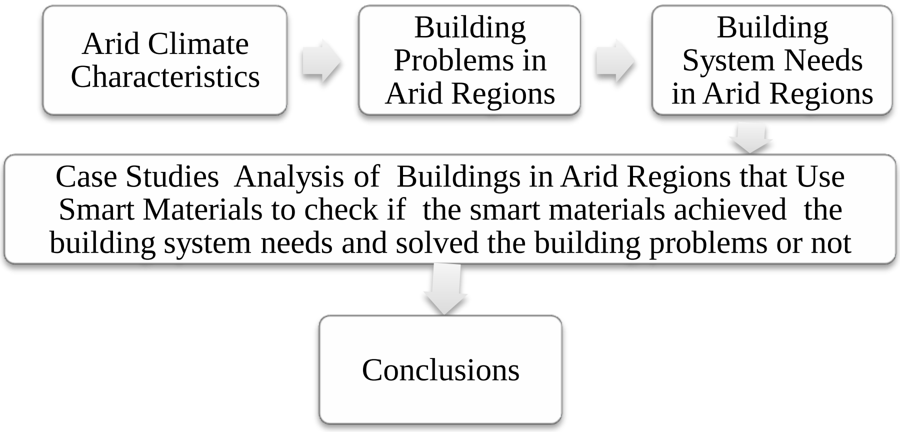

Fig. 4-1 The sequence of case study analysis

source: author

4.3 Dar Headquarters Smart Village

A new workplace that will enable innovation, infuse staff with a sense of belonging, allow flexibility and change, and promote collaboration throughout the organization.

4.3.1 Basic Data

Location	Cairo, Egypt
Building type	Office building
Architect	Perkins+Will Architects
Smart materials used	Photovoltaic panels

Dar al-Handasah, an international engineering and architectural firm, is consolidating all of its offices currently scattered throughout Cairo. The new 42,300 GSM headquarters will provide work and amenity space for approximately 2000 employees, including the company's Global Executive Leadership. The project is targeting LEED[1]-NC Gold. Fig. (4-1) shows the elevations of the project.

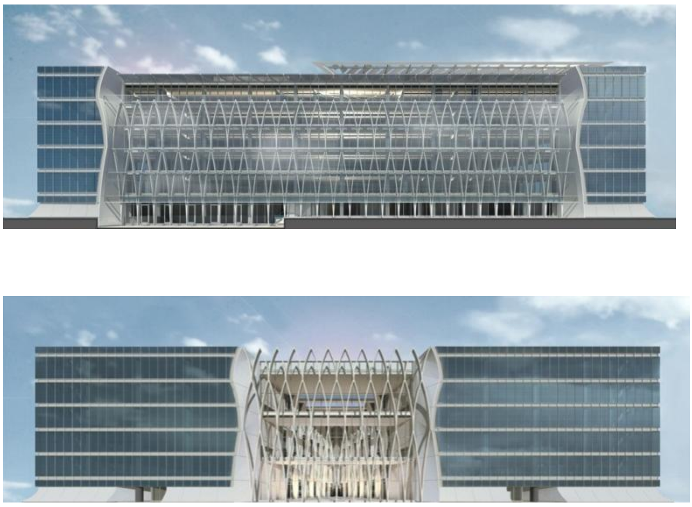

Fig. 4-2 Dar Headquarters Elevations.

Source: <u>http://www.perkinswill.com/work/dar-smart-village-headquarters.html</u>, accessed (10-5-2013)

The six floors of the building are approximately 4000 GSM each and the below-grade parking consists of three levels. To maintain such a large floor plate while maximizing day lighting penetration and views, the team folded the building upon itself and

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[1] The LEED rating systems are designed for rating new and existing commercial, institutional, and residential buildings. They are based on accepted energy and environmental principles and strike a balance between known, established practices and emerging concepts. Each rating system is organized into 5 environmental categories: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, and Indoor Environmental Quality. (U.S Green Building Council, (2009) , <u>LEED 2009 for Existing Buildings Operations and Maintenance</u> , Washington, U.S. Green Building Council).

designed a large glass atrium that draws in natural light from both the interior and exterior perimeter walls, as shown in fig. (4-2). To increase daylight penetration, the six-story atrium has a west-facing glass wall and skylights.

Fig. 4-3 Using the large glass atrium that draws in natural light .

Source: http://www.perkinswill.com/work/dar-smart-village-headquarters.html, accessed (10-5-2013)

4.3.2 The Environmental Treatments Used in the Building

The building uses many environmental treatments we can divide it into two categories: traditional treatments and treatments using smart materials.

4.3.2.1 Traditional Treatments

Although these elements promote heat gain, the atrium is designed as a thermal buffer between the exterior climate and the conditioned climate of the building. The skylights double as operable passive ventilation and to further enhance comfort in the space, the monumental stair is surrounded by a six-story water wall that removes condensation from the air and cools the space through evaporation. The monumental stair has a heliostat chandelier that drives daylight deep into the building core and is also a visual focus in the atrium space. Fig. (4-3) shows a sectional view showing the air flow in the building.

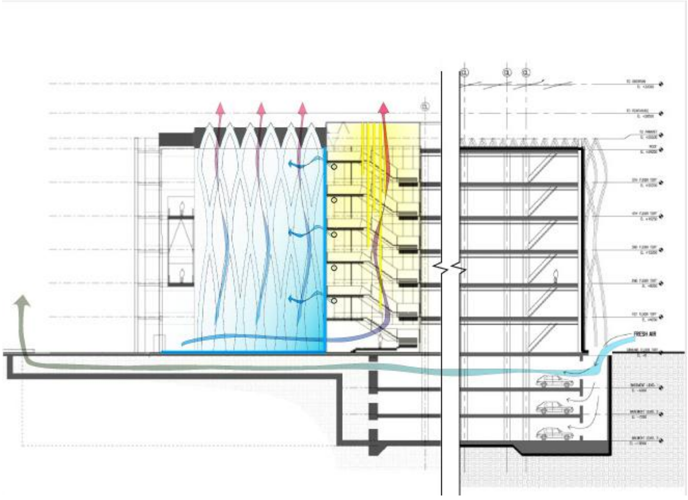

Fig. 4-4 A sectional view showing the air flow in the building

Source: http://www.perkinswill.com/work/dar-smart-village-headquarters.html, accessed (10-5-2013)

The warm climate of Cairo creates the challenge of reducing overall energy demands. The unique triangular shape of the building minimizes direct eastern and western exposure, which present the largest energy and comfort challenges. A vertical shading system is also used to shade approximately 75% of the building at over 50% of the total surface area[2]. Fig. (4-4) shows the vertical shades that used to reduce heat gain and glare.

Fig. 4-5 Using vertical shades to reduce the heat gain and glare.

Source: http://www.perkinswill.com/work/dar-smart-village-headquarters.html, accessed (10-5-2013)

4.3.2.2 Smart Materials Treatments

The upper floor of the building is net-zero demonstration space that utilizes sustainable elements integrated into the architecture. The rooftop event space is covered with 1000 SM of photovoltaic panels that gather solar energy while simultaneously acting as a shading device. The combined sustainable strategies result in an approximate 26% energy reduction over the ASHRAE[3] 90.1[4].

4.3.2.3 Key Features[5]

- Use of the atrium as an environmental "transition" zone with a water feature to temper & reduce humidity.
- Dedicated outside Air Systems (DOAS) with energy recovery and dehumidification systems.
- Reduced fan and pumping energy through system design and equipment selection.
- Enhanced electronic air filtration systems.
- Thermally powered variable volume air diffuser systems.
- Maximized day-lighting through building envelope and atrium design with automatic controls.

Fig. (4-5) shows the layout of the building, expressing all the environmental features that used in it.

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[2] Perkins+Will, (2011), http://www.perkinswill.com/work/dar-smart-village-headquarters.html , (accessed 10-5-2013)

[3] ASHRAE Standard 90.1–2007 is an industry standard that provides minimum requirements for the energy-efficient design of commercial buildings and criteria for determining compliance with these requirements. (U.S Green Building Council, (2011), Advanced Energy Modeling for LEED: Technical Manual Vol. 2, Washington, U.S. Green Building Council).

[4] Perkins+Will, (2011), http://www.perkinswill.com/work/dar-smart-village-headquarters.html , (accessed 10-5-2013)

[5] Perkins+Will, (2011), Ibid.

