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Nano and Biotech Based Materials for Energy Building Efficiency

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Foreword

No one doubts the need to reduce energy consumption in buildings but at the same time ensuring they are healthy for their occupiers. The passive features such as mass, orientation, building form are well-known natural means of controlling the internal thermal conditions. But materials and the ways they are chosen and arranged are vital for low-energy building design. Innovation however can enable materials whether new or traditional ones to perform more effectively in respect of energy consumption and this is the essence of this book. Today, we see on the one hand architects using simple materials such as straw bales, hemp, rammed earth, wood and bamboo but on the other hand others are exploring ways of using materials like titanium, digital embedded structures and nature-inspired biomimetic materials. As insulation improves, operational energy decreases and this means embodied energy is playing an increasing important role in the energy equation too.

This book in 17 chapters reveals the current state of knowledge about nanomaterials and their use in buildings ranging from glazing, vacuum insulation to PCM composites. More recent applications of organic photovoltaics, photo-bioreactors, bioplastics and foams make this book an exciting read whilst also providing copious references to current research and applications for those wanting to pursue future possibilities.

Recent buildings such as the Cybertecture Egg office building in Mumbai by James Law with Ove Arup; the Bio-Intelligent Quotient (BIQ) building in Hamburg by Arup and Splitterwerk and the Edge Building by Deloitte with OVG in Amsterdam are all affecting our thinking about architecture and building in terms of materials, sensing systems and use of innovative technology.

The Cybertecture Egg has an intelligent glass façade with variable fritting, shading and tinting, but furthermore it introduces the concept of cybertecture which uses intangible materials of technology, multimedia, intelligence and interactivity. Nanomaterials are part of this story. The façade is not just a climatic moderator but also becomes a communication channel by embedding sensors into materials, and this sees the emergence of interactive facades not just with the climate but also with people. The Edge building has many sensors monitoring the building performance as well as—like in the Mumbai building—the health of the users (the data of which are protected). The BIQ building has a facade which has bioreactors built in, and algae is grown in them which is harvested for bio fuel whilst also shading the building, and two chapters in this book describe about research in this area.

Nanomaterials can strengthen steel and concrete, make surfaces self-cleaning, make materials fire resistant, detect structural fissures, improve efficiency of solar panels and improve the insulating properties of materials. One example is titanium dioxide particle coatings that when exposed to ultraviolet light can generate reactive molecules which prevent bacterial films forming on surfaces. Various chapters in the book show how nanomaterials improve the insulation of construction with thermal insulation values some 40 times better than traditional fibreglass materials.

There is a need for this book to guide practitioners and researchers through the maze of development taking place in nanomaterials. The distinguished editors have gathered an international team of authors working at the forefront of knowledge in this field and readers will find their knowledge much enriched by what they describe. The chapters also indicate an exciting pathway into the future.

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Chapter 1
Introduction to Nano- and Biotech-Based Materials for Energy Building Efficiency

F. Pacheco Torgal

Abstract This chapter starts with an overview of the unsustainable energy consumption which is due to fast population growth and related greenhouse gas emissions. The case of energy efficiency building is introduced. A short analysis of the ambitious European nearly zero-energy building (NZEB) target is presented. Shortcomings of current materials concerning energy building efficiency are reviewed. Examples of promising nano- and biotech-based materials for energy building efficiency are briefly covered. A book outline is presented.

1.1 The Paramount Challenge of Sustainable Energy Consumption

The rise in energy consumption is directly related to the increase in world population (Fig. 1.1). Since each day there are now about 200,000 new inhabitants on planet Earth (WHO 2014), this means that the increase in electricity demand will continue (King et al. 2015). It is also expected that the annual electricity consumption per capita (Fig. 1.2) in low- and middle-income countries will rise as a consequence of future higher income and related higher comfort standards (World Bank 2014). This means increased pressure in electricity demand. It is then no surprise to see that the world net electrical consumption will increase from 20.1 trillion kWh in 2010 to 25.5 trillion kWh by 2020 and 35.2 trillion kWh by 2035 (WEO 2013). Unfortunately, only 21 % of world electricity generation was from renewable energy in 2011 with a projection for nearly 25 % in 2040 (WEO 2013). Also, recent studies (Hadian and Madani 2015) using a stochastic multi-criteria analysis framework to estimate the relative aggregate footprint scores of energy sources under three different sustainability criteria (carbon, water and land footprint) and cost of energy production showed that some of the renewable

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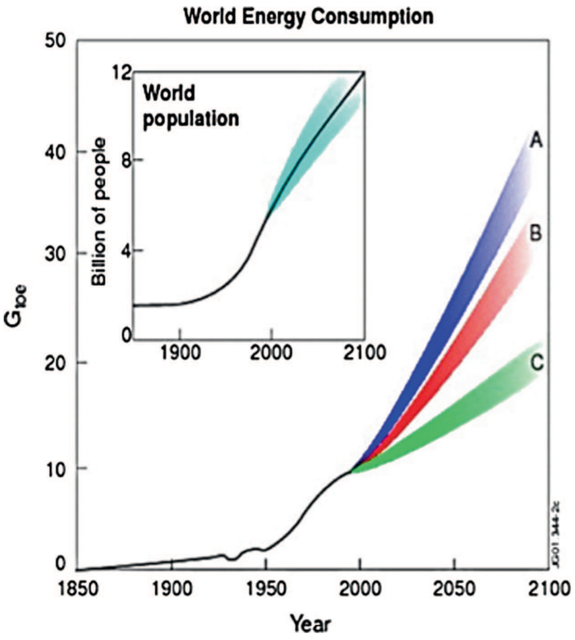

Fig. 1.1 World energy consumption in the past 150 years (Amouroux et al. 2014)

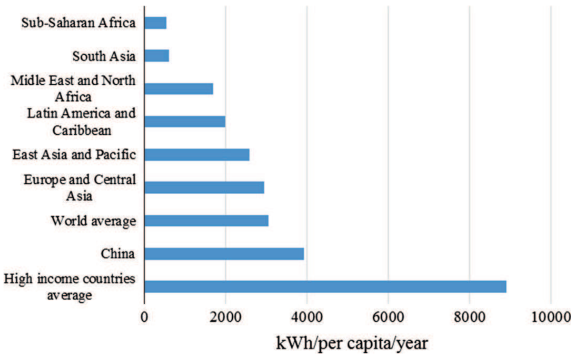

Fig. 1.2 Annual electricity consumption per capita

energy sources (hydropower and solar PV) are not as "green" as perceived based on the current state of the energy production methods/technologies. And some renewable energy sources such as biofuel and ethanol are even worse than the fossil fuels such as natural gas.

As a consequence in the next decades, the majority of electric energy will continue to be generated from the combustion of fossil fuels such as coal, oil and gas releasing not only carbon dioxide but also methane and nitrous oxide. It is worth remember that China is largest energy consumer in the world (10.3 billion tonnes of CO_2, 29 % of world emissions) (JCR 2014) and that Chinese coal plants are responsible for 80 % of electricity generation (Shealy and Dorian 2009), meaning that its electric production will continue to be associated with high CO_2 emissions. However, it is also important to recognize that China has just a 7.4 tonnes per capita CO_2 emissions level, while Australia, USA and Brazil (the top 3 per capita emitters) are responsible for 16.9, 16.6 and 16.6 tonnes pf CO_2 per capita, respectively (JCR 2014). As the source of two-thirds of global greenhouse gas emissions, the energy sector is therefore pivotal in determining whether or not climate change goals are achieved. Climate change is one of the most important problems faced by the Human being, which is associated with the rise in the sea level, ocean acidification, heavy rain, heat waves and extreme atmospheric events, environment deterioration and wildlife extinction, health problems and infrastructure damage (Williams et al. 2012; IPCC 2014). Tackling climate change will therefore require strong efforts aimed at curbing greenhouse gas emissions from the energy sector. Energy efficiency is very important for this context because efficiency improvements show the greatest potential of any single strategy to abate global GHG emissions from the energy sector (IEA 2013).