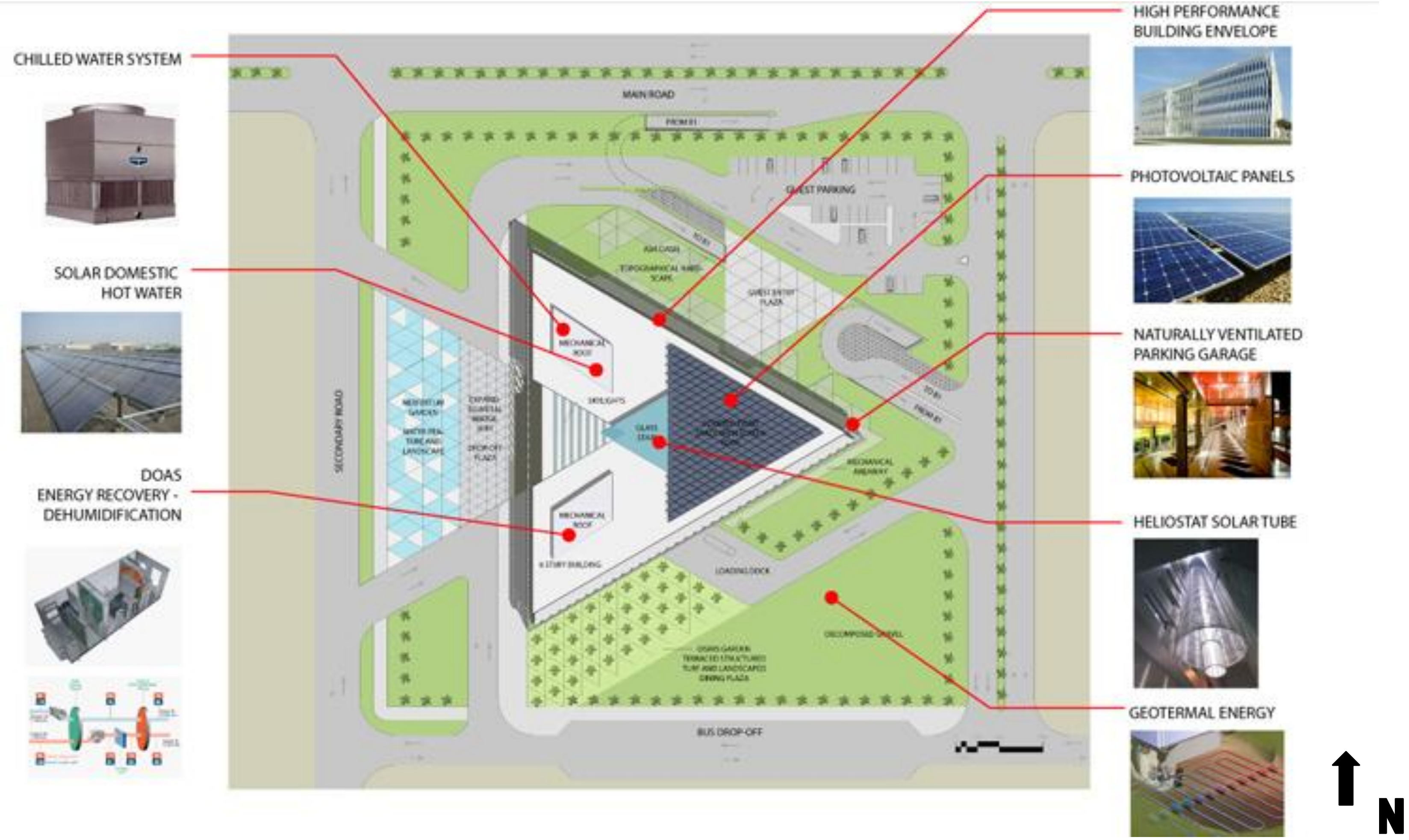

Fig. 4-6 Shows the triangular shape of the building which minimize the direct eastern and western exposure, The upper floor of the building is net-zero demonstration space that utilizes sustainable elements integrated into the architecture.

Source: Source: http://www.perkinswill.com/work/dar-smart-village-headquarters.html, accessed (10-5-2013)

4.4 Spiraling Triple Towered Eco Skyscraper for Cairo

The eco-skyscraper is dubbed “Space-Scraper” and located in the southern part of Cairo, Egypt. Designed by Mohamed Abdel-Aziz, this mixed-use development is composed by three twisting towers that are interconnected by a “geo-sphere” health center at the top.

4.4.1 Basic Data

Location	Cairo, Egypt
Building type	Mixed uses(offices, hotels, residential, and commercial)
Architect	Mohamed Abdel-Aziz
Smart materials used	Solar panels

Located directly on the banks of the Nile River, in the Maadi neighborhood located in the southern part of Cairo, Space-Scraper was designed to take advantage of all the many nearby attractions, like the river, the pyramids, which is not too far away.

The eco tower is supported by a wide ground floor podium, which contains seven floors of commercial space and includes restaurants, cinemas, and retail areas. Then three towers of varying heights spiral towards the sky and cradle a sphere which contains a health center with a spa, swimming pools and other fitness areas. The tallest of the towers contains office space, the medium has residential and the shortest has the hotel.

Fig. (4-6) & (4-7) expressing different views of the building showing the three towers and el podium.

Fig. 4-7 Spiraling Triple Eco Skyscraper for Cairo

Source: http://inhabitat.com/spiraling-triple-towered-eco-skyscraper-for-cairo/, accessed (12-5-2013)

Fig. 4-8 Night shot to the building shows the three towers of the building and the podium

Source: http://inhabitat.com/spiraling-triple-towered-eco-skyscraper-for-cairo/, accessed (12-5-2013)

4.4.2 The Environmental Treatments Used in the Building

The architecture is definitely an eco-friendly one since it uses different treatments such as:

4.4.2.1 Smart Materials Treatments

The building is powered by solar panels that used to support the building with electric power.

4.4.2.2 Other Treatments

The building uses wind turbines and equipped with water recollection systems, to make the building an eco-friendly one.

4.5 Rotating Tower Dubai

Visionary architect Dr. David Fisher is the creator of the world's first building in motion - the revolutionary Dynamic Tower. It will adjust itself to the sun, wind, weather and views by rotating each floor separately. This building will never appear exactly the same twice.

4.5.1 Basic Data

Location	Dubai, UAE
Building type	Mixed use (office, hotel, residential apartments)
Architect	David Fisher
Smart materials used	Photovoltaic panels

The Dynamic Tower in Dubai will be 1,380 feet (420 meters) tall, 80 floors, apartments will range in size from 1,330 square feet (124 square meters), to Villas of 12,900 square feet (1,200 square meters) complete with a parking space inside the apartment. It will consist of offices, a luxury hotel, residential apartments, and the top 10 floors will be for luxury villas located in a prime location in Dubai[6]. Fig. (4-8) shows the endless shape of the tower.

Fig. 4-9 Rotating Tower Dubai endless shape

Source: http://www.dynamicarchitecture.net, accessed (10-5-2013)

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[6] Unusual Architecture, (2008), http://unusual-architecture.com/rotating-tower-dubai-uae/ (accessed 16-5-2013).

The Dynamic Architecture building has been aptly named Rotating Tower as the floors would be capable of rotating around a central axis. It will be continually in motion, changing shape and giving residents the ability to choose a new view at the touch of a button. The form of the building would constantly change as each floor rotates separately giving a new view of the building as it turns. According to Fisher, the building ensures a very high resistance to earthquakes as each floor rotates independently.

Fig. 4-10 An illustration of how the single modules are assembled around the core of the tower.

Source: http://www.dynamicarchitecture.net, accessed (10-5-2013)

The new tower is the first building of its size to produce in a factory. Each floor, made up of 12 individual units, complete with plumbing, electric connections, air conditioning, etc., will be fabricated in a factory. These modular units will be fitted on the concrete core or spine of the building at the central tower. Fig. (4-9) expressing an illustration of how the single modules fitted on the concrete core.

4.5.2 The Environmental Treatments Used in the Building

The building will be powered entirely by sun and wind energy. And, the architect claims that the building will generate 10 times more energy than required to power it, thus making it a positive energy building through:

4.5.2.1 Using Smart Materials

Solar panels will be fitted on the roof to harness sunlight, and generate electricity, as shown in fig. (4-10).

Fig. 4-11 Using photovoltaic panels between the tower's floors

Source: http://www.dynamicarchitecture.net, accessed (10-5-2013)

4.5.2.2 Using Other Treatments

a total of 48 wind turbines will be sandwiched between the rotating floors, placed so that they are practically invisible. Each wind turbine could produce up to 0.3 megawatt of electricity, and it is estimated that 1,200,000 kilowatt-hours of energy would be generated every year[7].

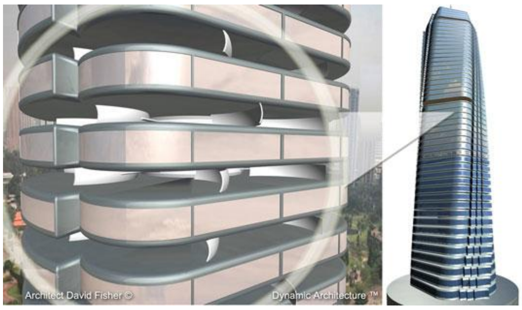

Fig. 4-12 using the horizontal wind turbines, placed between the tower's floors

Source: http://www.dynamicarchitecture.net, accessed (10-5-2013)

4.6 Kempinski Hotel and Residences Sail Tower

Inspired by its prominent location directly on the Red Sea, this project explores the concept of the "architectural sail" as a multifunctional architectonic element that responds to the essential influences of program, site and climate to create a unique expression of texture and light.

4.6.1 Basic Data

Location	Jeddah, Saudi Arabia
Building Type	Mixed use(residential, multi-family residence, tourism, hotel)
Architect	Perkins+Will Architects
Smart materials used	LED

The project, situated along the Corniche in Jeddah, and extends the growth of waterfront development advancing north from the old city center. The recent growth of Jeddah as a resort destination for both Saudis as well as foreigners has raised the matter of how to create successful hospitality environments that address both climatic and cultural issues.

Fig. 4-13 shows the podium of the tower

Source:http://www.perkinswill.com/work/kempinski-hotel-and-residences-sailtower.html, accessed (7-5-2013)

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[7] Unusual Architecture, (2008), http://unusual-architecture.com/rotating-tower-dubai-uae/ (accessed 16-5-2013).

The sails, designed to be prefabricated off-site, are composed of aluminum frames wrapped with a durable, Teflon-coated synthetic fabric. Erected off-site and flat-packed, the units can be transported by elevator to each floor, expanded with an internal screw jack ‘mast’ mechanism, and set in place. The program for the 60-story, 63,000 sm building mixes a 242-key luxury hotel, 104 residential units, amenities, support spaces, and 600-car enclosed parking[8]. Fig. (4-12) & (4-13) show the shape of the podium and tower.

Fig. 4-14 Kempinski Hotel and Residences SailTower

Source:http://www.perkinswill.com/work/kempinski-hotel-and-residences-sailtower.html, accessed (7-5-2013)

The client requested that the tower be as tall as zoning permitted. In contrast to the ubiquitous "shape-making" that characterizes recent commercial development in places in the Gulf, the building is a simple, slender rectangle, oriented along the E/W axis to optimize solar exposure, shade the entrance court to the north and maximize views to the water. Major program elements are organized as a continuous ribbon from below grade to penthouse, becoming more private as they rise. Correspondingly, balcony size increases with height to create outdoor rooms at the upper residential levels. Fig. (4-14) expressing the building orientation to optimize the water view.

Fig. 4-15 The building is oriented to optimize water view.

Source:http://www.perkinswill.com/work/kempinski-hotel-and-residences-sailtower.html, accessed (7-5-2013)

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[8] URL: http://www.perkinswill.com/work/kempinski-hotel-and-residences-sailtower.html, accessed (7-5-2013)

4.6.2 The Environmental Treatments Used in the Building

This gradual deepening of exterior space and rotating of the architectural sails to open to the view creates a dramatic pattern and texture for the skin of the building while giving privacy between adjacent rooms, orienting views to the water, and limiting the negative effects of sun and wind.

4.6.2.1 Using Smart Materials Treatments

Because the panels become perpendicular at the top of the building where the balconies are deepest, the building transforms from an expression that is primarily surface at its base to one that is primarily void as the enclosure dematerializes with height. The sails in turn become sources of light in the evening, with integrated LED fixtures providing a soft glow that can be programmed to create a dynamic, flowing array throughout the entire surface of the building. This approach is based on innovative tectonics rather than formal gesture, results in a unique architectural expression with a clear sense of place and identity. Fig. (4-15) express the LED shape and how it looks at night when it produces light.

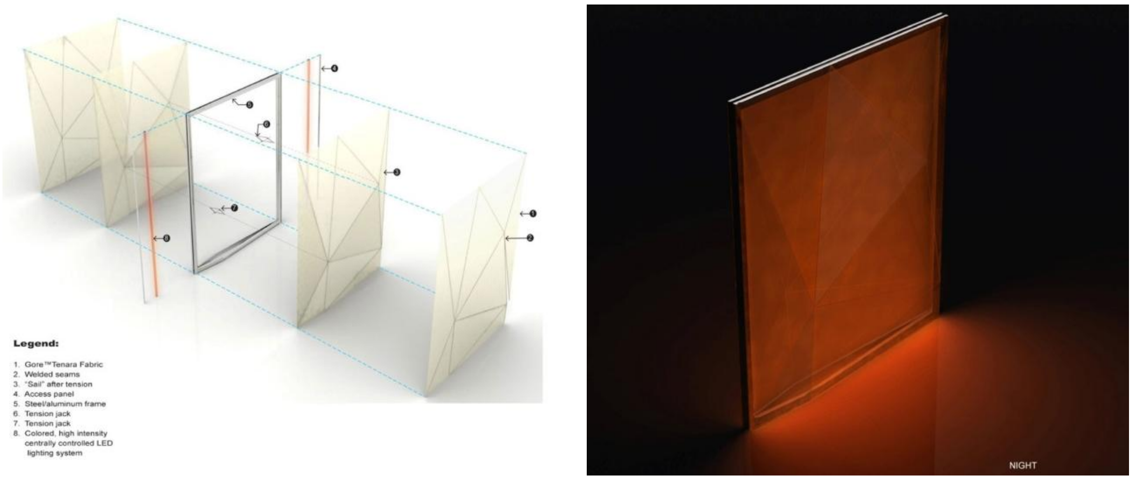

Fig. 4-16 Using LEDS to provide a soft glow of light

Source: Source:http://www.perkinswill.com/work/kempinski-hotel-and-residences-sailtower.html, accessed (7-5-2013)

4.7 World's Highest LED Screen

Dubai is set to be home to the world’s largest LED screen - a curved, tall monster that will be visible from a distance of just under 1 mile.

4.7.1 Basic Data

Location	Dubai, UAE
Building type	Mixed use (commercial and office building)
Architect	Tameer Holding
Smart materials used	LED

Tameer Holding, a development company based in the United Arab Emirates will build the massive screen which will be situated within the Mahan district of the entertainment complex Dubailand.

The world's largest LED display from the hand of the UAE, will be installed to dubai, according to research Majan commercial center of the LED panel Tameer Holding introduction, this huge LED screen Podium "called", it is sufficient 33 floors so high, covering the whole building body side, even if in 1.5 kilometers it also clearly visible.

Podium will combine architecture and technology to deliver a powerful medium for advertising, messaging and art. The highly-reflective tinted glass will be utilized to achieve a striking visual impact, giving the massive screen a bluish glow, as shown in fig. (4-16). Aluminum panels, mullions and canopies will frame the glass components in buffed natural aluminum.

Fig. 4-17 World’s largest led screen building

Source: http://mtidry.wordpress.com/2010/01/28/dynamicexteriors/, accessed (12-5-2013)

The building itself will offer 33 levels of commercial office space and two floors of retail, with additional retail stores available on the ground level and mezzanine. A grand and spacious lobby will feature a water cascade to be delivered by the illusion of water passing through fluted glass channels. A whopping four floors will be dedicated to car parking, utilizing.

4.7.2 Smart Materials Used and its Effect

The LED panel is advertising, information dissemination and artistic dissemination of good carrier. And "Podium" screen, the double is dozens of floors of the building, including 33 layer is commercial office, retail shopping district 2 layer, layer 4 is no-parking area. Tameer in design and manufacture the led panel had adopted new technology when, make its will not prevent natural led light, even screen behind the office area also can have bright environment.

4.8 Masdar City

Masdar City combines state-of-the-art technologies with the planning principals of traditional Arab settlements to create a desert community that aims to be carbon neutral and zero waste.

4.8.1 Basic Data

Location	Abu Dhabi, UAE
Building type	Mixed use(residential, commercial, institutions, services)
Architect	Foster+ Partner
Smart materials used	Photovoltaic cells

Planned Investment: $28 Billion

Fast Track:7 years

Full City Development: Residential, Commercial, Institutions, Full services.

. The 640-hectare project is a key component of the Masdar Initiative, established by the government of Abu Dhabi to advance the development of renewable energy and clean-technology solutions for a life beyond oil. The city will become a centre for the advancement of new ideas for energy production, with the ambition of attracting the highest levels of expertise. Knowledge gained here has already aided the development of Abu Dhabi's 'Estidama' rating system for sustainable building.

A mixed-use, low-rise, high-density development, Masdar City includes the headquarters for the International Renewable Energy Agency and the recently completed Masdar Institute. Strategically located for Abu Dhabi's transport infrastructure, Masdar is linked to neighboring communities and the international airport by existing road and rail routes. The city itself will be

Fig. 4-18 Masdar City

Source: http://www.utilities-me.com/pictures/gallery/masdar.jpg, accessed (20-5-2013)

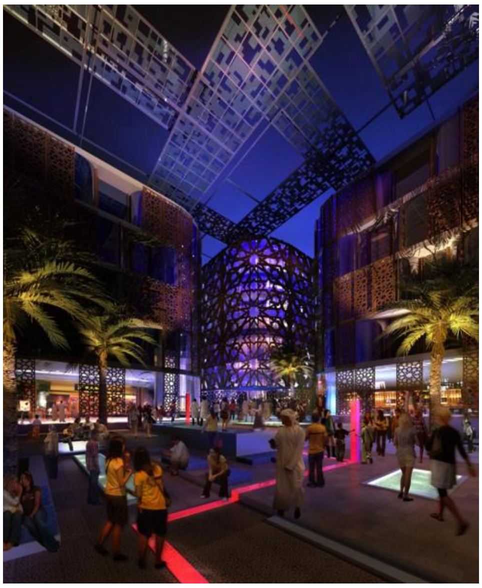

Fig. 4-19 Image shows the streets at night

Source: http://www.fosterandpartners.com/projects/masdar-development/, accessed (20-5-2013)

the first modern community in the world to operate without fossil-fuelled vehicles at street level. With a maximum distance of 200 meters to the nearest rapid transport links and amenities, the city is designed to encourage walking, while its shaded streets and courtyards offer an attractive pedestrian environment, sheltered from climatic extremes. The land surrounding the city will contain wind and photovoltaic farms, research fields and plantations, allowing the community to be entirely energy self-sufficient. Fig. (4-18) & (4-19) shows the streets in masdar city.

The development is divided into two sectors, bridged by a linear park, and is being constructed in phases, beginning with the larger sector. The master plan is designed to be highly flexible, to allow it to benefit from emergent technologies and to respond to lessons learnt during the implementation of the initial phases. Expansion has been anticipated from the outset, allowing for growth while avoiding the sprawl that besets so many cities. While, Masdar's design represents a specific response to its location and climate, the underlying principles are applicable anywhere the world. In that sense it offers a blueprint for the sustainable city of the future.

Fig. 4-20 Life in Masdar City, street scapes.

Source: http://www.fosterandpartners.com/projects/masdar-development/, accessed (20-5-2013)

4.8.2 The Environmental Treatments Used in the Building

Masdar City is an emerging global clean-technology cluster located in what aims to be one of the world’s most sustainable urban development’s powered by renewable energy. Located about 17km from downtown Abu Dhabi, Masdar will eventually be home to companies, researchers, and academics from across the globe, creating an international hub for companies and organizations focused on renewable energy and clean technologies. Inspired by the architecture and urban planning of traditional Arab cities, Masdar City incorporates narrow streets; the shading of windows, exterior walls and walkways; thick-walled buildings; courtyards and wind towers; vegetation and a generally walk able city.

The design provides the highest quality living and working environment with the lowest possible carbon footprint and includes a northeast-southwest orientation of the city. This makes best use of the cooling night breezes and lessens the effect of hot daytime winds. The intelligent design of residential and commercial spaces will reduce demand for artificial lighting and air conditioning. All buildings will surpass the highest sustainable building standards currently set by internationally recognized organizations. Fig. (4-20) shows the interior of the city.

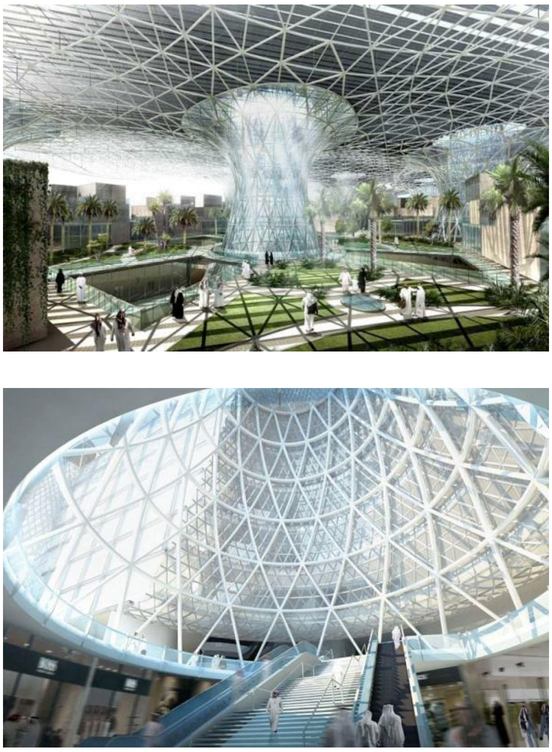

Fig. 4-21 Life in Masdar City, Masdar interior

Source: http://www.e-architect.co.uk/dubai/masdar_headquarters_abu_dhabi.htm, accessed (20-5-2013)

4.8.2.1 Using Smart Materials

The city will be powered with photovoltaic cells at the roof and shades.