1.2 Energy Efficiency Building

The building sector is responsible for high energy consumption, and its global demand is expected to grow in the next decades. Between 2010 and 2050, the global heating and cooling needs are expected to increase by 79 % in residential buildings and 84 % in commercial buildings (Ürge-Vorsatz et al. 2015).

Energy efficiency measures are therefore crucial to reduce GHG emissions of the building sector. Recent estimates (Ürge-Vorsatz and Novikov 2008; UNFCCC 2013) state that energy efficiency concerning buildings' heating and cooling needs could allow a reduction between 2 and 3.2 $GtCO_2e$ per year in 2020. Other estimates mentioned a potential reduction of around 5.4–6.7 $GtCO_2e$ per year in 2030 (UNEP 2013). In order to achieve such reductions, the implementation of building codes associated with the high energy performance must be seen as a top priority. In the last decade, several high energy performance building concepts have been proposed, from low-energy building through passive building and zero-energy building to positive energy building and even autonomous building (Thiers and Peuportier 2012). For the Building Technologies Programme of the US Department of Energy (DOE), the strategic goal is to achieve *marketable zero energy homes in 2020 and commercial zero energy buildings in 2025*. However, commercial definitions maybe tainted by biased view, allowing for energy-inefficient buildings to achieve the status of zero energy thanks to oversized PV systems (Sartori 2012). Rules and definitions for near zero-energy buildings or even zero-energy buildings are still subject to the discussion at the international level (Dall'O et al. 2013). Some authors (Adhkari 2012) use ZEB as "net zero-energy buildings" and NZEB as "nearly zero-energy buildings". "Net" refers to a balance between energy taken from and supplied back to the energy grids over a period of time. Therefore, Net ZEB refers to the buildings with a zero balance, and the NZEB concept applies to buildings with a negative balance.

The European Energy Performance of Buildings Directive 2002/91/EC (EPBD) has been recast in the form of the 2010/31/EU by the European Parliament on 19 May 2010. One of the new aspects of the EPBD is the introduction of the concept of nearly zero-energy building (NZEB). Of all the new aspects set out by the new directive, the NZEB target is the one that European countries have more difficulty to enforce Member states. The article 9 of the European Directive establishes that, by the 31 December 2020, all new constructions have to be NZEBs; for new public buildings, the deadline is even sooner—the end of 2018. Unfortunately, the status of the EPBD implementation in EU countries is disappointing because so far only a minority of countries have transpose the EPBD into their national laws (Antinucci 2014).

Be there as it may, new buildings have limited impacts on overall energy reduction as they represent just a tiny fraction of the existent building stock (Xing et al. 2011). Also, it is estimated that in Europe, only 1 % of the continent's building stock in any given year is newly built. Existing buildings constitute, therefore, the greatest opportunity for energy efficiency improvements. Besides, new homes use four to eight times more resources than an equivalent refurbishment (Power 2008), which constitutes an extra and sustainable argument in favour of building refurbishment. Building energy efficiency refurbishment is also crucial to address an important social problem, energy poverty. This problem affects between 1.3 billion and 2.6 billion people from underdeveloped regions of the world. Between 50 and 125 million people in Europe alone suffer from energy poverty (Atanasiou et al. 2014). This has important health consequences for children and older people leading to an increase in medical costs. Infants, living in energy-poor homes, are associated with a 30 % greater risk of admission to hospital. Indoor cold is also highly correlated with premature mortality. Between 30 and 50 % of excess winter mortality is attributed specifically to energy-inefficient housing conditions. Besides, direct financial help to low-income households or the use of energy subsidies can only address this problem in a partial manner without solving it in a long term, while the funding of building energy efficiency refurbishment works is also able to generate value-added and economic growth (Atanasiou et al. 2014).