4.8.2.2 Using Other Sustainable Treatments

The city uses many sustainable treatments like wind turbines, electric chillers, and water and waste treatments.

Water: grey water recycling, Desalination of seawater, Treated Sewage Effluent (TSE) from black water, Recycled water uses in irrigation, cooling systems, and construction (concrete batching).

Waste: Segregation into waste streams, converting waste to energy.

Fig.(4-21) shows the city layering, fig.(4-22) shows the sustainable elements used in the City and their environmental impact.

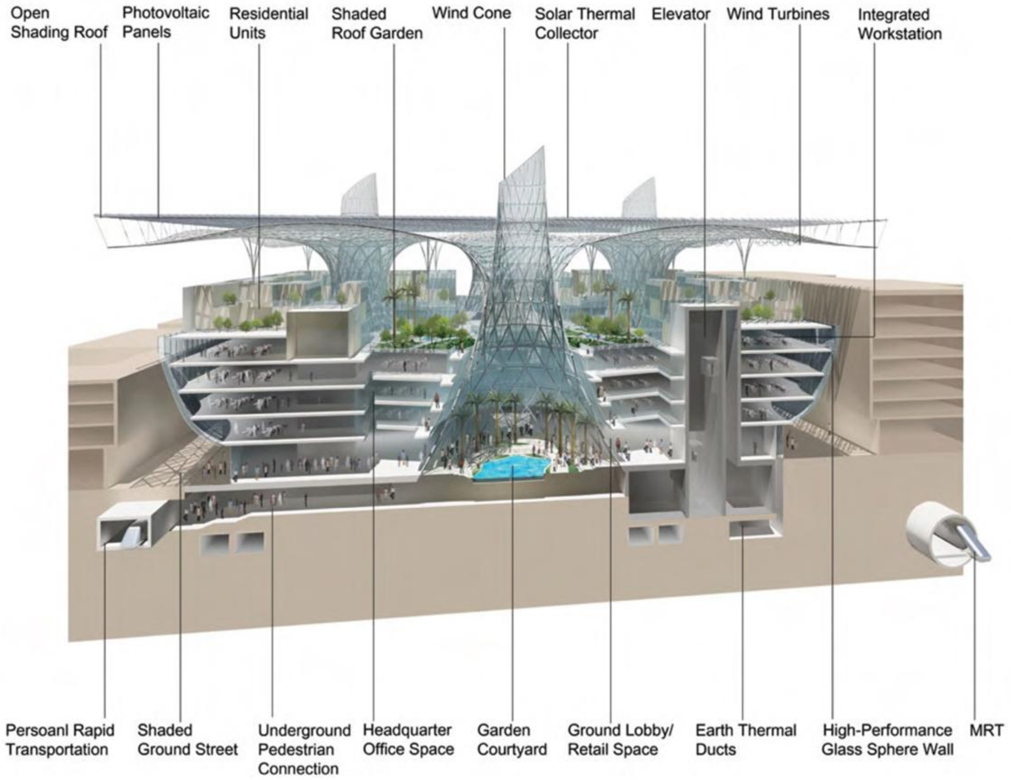

Fig. 4-22 Masdar City layering

Source: http://www.renewablepowernews.com/wp-content/uploads/Masdar-HQ-Sustainability-strategies-section2.jpg, accessed (20-5-2013)

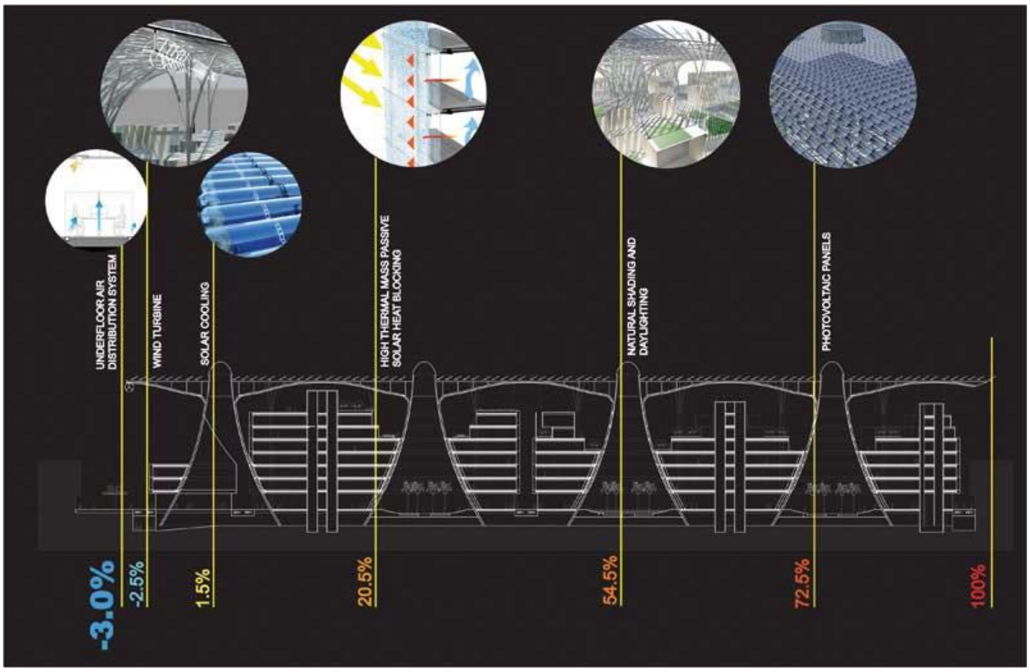

Fig. 4-23 Shows the sustainable elements used in Masdar City and their environmental impact

Source: http://www.e-architect.co.uk/images/jpgs/dubai/masdar_headquarters_edelman250208_8.jpg, accessed (20-5-2013)

4.9 Council House 2

Melbourne Council House 2 (CH2) is a multi-award winning and inspirational building that has reduced CO2 emissions by 87%, electricity consumption by 82%, gas by 87% and water by 72%. The building purges stale air at night and pulls in 100% fresh air during the day. The building exterior moves with the sun to reflect and collect heat, and turns sewage into usable water. The building has improved staff effectiveness by 4.9% and will pay for its sustainable features in a little over a decade[9].

4.9.1 Basic Data

Location	Melbourne, Australia
Building type	Office building
Architect	Design Inc
Smart materials used	Photovoltaic and phase change materials

Council House 2 is a 10-storey office building for about 540 City of Melbourne staff, located at 240 Little Collins Street, Melbourne Australia. It has ground-floor retail spaces and underground parking and was officially opened in August 2006. CH2 has been designed to copy the planet's ecology using the natural 24-hour cycle of solar energy, natural light, air and rainwater, to power, heat, cool, and water the building.

CH2 has been designed to copy the planet's ecology using the natural 24-hour cycle of solar energy, natural light, air and rainwater, to power, heat, cool, and water the building.

Fig. 4-24 Council House Exterior

Source: http://architecture.rmit.edu.au/Projects/Images/sustainable/CH2Exterior.jpg, accessed (22-5-2013)

4.9.2 Environmental treatments

CH2 has been successful because it has taken a ‘ground up’ green design approach, for example:

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[9] URL: http://www.c40cities.org/c40cities/melbourne/city_case_studies/council-house-2-ch2-new-municipal-office-building-eco-buildings-co2-87-electricity-82-gas-87-and-water-72 , accessed(27-5-2013).

- designers considered the best environmental options and solutions
- recycled products such as concrete, cement, steel and timber were used in construction
- sustainable and energy savings products were used at every point
- a formal accreditation system was set up requiring all contractors, service providers and companies supplying products, to meet strict standards of sustainability in their products and services.

Fig. (4-26) & (4-27) show a section and a bioclimatic section to the sustainable process in the building and their effects.

4.9.2.1 Smart Materials Treatments

Photovoltaic cells: which generate electricity and power a façade of louvers which track the sun to ensure the building is shaded. Fig. (4-24) shows the solar shading when they are opened.

Solar panels: used for water heating.

Phase change materials: water is piped to phase change plant for re-cooling.

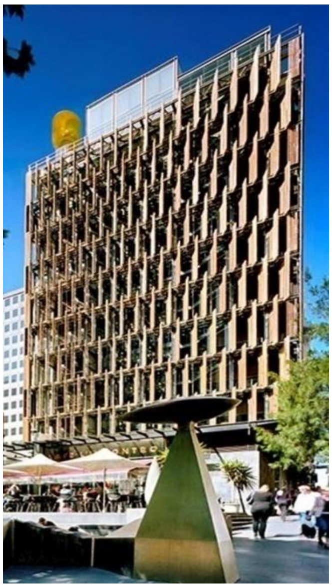


Fig. 4-25 The building when the solar shadings are opened

Source: http://www.adelaidehydronicheating.com.au/rebates%20fotos/chs%20building.jpg, accessed (27-5-2013)

4.9.2.2 Other sustainable treatments

The timber shades made of recycled lumber that open depending on the intensity of the sun.

Water: CH2 takes about 100,000 liters of toilet water every day from a nearby sewer in Little Collins Street. This sewage is then processed, along with sewage from the building, through a multi-water treatment plant on site. The system filters out the water and sends the solids back to the sewer. (City sewers typically hold about 95% of water, this water is a burden to the system and would otherwise be wasted). The extracted water is treated using a micro-filtration system that creates A-grade clean water suitable for non-drinking uses. Some of the recovered water is used for water-cooling, plant watering and toilet flushing; the rest is used in other council buildings, city fountains and used to water plants.

Heating: CH2's north façade has 10 dark colored air ducts that absorb heat from the sun; the hot air rises taking the stale air up and out of the building. The south façade has light-colored ducts that draw in 100% fresh air from the roof and distribute it down through the building. The west façade has louvers made from recycled timber that move according to the position of the sun and are powered by photovoltaic roof panels. Fig. (4-25) shows heating and cooling in Council House 2.

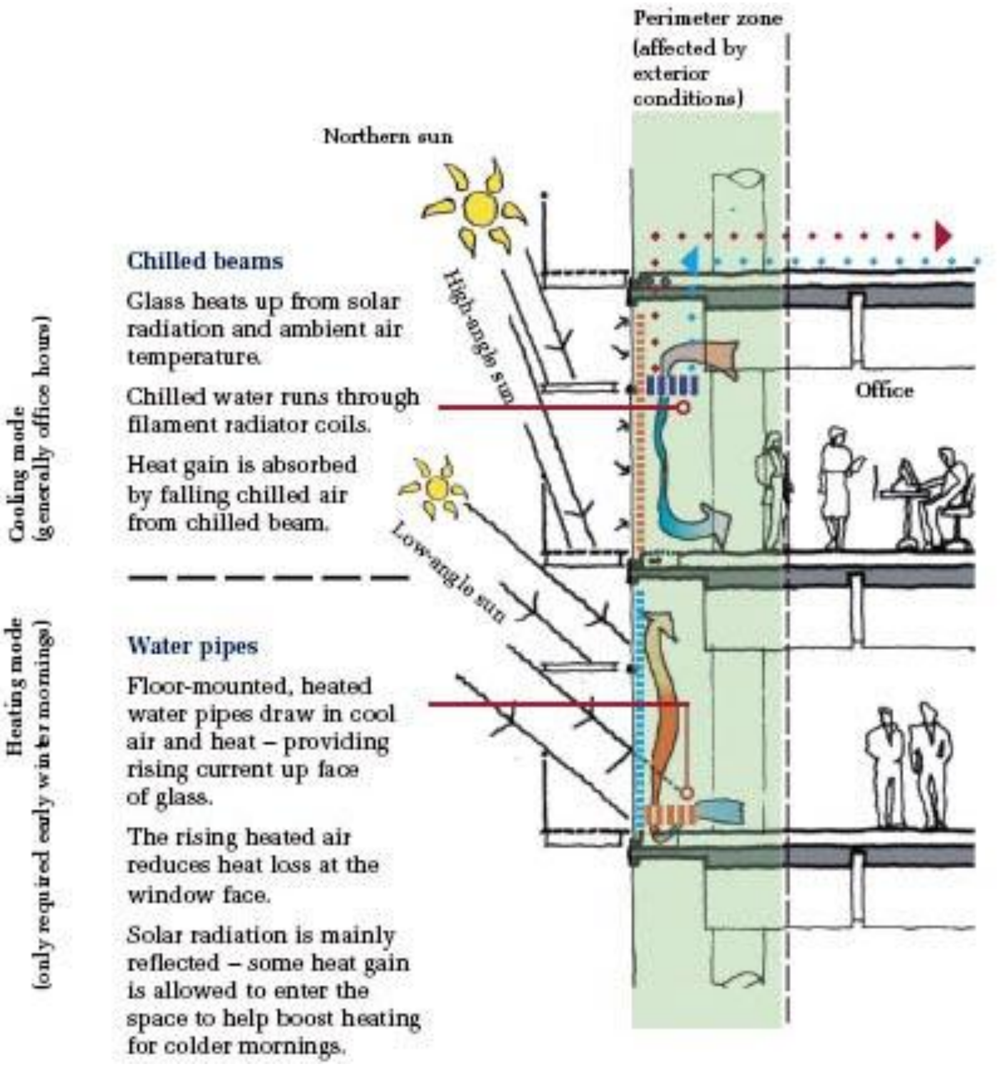


Fig. 4-26 Heating and cooling in Council House2

Source:http://architectureau.com/site_media/media/files/archive/architecture_australia/images/2007/01/images/190301.jpg, accessed (27-5-2013)

Undulating high thermal mass concrete ceilings which improve air circulation, cooling and natural light and reduce energy demands by 14% in summer.Glare control throughout the building.

'Shower towers' that cool water and air using low amounts of energy.

A green roof space generating oxygen.

Roof mounted wind turbines that purge air during the night and generate electricity during the day.

Automatic night-purge windows to cool the concrete ceilings.

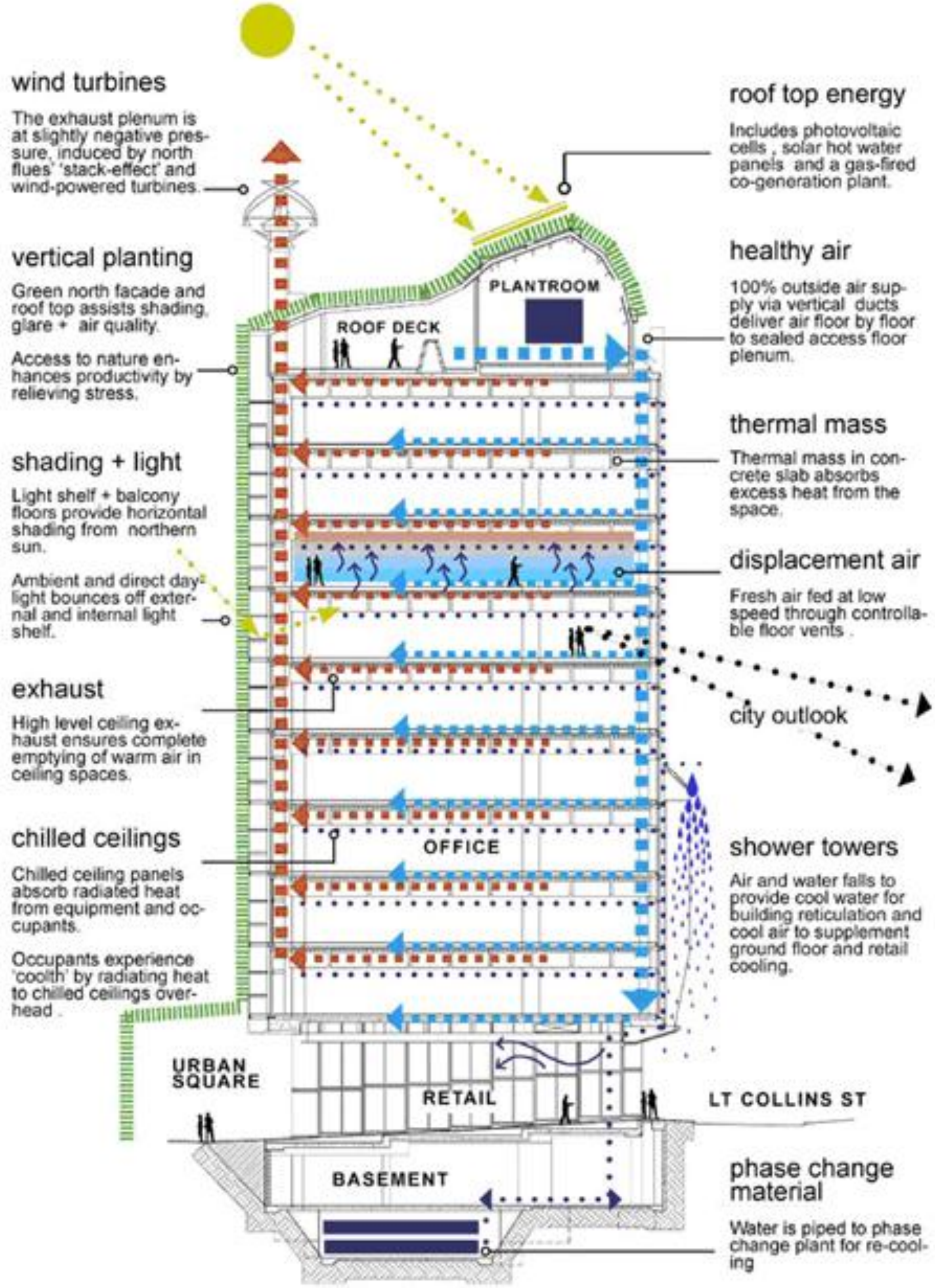
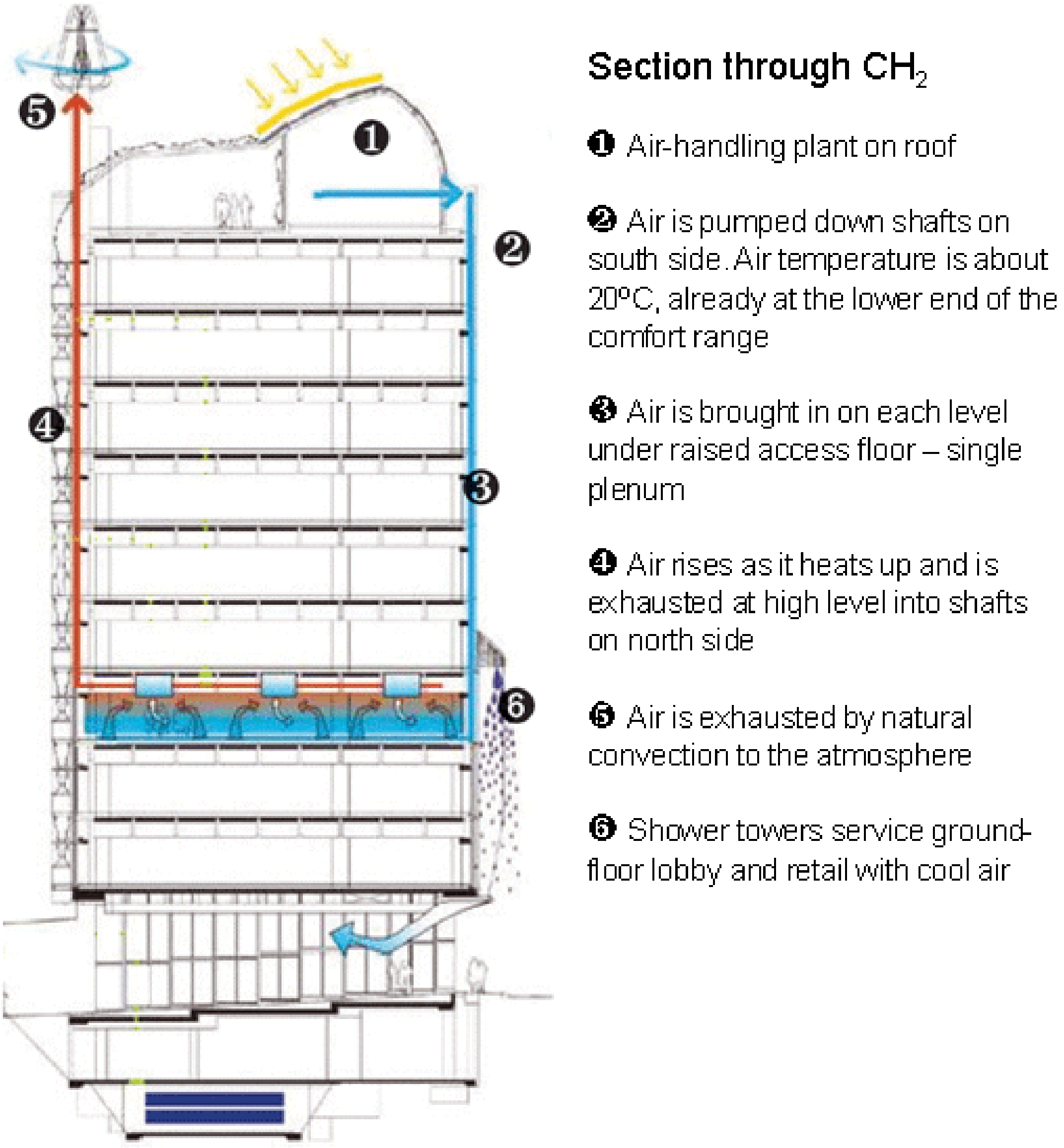