Its important to mention that EPBD recast does not cover existent buildings; however, the Energy Efficiency Directive (2012/27/EU) approved by the European Parliament on 25 October 2012 that each Member states had have to transpose into national laws until 5 June 2014 addresses the energy efficiency refurbishment of existent buildings (Articles 4 and 5). According to Article 4, Member states will have to define *establish a long-term strategy for mobilising investment in the renovation of the national stock of residential and commercial buildings, both public and private*. As to Article 5 content it requires that *each Member state shall ensure that, as from 1 January 2014, 3 % of the total floor area of heated and/or cooled buildings…is renovated each year to meet at least the minimum energy performance requirements*. Also according to the Article 4 of the EED, the first version of the building renovation strategy was to be published by 30 April 2014. However, the report published in November 2014 revealed that only 10 renovation strategy plans were submitted (BPIE 2014). Of those only the strategies of four (Czech Republic, Romania, Spain and UK) were considered acceptable because they met the basic requirements set by Article 4. The strategies of France, Germany and Brussels capital region needed to be corrected and resubmitted. The strategies of three countries (Austria, Denmark and the Netherlands) were rejected because they do not fulfil the basic requirements of Article 4. In January 2015, an addendum was published (BPIE 2015), showing that only the renovation strategy of Austria remain rejected although his compliance level increased from 28 to 40 % and also that the overall compliance level increased from 58 to 63 %. This means that much more effort must be put in the building energy efficiency refurbishment agenda. The scientific community has some responsibilities in this situation because a recent study on energy-efficient renovation peer-reviewed articles (Friege et al. 2014) concluded that the literature "lacks a deep understanding of the uncertainties surrounding economic aspects and non-economic factors driving renovation decisions of homeowners". Of course, this gap does not help the building renovation decisions nor political decisions that could boost the investments on this field. Pikas et al. (2015) recently found that in all 17 jobs per 1 million euro of investment in building renovation had been generated per year. These authors also found that 32 % tax revenue would be excepted from renovation-related activities, meaning that an official 32 % governmental investment would be economically neutral. This study confirms the predictions of Oliver Rapf, executive director, BPIE when he said that …*renovation of buildings to high energy performance standards could be one of the most cost effective investments a nation can make, given the benefits in terms of job creation, quality of life, economic stimulus, climate change mitigation and energy security that such investments deliver* (Pikas 2015).

1.3 Shortcomings of Current Materials and Promising Nano- and Biotech-Based Investigations Concerning Energy Building Efficiency

New building envelope materials and technologies are needed to increase energy efficiency and energy savings at much lower cost than is possible today (IEA 2013), and some of the technologies needed for the retrofitting of the EU's building stock are already available in the market. However, their diffusion varies across Member states due to a lack of market actors' awareness about the savings potential of the best available technologies (JCR 2015).

Probably, the most-known limitation of current materials concerning energy building efficiency has to do with the "low" performance of current thermal insulators. The urgent need to reduce building energy consumption led to a steady increase in the thickness of thermal insulation materials over the years. In some countries of northern Europe, the insulation thickness has almost doubled (Fig. 1.3). This limitation has important economic and technical consequences. Such high thickness means less available internal space in existent buildings as well as an