Fig. 4-27 Bioclimatic section

Source: http://www.yourbuilding.org/library/Case%20study%20figure%205.jpg, accessed (27-5-2013)



Section through CH$_2$

❶ Air-handling plant on roof

❷ Air is pumped down shafts on south side. Air temperature is about 20°C, already at the lower end of the comfort range

❸ Air is brought in on each level under raised access floor – single plenum

❹ Air rises as it heats up and is exhausted at high level into shafts on north side

❺ Air is exhausted by natural convection to the atmosphere

❻ Shower towers service ground-floor lobby and retail with cool air

Fig. 4-28 Section through the building shows the sustainable process in the building

Source: http://www.building.co.uk/Journals/Graphic/h/j/s/CROSS-SECTION.gif, accessed (27-5-2013)

4.10 National Renewable Energy Laboratory's Research Support Facility

The building showcases sustainable, high-performance design as NREL's newest addition to its portfolio of energy efficient buildings.

4.10.1 Basic Data

Location	Golden, Colorado
Building type	Mixed use(energy laboratory’s research, offices)
Architect	RNL
Smart materials used	Photovoltaic, photochromic and thermochromic glazing

While functioning as an office space, the building doubles as a laboratory of technologies; allowing researchers to collect real-time performance data, measuring and tracking the building's energy use. This facility houses approximately 1,300 occupants the building performance has generated numerous awards for the facility as well as a LEED Platinum rating[10.]

The design/build team used a whole-building integrated design process so the Research Support Facility could serve as a model for cost-competitive, high-performance commercial buildings. The process encouraged innovation, reduced owner's risk, resulted in faster construction, controlled costs, optimized team member's expertise, and established measurable success criteria. The first design focus was on energy efficiency features, followed by renewable energy strategies. Extensive energy modeling was used to establish the basic structure and design of the building, with the energy performance requirements guiding its form and impacting its various functions.

Fig. 4-29 The RSF has a skewed-H-shaped plan defining exterior courtyards. The building's two wings are elongated on the east-west axis to make the most of sunlight for interior illumination.

Source: http://continuingeducation.construction.com/article_print.php?L=5&C=728, accessed (28-5-2013)

4.10.2 Environmental Treatments

Unlike traditional design where architecture defines the form and impacts the function of building, energy performance requirements drove the RSF. Incorporates the best in energy efficiency, environmental performance, and advanced controls using a “whole building” integrated design process.

4.10.2.1 Smart Materials Treatments

The building used different types of smart materials:

Photovoltaic cells: the RSF roof has a south-facing 10-degree slope, and a standing seam metal roof that offers an optimal mounting surface for a rooftop photovoltaic (PV) system. The roof is covered with 450 kW of PV panels that are more than 17% efficient. The rooftop array alone will not offset the RSF’s energy needs, so several adjacent parking structures will be covered with additional PV. The combination rooftop array and parking structure arrays will provide 1.6 MW of PV to offset all the RSF’s annual energy needs[11].

Thermochromic glazing: the eastern elevation features thermochromic window to resist the heat transfer or reduce heat loss.

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[10] URL: http://www.commercialwindows.org/case_nrel.php , accessed (27-5-2013).

[11] URL: http://www.commercialwindows.org/case_nrel.php , Ibid.

Electrochromic glazing: the west elevation features electrochromic glazing it tints in response to a small electric current to reduce heat gain.

4.10.2.2 Other Sustainable Treatments

Building efficiency features through day lighting and natural ventilation where:

Day lighting:

A light louvers day lighting systems reflect sunlight to the ceiling, create an indirect lighting effect. Fixed sunshades limit excess light and glare, as shown in fig. (4-29).

Light enters through the upper glass and highly reflective louvers direct it toward the ceiling and deeper into the space.

Light colored, reflective surfaces and low cubicle heights permit the penetration deep into workspaces.

Natural Ventilation

During mild weather, operable windows allow for natural ventilation.

Automatic windows are controlled and operated primarily to support nighttime pre-cooling.

Triple-glazed windows: with individual overhangs maximize day lighting and minimize glare, as well as heat loss and gain.

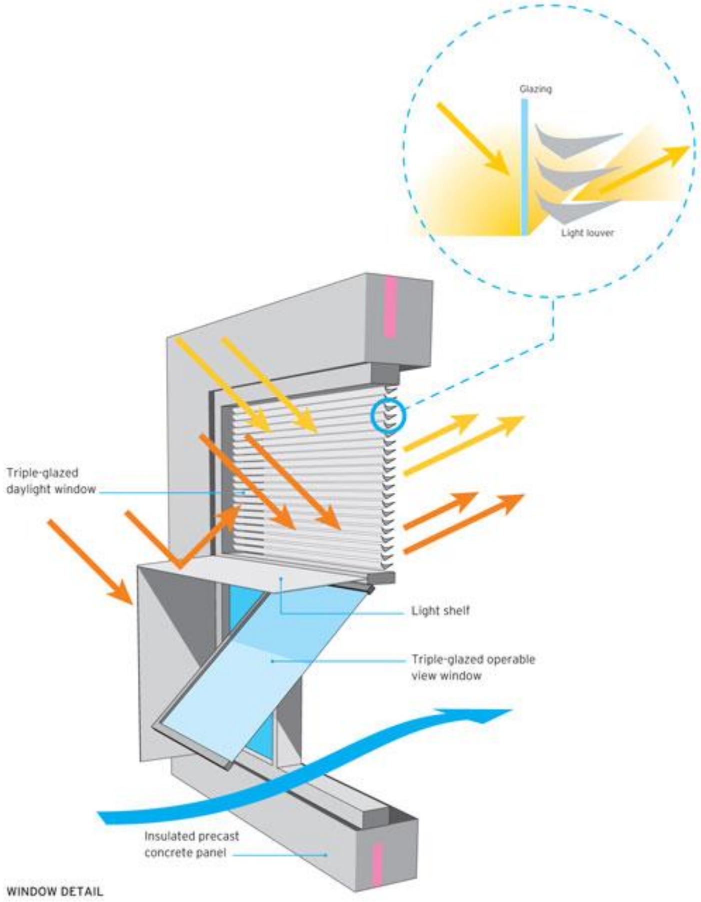

Fig. 4-30 A light louver day lighting system reflects sunlight to the ceiling, creating an indirect lighting effect. Fixed sunshades limit excess light and glare.

Source: http://continuingeducation.construction.com/article_print.php?L=5&C=728, accessed (28-5-2013)

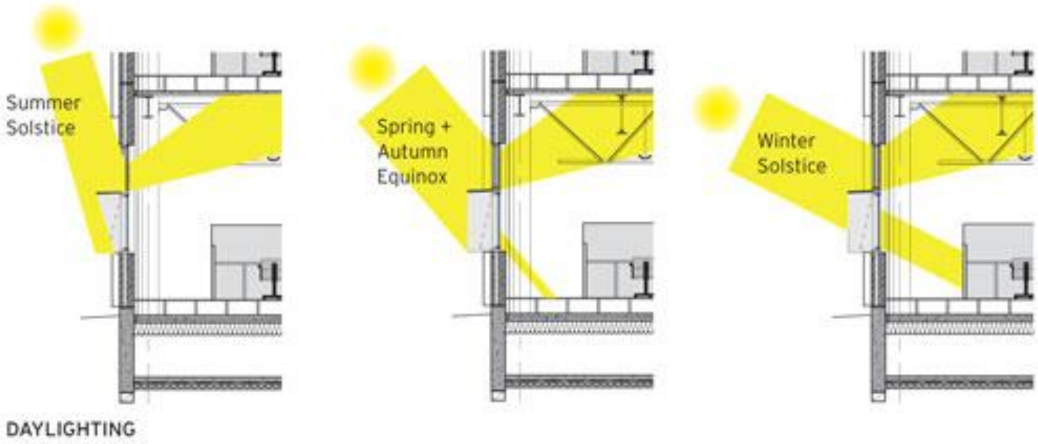

Fig. 4-31 The geometry of the windows and shading devices on the RSF's south-facing windows limits heat gain and glare while allowing for effective day lighting.

Source: http://continuingeducation.construction.com/article_print.php?L=5&C=728, accessed (28-5-2013)

Various day lighting strategies were used to reduce the power consumption of the building considerably compared to ASHRAE 90.1-2007. Two long wings, with an east-west orientation increase the natural daylight entering the building. The windows on these wings allow light to enter through the upper glass and then highly reflective louvers direct it toward the ceiling and deeper into the space — creating an indirect lighting effect. Light-colored reflective surfaces and low cubicle heights permit the penetration of light deep into workspaces. These day lighting strategies allow for fully daylight office spaces with no occupant more than thirty feet from a window[12]. Fig. (4-31) & (4-32) show the geometry and shading devices on the south-facing.