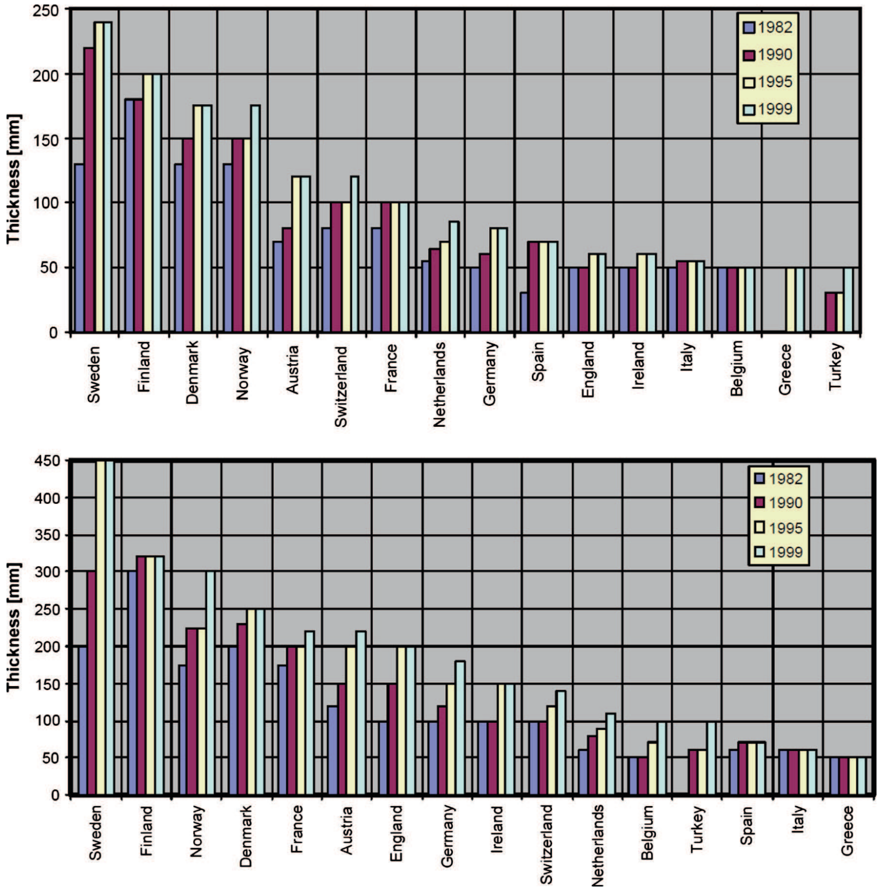

Fig. 1.3 Evolution of thermal insulation thicknesses in several European countries: above in walls and below in roofs (Papadopoulos 2005)

increase in insulation costs. The development of high-performance thermal insulator materials (with low thickness) has thus become a technical and scientific challenge that justified and still justifies new investigations.

Another important issue concerning current building materials and energy efficiency has to do with the fact that there is a limit beyond which no further reductions on energy consumption can be achieved within the EPBD framework. In that context, the use of building materials with lower embodied energy becomes a priority area. The energy embodied in construction and building materials (embodied energy) covers the energy consumed during its service life. There are, however, different approaches to this definition, namely the energy consumed from the extraction of raw materials to the factory gate (cradle to gate), from extraction to site works (cradle to site) or from extraction to the demolition and disposal (cradle to grave). Berge (2009) considers embodied energy as only the energy needed to bring the material or product to the factory gate (first case), and the transport energy and the energy related to the work execution as being both included in the construction phase of the building. According to this author, the embodied energy represents 85–95 % of the material total energy (the remaining 5–15 % being related to the construction, maintenance and demolition of the building). As to the third case, the embodied energy includes all energy consumption phases from the production at the cradle. As to the transport energy, it depends on the mode of transport: sea, air, road or rail. In recent decades, the operational energy in buildings (lighting, heating, cooling, etc.) was accepted as being the major contributor, while the embodied energy was found to represent only a small fraction (10–15 %). Consequently, much effort has been made towards the reduction of operational energy by increasing the energy efficiency of buildings. However, as operational energy is reduced, the percentage of the embodied energy in the total energy consumption of the buildings becomes increasingly prevalent. Some authors (Sandrolini and Franzoni 2010) recognized that energy savings by means of more efficient thermal insulation (as well as increasing renewable energy use) is an insufficient approach further suggesting the inclusion of embodied energy as an important parameter for sustainable construction.