Fig. 4-32 South-facing windows with shading projections surrounding the vision area.

Source: http://www.commercialwindows.org/case_nrel.php, accessed (28-5-2013)

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[12] URL: http://www.commercialwindows.org/case_nrel.php , accessed (27-5-2013).

4.10.2.3 Key Design Strategies

The building includes many design strategies such as[13]:

- Optimal orientation and office space layout to maximize day lighting while minimizing unwanted heat gains and losses. Fully daylight office wings with south-facing windows that reflect daylight to the ceiling and deep into the office space with light-reflecting devices.
- Continuous insulation precast wall panels with thermal mass.
- A labyrinth of thermal storage in the crawl space to provide passive heating and cooling.
- Triple-glazed operable windows for high performance and natural ventilation, individual window sunshades to provide shade when needed.
- Radiant heating and cooling, under-floor distributed ventilation.
- Outdoor air preheating using transpired solar collectors before delivery to the thermal storage labyrinth and occupied spaces. A data center that uses evaporative cooling, outside air ventilation, waste heat capture, and efficient servers.
- Roof top-and parking lot-based photovoltaic (2.5 MW).

Fig. (4-32)& (4-33) & (4-34) show the different types of environmental control used in the building.

Fig. 4-33 The project utilizes strategies that leverage light and air to increase energy performance and improve workplace performance.

Source: http://www.aiatopten.org/node/103, accessed (28-5-2013)

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[13] URL: http://www.commercialwindows.org/case_nrel.php , accessed (27-5-2013).

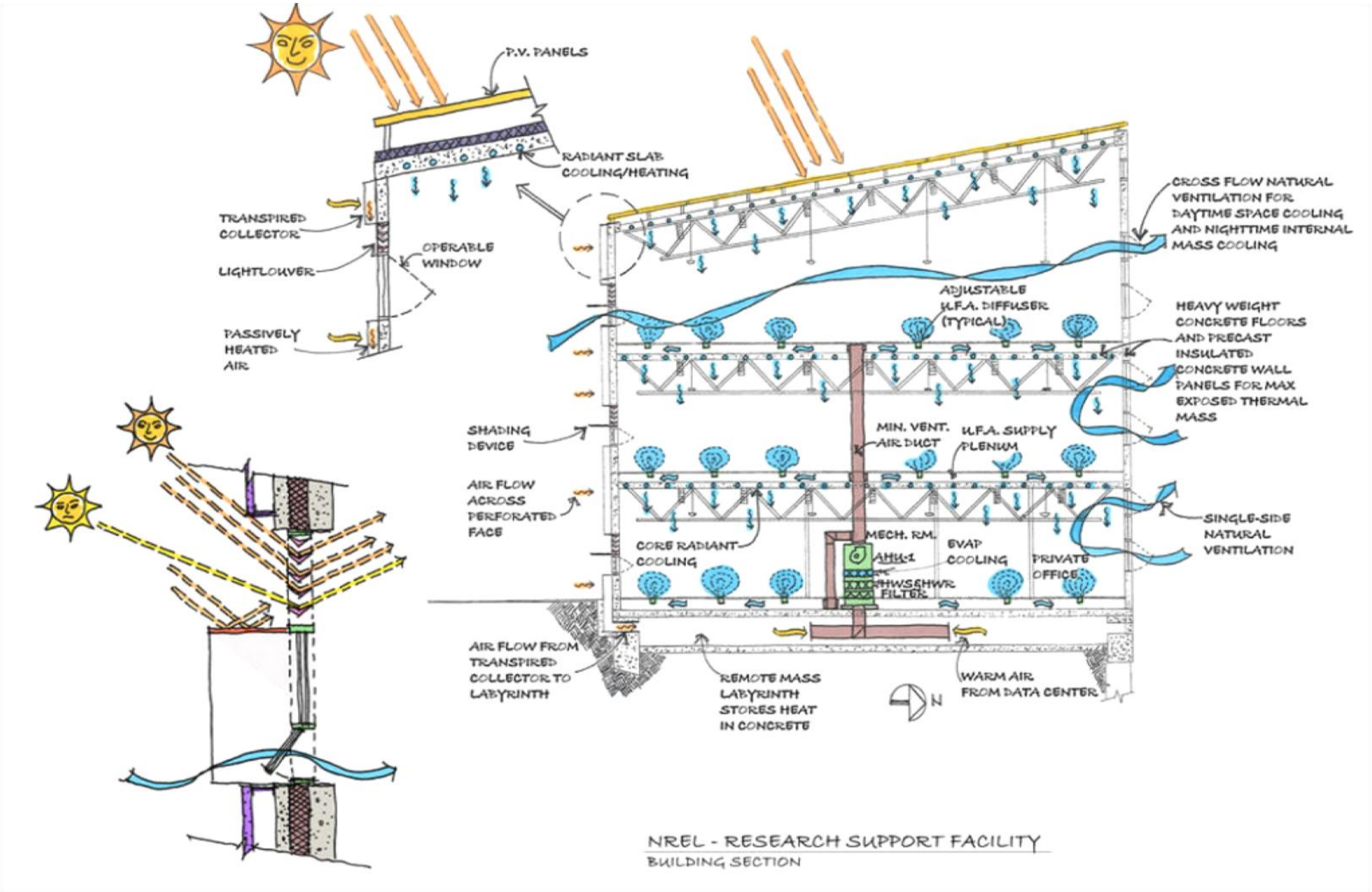

Fig. 4-34 Building section shows the different types of environmental control

Source: http://www.aiatopten.org/node/103, accessed (28-5-2013)

1 Permeable landscaping
2 Fresh air intake
3 Thermochromic east-facing glazing
4 Transpired solar collectors (not visible)
5 Photovoltaics
6 Electrochromic west-facing glazing (not visible)
7 Low-profile open offices
8 Raised floor system
9 Radiant ceiling slabs
10 Thermal labyrinth
11 Louvered sunshade

Fig. 4-35 Building and Energy Diagram

Source: http://continuingeducation.construction.com/article_print.php?L=5&C=728, accessed (28-5-2013)

4.11 Conclusions

According to the case study analysis, it was found that:

Using smart materials in buildings in arid regions helps in solving the buildings different problems (such as overheating and high energy consumption, high solar radiation through building envelope, and lighting problems), achieving the users comfort (thermal and visual comfort), achieving building system need such as: optimization of lighting systems by using LEDs as in case of Kempinski Hotel and Residences Sail Tower, control of solar radiation transmitting through the building envelope by using thermochromic and electrochromic glazing as in case of National Renewable Energy Laboratory's Research Support Facility, energy delivery by using photovoltaic cells as in case of DAR Headquarters Smart Village and Masdar City and National Renewable Energy Laboratory's Research Support Facility.

The future of smart materials and structures is wide open and they have a great effect when they used in buildings especially in the early stages rather than replacing existing materials . Designer's talents, capabilities, and the ability to think outside the box are the factors that determine the usage of smart materials treatments in the different architectural projects.

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Building materials have been developed with time, starting with natural materials such as clay, sand, wood, and rocks. Reaching the industrialized materials which has developed starting from concrete, glass, steel, composite materials, till reaching smart materials which have made a big shift in the architecture.

There are different classification systems for smart materials and traditional materials. There are three types of classification: traditional material classification systems, alternative classification systems, and classification systems for advanced and smart materials where:

a) Traditional material classification systems: has three types of classifications material science classifications which focus on the internal structures of materials, engineering classifications which Focus on mixes the form of material structures with properties, and traditional architectural classifications which focus on listing materials and uses in accordance with standard building requirements.

b) Alternative classification systems: which have many attempts to introduce new materials to designers through it.

c) Classification systems for advanced and smart materials: characterize the materials to be multi-layered with one layer characterizing the material according to its physical behavior (what it does) and another layer characterizing the material according to its phenomenological behavior (the results of the physical behavior).

There are many definitions used to define smart materials from these definitions we can conclude that :

a) Smart materials have changeable properties, and they can reversibly change their shape, color, or properties under any stimulus such as light, temperature, moisture, mechanical force and/or electric and magnetic force.

b) They can react to environmental conditions or can alter their properties in response to this conditions.

Smart materials have four fundamental characteristics which are: property change, energy exchange, reversibility/ directionality, and size/ location, where:

a) Property change: These materials undergo a change in a property or properties – chemical, thermal, mechanical, magnetic, optical or electrical – in response to a change in the conditions of the environment of the material.

b) Energy exchange: These materials, which can also be called ‘First Law’ materials, change an input energy into another form to produce an output energy in accordance with the First Law of Thermodynamics.

c) Reversibility/ Directionality: Materials with bi-directional property change or energy exchange behaviors can often allow further exploitation of their transient change rather than only of the input and output energies and/or properties.

d) Size/ Location: The elimination or reduction in secondary transduction networks, additional components, and, in some cases, even packaging and power connections allows the minimization in size of the active part of the material.

The classification of smart materials is based on the relationship between the stimulus and response in the following fields: electrical, magnetic, optical, thermal, mechanical fields, and the effect of each field on the other. Smart materials have three types characterization where:

a) First classification: The different types of smart materials have been differentiated on a case basis from the point of view of their importance in the context of realized or future architectural applications. It has seven types: shape changing smart materials, color and optically smart materials, adhesion changing smart materials, light emitting smart materials, electricity generating smart materials, energy changing smart materials, and matter changing smart materials.

b) Second classification: The types of smart materials are classified based on their inherent properties, molecular alterations, and the embedded control systems. Accordingly, there are three types of smart materials: thermo-responsive materials; light-responsive materials; stimulus (force) – responsive materials.

c) Third classification: categorize smart materials in relation to their actions and their energy stimulus. Based on this approach, smart materials can be classified in two basic ways, Type 1 smart materials property-changing materials, and Type 2 smart materials energy-exchanging.

The Köppen Climate Classification System recognizes five major climatic type: Tropical Moist Climates, Dry Climates (arid climate), Moist Mid-latitude Climates with Mild Winters, Moist Mid-Latitude Climates with Cold Winters, and Polar Climates: with extremely cold winters and summers.

Arid regions spread over 40% of the land surface, they are found most predominantly in Asia and Africa. Three arid zones can be delineated by this index: namely, hyper-arid, arid and semi-arid.