Szalay (2007) even suggested that the EPBD recast could include requirements of embodied energy. Unfortunately that was not the case. Instead, the European strategy decided to addresses the overall environmental impact of construction and building materials (energy consumption included) in the new Construction Products Regulation—CPR (Directive (EU) 305/2011) which is in effect since 1 July 2013 replacing the Directive 89/106/EEC, already amended by Directive 1993/68/EEC, known as the Construction Products Directive (CPD).

Pacheco-Torgal et al. (2013a, b) studied a 97 apartment-type building, concerning both the embodied energy as well as the operational energy. The results show that the embodied energy in reinforced concrete (concrete plus steel) represents 70 % of the total; therefore, high energy reductions can only occur by lowering the energy in this material. The operational energy was found to signify an average of 187.2 MJ/m^2/yr and the embodied energy accounting for approx. 2372 MJ/m^2 and representing just 25.3 % of the former. If the buildings were in the AA + energy class, this would mean that the embodied energy could be as much as 400 % of the operational energy for a service life of 50 years. A recent review by Cabeza et al. (2013) highlights the research efforts to develop new materials with less embodied energy, which are crucial to the energy building efficiency agenda.

Also important although not directly related to building energy efficiency is the fact that most thermal insulation materials are associated with negative environmental impacts in terms of toxicity. Polystyrene, for example, contains antioxidant additives and ignition retardants; additionally, its production involves the generation of benzene and chlorofluorocarbons. Polyethylene is obtained from the polymerization of ethylene, containing 0.5 % of additives such as phenol-based antioxidants, UV stabilizers and dyes, including aluminium, magnesium hydroxide and chloroparaffin as ignition retardants. Polypropylene is obtained from the polymerization of propylene with additives similar to those used in polyethylene.

Polyurethane is obtained from isocyanates, which are widely known for their tragic association with the Bhopal disaster (Pacheco-Torgal et al. 2012). This substance is highly toxic (Marczynski et al. 1992; Baur et al. 1994), and there are multiple records of serious health problems in workers using polyurethane (Littorin et al. 1994; Skarping et al. 1996). Chester et al. (2005) even reported the death of a worker due to the simple application of polyurethane. The production of polyurethane also involves the production of toxic substances such as phenol and chlorofluorocarbons. Also important is the fact that several thermal insulation materials release toxic fumes when subjected to fire. Liang and Ho (2007) studied the toxicity during fires of several insulation materials and concluded that polyethylene and polyurethane foams should not be used unless covered by incombustible materials. Dourodiani et al. (2012) mentioned that the fumes produced from burning of the expanded polystyrene used in the ceilings caused the death of several workers. Those authors also mentioned that even when the toxic fumes exposition is not high enough to lead to human deads, it can be responsible for other serious health problems such as chromosome damage, cancer and even birth defects. This issue is very important because the information on the toxicity of building materials is a crucial aspect under the new CPR. While the CPD only considered a very limited range of dangerous substances, e.g. formaldehyde and pentachlorophenol, the CPR links this subject to the Regulation (EC) No 1907/2006 (Registration, Evaluation, Authorisation and Restriction of Chemicals—REACH Regulation). The introduction of the CPR states that *the specific need for information on the content of hazardous substances in construction products should be further investigated*. Besides, the Article 67 mentions that *By 25 April 2014, the Commission shall assess the specific need for information on the content of hazardous substances in construction products and consider the possible extension of the information obligation provided for in Article 6(5) to other substances*. Regarding energy building efficiency, high-performance, non-toxic thermal insulators, as well as low embodied energy building materials, are therefore needed.

Although the 1959 speech of Fenyman at the American Physical Society at Caltech is considered the beginning of the nanotechnology era, only in the 1980s has this area start an exponential growth (Glanzel et al. 2003). In the last decades, nanotechnology was became a hot area crossing different scientific areas from electronics to life sciences, and still only in the last years have the nanotech investigations for the construction industry began to have enough expression justified by the published works on that particular field (Smith and Granqvist 2010; Pacheco-Torgal and Jalali 2011; Hanus and Harris 2013; Pacheco-Torgal et al. 2013a).