The climate of arid regions is the main factor that affects such regions. The climate varies between the different types of arid regions. The climate of hot-dry zones are in general characterized by high temperatures, with sharp variations in both diurnal (day / night) and seasonal (summer-/ winter) temperatures; and precipitation (rainfall, snow) which is scarce, irregular and unreliable, but may nevertheless cause severe floods. Cold winds and dust/sandstorms prevail in winter. The solar radiation intensity is high and enhanced by the radiation reflected from the ground. These characteristics cause many problems to buildings in arid regions such as: overheating and high energy consumption, high solar radiation through the building envelope, lighting problems such as glare, and dust penetration.

The smart materials can produce direct effects on the energy environments (luminous, thermal and acoustics), or they can produce indirect effects on systems (energy generation, mechanical equipments). The following categories organize smart materials according to their effects:

a) Luminous environments: include transparency and color change, and light emission.

b) Thermal environments: include heat transfer, and heat absorption.

c) Acoustics environments: include sound absorption.

d) Kinetic environments: include energy production, energy absorption, and shape change.

Smart materials products and systems have many forms available to the designer, e.g., paints, films, glasses, dyes, and fabrics, façade and lighting systems.

There are many building system needs such as: Control of solar radiation transmitting through the building envelope, Control of conductive heat transfer through the building envelope, Control of interior heat generation, energy delivery, Optimization of lighting systems, Optimization of HVAC systems, and Control of structural systems.

By the mapping of typical building system design needs in relation to potentially applicable smart materials and smart materials and their relevant property characteristics of current and/or defined architectural applications . With the exception of some of the glazing technologies, most of the current applications tend to be pragmatic and confined to the standard building systems: structural, mechanical and electrical. As these systems are often embedded within the building’s infrastructure, many of the smart materials tend to be ‘hidden’. Most noticeable in the mapping is that many smart materials are deployed as sensors. The most visible category for smart material application is in the window and facade systems area. In contrast, lighting systems perhaps have the most impact on the user’s perception of the building. Energy systems have steadily become more important as concerns regarding the global environment have mounted.

From the analytical study we can conclude that smart materials have many contributions in solving the environmental problems of arid regions and in achieving building system needs such as: achieving thermal comfort, optimizing the energy efficiency, and generate energy.

5.2 Recommendations

In reference to the discussed issue above, the research puts forward the following recommendations:

By studying the relationship between the building needs and smart materials applications. Smart materials are recommended to be used as a substitute for traditional materials, to improve the performance of standard building systems.

According to the characteristics and behaviors of smart materials, the impact of using these materials as the fundamental elements in the design concept instead of just use for improving existing elements, will create a greater potential.

Smart technologies are recommended to be implemented in the architectural field in Egypt, that will make a great benefit as it will help with: users comfort, energy conservation, and will raise building performance.

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ملخص الرسالة

ظهر فى الاونة الاخيرة العديد من مظاهر التطور التكنولوجى فى كافة المجالات ومنها مجال المواد مثل المواد الذكية التى فرضت نفسها بصورة كبيرة مؤخرا فى جميع المجالات ومنها العمارة.

والمواد الذكية هى التى تتفاعل نتيجة للتغيرات فى البيئة المحيطة بها. هذا التغير يمكن ان يكون على مستوى اللون، الحجم، او توزيع الضغوط، وهذه القدرة على احداث التغيير جعلت المواد الذكية من المواد المؤثرة التى تستخدم فى المبانى في ضوء أنها تتغير طبقا للظروف المحيطة.

ويساعد استخدام المواد الذكية فى العمارة بشكل كبير على حل الكثير من مشكلات المبانى مثل الاستخدام الزائد للطاقة ، وارتفاع تكلفة المواد والانظمة المستخدمة فى المبانى ، وأنها تمكن المعمارى من تصميم بيئة افضل لمستخدمى المبانى خصوصا تلك التى تقع فى المناطق الجافة التى تعانى من الكثير من المشكلات مثل: ارتفاع درجات الحرارة ، انخفاض الرطوبة النسبية ، زيادة الاكتساب الحرارى فى المبنى، والكثير من مشكلات الاضاءة و الطاقة.

ويتكون هذا البحث من ثلاثة اجزاء رئيسية: **الجزءالاول** و يختص بالشق النظرى و يتكون من فصلين هما الفصل الاول و يشمل المقدمة العامة و الفصل الثانى و يتحدث عن انواع و خصائص المواد الذكية، اما **الجزء الثانى** فيختص بتطبيقات المواد الذكية و الاماكن الجافة و خصائصها و يتضمن الفصل الثالث الذى يختص بتطبيقات المواد الذكية على المبانى فى المناطق الجافة، وأما **الجزء الثالث** فيختص بالدراسة التحليلية و النتائج و يحتوى على فصلين هما الفصل الرابع و يشمل تحليل الامثلة محل الدراسة و الفصل الخامس و يعرض النتائج و التوصيات. و فيما يلى نبذة مختصرة عن كل فصل:

الفصل الاول: المقدمة و الخلفية النظرية:

وينقسم الى جزئين: الجزء الاول و يتضمن مقدمة عن انواع المواد ومراحل تطور كل مادة وصولا الى المواد الذكية، والجزء الثانى و يتضمن انواع التصنيفات المختلفة للمواد التقليدية والمواد الذكية.

الفصل الثانى:انواع و خصائص المواد الذكية:

ينقسم الى جزئين: الجزء الاول يختص بالتعريفات المختلفة للمواد الذكية والخصائص المميزة لتلك المواد، اما الجزء الثانى فيختص بانواع التصنيفات المختلفة للمواد الذكية.

الفصل الثالث: تطبيقات المواد الذكية على المبانى فى المناطق الجافة

يوضح هذا الفصل انواع الاقاليم المناخية المختلفة ومنها الاقاليم الجافة و انواعها وخصائصها و مشكلات المبانى الناتجة عن هذه الخصائص، والتطبيقات المختلفة للمواد الذكية وكيفية استغلالها لتحقيق احتياجات المبانى و التغلب على المشكلات الناتجة عن الخصائص المناخية لهذا الاقليم.

الفصل الرابع: الامثلة التحليلية

يقوم هذا الفصل بتحليل عدد من الامثلة المحلية و العالمية التى تم اختيارها اما لفكرتها التصميمية مثل مبنى البرج الدوار فى دبى ، او من حيث الاهتمام بالاثر البيئى للمبنى مثل مبنى دار الهندسة بالقرية الذكية بالقاهرة ومدينة مصدر ، وقد تم تحليل هذه الامثلة طبقا المعلومات الاساسية مثل موقع المبنى و نوعه و المهندس المصمم و المواد الذكية المستخدمة و اظهار مدى مساهمة هذه المواد فى حل المشكلات المختلفة لهذه المبانى ورفع كفاءتها.

الفصل الخامس: النتائج و التوصيات

يعرض هذا الفصل النتائج المختلفة للدراسة النظرية و التحليلية وبيان مدى اهمية استخدام المواد الذكية فى المبانى فى المناطق الجافة ومن اهمها:

ان المواد الذكية لها اربع خصائص اساسية: القدرة على تغيير خصائصها ، وتبادل الطاقة ، القدرة على تغيير الحجم، وعندما يتم ازالة المؤثر ترجع المادة الى خصائصها الاصلية.

هناك ثلاثة انواع لتصنيف المواد الذكية: التصنيف الاول يقوم بتصنيف الانواع من وجهة النظر المعمارية، اما التصنيف الثانى فيعتمد على الخصائص الداخلية للمواد ، و التصنيف الثالث فيتم طبقا لافعال و طاقة تلك المواد.

يوضح نظام تصنيف المناخ (كوبين) وجود خمسة انواع مناخية رئيسية هى: المناخات المدارية الرطبة، المناخات الجافة ، المناخات الرطبة منتصف خط العرض مع شتاء معتدل، المناخات الرطبة منتصف خط العرض مع شتاء بارد، والمناخات القطبية.

مناخ المناطق الجافة هو العامل الرئيسي الذي يؤثر على هذه المناطق. يتميز مناخ المناطق الجافة بصفة عامة بدرجات حرارة عالية، مع وجود اختلافات حادة في (الصيف / الشتاء) ، وهطول الأمطار (الأمطار، الثلوج) وتكون قليلة وغير منتظمة. تسود الرياح الباردة والغبار / العواصف الرملية في فصل الشتاء. و يكون شدة الإشعاع الشمسي عالي. تتسبب هذه الخصائص فى العديد من المشاكل للمبانى فى تلك المناطق و منها: الارتفاع الزائد للحرارة و زيادة استهلاك الطاقة، ارتفاع الاشعاع الشمسى عن طريق الغلاف الخارجى للمبنى ، و بعض مشاكل الاضاءة مثل الوهج، و تغلغل الاتربة.

هناك العديد من احتياجات المبانى ومن اهمها: التحكم فى الاشعاع الشمسى الناتج عن الغلاف الخارجى للمبنى ، التحكم فى الانتقال الحرارى فى غلاف المبنى ، التحكم فى الحرارة الداخلية المتولدة فى المبنى، التقليل من استخدام الاضاءة الصناعية و انظمة التكييف.

من الدراسة التحليلية يمكننا أن نستنتج أن المواد الذكية لديها العديد من المساهمات في حل المشاكل البيئية في المناطق الجافة وتحقيق أنظمة البناء التى يحتاجها المبنى مثل: تحقيق الراحة الحرارية للمستخدمين، وتحسين كفاءة استخدام الطاقة، وتوليد الطاقة.

كما يقدم بعض التوصيات الخاصة بهذا المجال و منها: التوصية باستخدام المواد الذكية بشكل اكبر فى مصر لما فى ذلك من منافع كبيرة من حيث: تحقيق راحة المستخدمين ، و تقليل الطاقة المستهلكة، و رفع كفاءة اداء المبنى.

قال تعالى

يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنْكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ وَاللَّهُ بِمَا تَعْمَلُونَ خَبِيرٌ ﴿١١﴾ سورة المجادلة

صدق الله العظيم

تأثير استخدام المواد الذكية على الأداء البيئى للمبانى فى المناطق الجافة

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م/ نهى حسين حفناوى

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