A 2012 Scopus search of journal papers containing the terms “nanotechnology” and “eco-efficient construction” (Pacheco-Torgal et al. 2013a) revealed only five published papers and all in the field of cement materials. The same search carried out three years later shows twenty-six papers, eight of which are directly related to the energy building efficiency materials. This shows that a research shift from cement nanotech to nanotech energy efficiency materials has occurred in the last years.

Nanoporous aerogel is a perfect example of a high-performance thermal insulator but also of the time lag between nanotech scientific discoveries and the deployment of related commercial products. It was invented in the 1930s (Kistler 1931; Kistler and Caldwell 1932) and further developed in the 1950s by NASA. Aerogel is composed of air above 90 %, and silica nanoparticles have the lowest thermal conductivity of any solid of around 0.01 W/mK (around 13 mW/mK for commercial products).

Since the majority of energy losses in a building occur through windows, the use of aerogel as low thermal conductivity windows or skylights (Schultz et al. 2005; Jelle et al. 2012) with a U-values lower than 0.3 W/m^2 K (Buratti and Moretti 2012, 2013a, b) is especially important for energy building efficiency (Cotana et al. 2014; Ihara et al. 2015). However, since the cost of an aerogel window could be six times higher than a conventional window (Cuce 2014a), this constitutes a challenge that needs to be overcome. Aerogel is non-flammable, not carcinogenic (Buratti and Moretti 2012), has minimal health hazards (Aspen 2015) and does not release toxic fumes during fire, and it thus has a high potential to overcome some of the shortcomings of current thermal insulators being the subject of three chapters of this book. However, a recent study (Cuce et al. 2014a, b) showed that aerogel thermal insulation is not cost-effective for countries with warm climates. Even so it is worth mention that those authors assumed a high aerogel cost (600 €/m^3) and did not count on the economic value of space savings, which is an important advantage of aerogel over current thermal insulators. Since cost efficiency is a crucial aspect in order that aerogel (and other nanotech-based materials) can be widely use by the construction industry, this means that more investigations are needed that could give a more accurate picture of the real cost gap between aerogel and current thermal insulators.

Other important field relates to the development of cool materials incorporating new advanced nanomaterials (Santamouris et al. 2011; Jelle et al. 2015). Cool materials have high solar reflectance allowing for the reduction of energy cooling needs in summer. These materials are specially important for building energy efficiency because as a consequence of climate change, building coolings needs are expected to increase in the coming years (Crawley 2008). Depending on the climate zone, cooling loads are likely to increase by 50 to over 90 % until the end of the century (Roetzel and Tsangrassoulis 2012). According to the IEA (2013), energy consumption for cooling is expected to increase sharply by 2050—by almost 150 % globally and by 300 to 600 % in developing countries. The Cool-Coverings FP7 project (Escribano et al. 2013) which aims at the development of a novel and cost-effective range of nanotech improved coatings to substantially improve near-infrared reflective properties.

Also crucial for energy-efficient buildings is switchable glazing technology-based materials that refer to ‘materials and devices that make it possible to construct glazings whose throughput of visible light and solar energy can be switched to different levels depending on the application of a low DC voltage (electrochromics) or on the temperature (thermochromics) or even by using hydrogen (gasochromics). Electrochromic windows have shown a 54 % energy reduction in electrochromic windows when compared to standard single-glazed windows for a 25 years life cycle

(Papaefthimiou et al. 2006). Other authors (Yoshimura et al. 2009) studied gasochromic windows reporting a 34 % reduction on cooling needs when compared to standard double-glazed windows. Tavares et al. (2015) reported savings of about 14 % in the annual energy needs resulting by single glass replacement with double electrochromic glass controlled by solar radiation. According to these authors for this energy savings, the maximum permissible additional cost per m^2 of EC glass to a simple recover period of 10 years is 33.44 €. Several commercial solutions are already available on the market (SAGE Electrochromics—USA, Econtrol Glas, Saint Gobain Sekurit and Gesimat—Germany, amongst others) with a service life of 30 years and capable of 100,000 switching cycles. The most challenging point of smart windows at the moment is their higher cost compared to the other glazing technologies (Cuce and Riffat 2015). Hee et al. (2015) stated that due to the higher costs of dynamic glazing, it is more suitable to be installed in the building which needed high performance in terms of daylighting and energy saving such as commercial buildings. However, it is expected that in the next years, a higher performance and lower cost switchable glazing windows will be available.

Jelle (2011) predicted that the nano-insulation materials (NIMs), the dynamic insulation materials (DIMs) and the load-bearing insulation materials NanoCon could become promising nanotech-based thermal insulators. However, four years after his statement, no major advances were made concerning those materials not even regarding the wide use by the construction industry of nanotech-based insulator materials. The reason for that may lie on the fact that the construction industry has a risk-averse nature having a recalcitrant approach to new technology adoption (Arora et al. 2014). Fortunately, recent forecasts show that the European market for building energy-efficient products (and services) alone will grow from €41.4 billion in 2014 to €80.8 billion in 2023 (NR 2014), meaning that investigations on high-performance thermal insulators will have an important market to explore justifying its funding.

Much like nanotechnology, biotechnology constitutes another hot scientific field that has grown exponentially in the last decades. Having the potential to develop more sustainable solutions, it also has a huge commercial potential (Meyer 2011). Biotechnology is one of the six key enabling technologies (KETs) that will be funded under the EU Framework Programme Horizon 2020 (Pacheco-Torgal 2014). Investigations on cellulose nanocrystals (cellulose elements having at least one dimension in the 1–100 nm range) constitute an important and recent field with the potential to enable the development of promising eco-efficient high-performance materials (Charreau et al. 2013). Concerning the contribution of biotech advances for energy building efficiency, a new generation of bioaerogels was developed in the past decade from various polysaccharides such as cellulose, cellulose esters, marine polysaccharides, pectin and starch (Demilecamps et al. 2015). Cellulose being the most abundant polymer on Earth, renewable, biodegradable, carbon neutral, having the potential to be processed at industrial-scale quantities and at low cost could become a green source to future aerogel thermal insulators.

Bioplastics are also another recent biotech output that could have future impact on low embodied energy building material, thus contributing for energy building efficiency. There is not a unique definition on bioplastics, but the one set by the Business–NGO Working Group for safer chemicals and sustainable materials (Alvarez-Chavez et al. 2012) seems to be a very accurate one: "as plastics in which 100 % of the carbon is derived from renewable agricultural and forestry resources such as corn starch, soybean protein and cellulose". Although these current biomaterials have a high cost, the recent investigations (Xu and Yang 2012) show that the production of bioplastics from biowastes could enhance the cost efficiency.

Several books have already been written addressing nanotech-based materials for the construction industry. Still recent investigations (Arora et al. 2014) show that the construction industry practitioners display moderate levels of awareness regarding that issue. Besides, most of them have a narrow focus on the energy building efficiency issue. Also, biotech-based materials for energy building efficiency is a book desert area. Therefore, this book intents to provide a contribution (even small as it is) for the energy building efficiency agenda by gathering important contributions of world experts on nano- and biotech-based materials. This publication will help future standardization efforts regarding these innovative materials. It will also help the building industry stakeholders to be aware of the state-of-the-art energy building efficiency-related materials which is a crucial step to speed up their commercialization and its effective use in deep retrofitting actions.

1.4 Book Outline

Chapter 2 deals with the aerogel-based plasters. A short overview on market trends of thermal insulation plasters is presented. Plaster composition, physics, thermal, acoustic, and hygrothermal properties are discussed. In situ applications of aerogel plasters are analysed, and the potential of the investigated materials is highlighted.

Highly energy-efficient silica aerogel windows are the subject of Chap. 3. The characteristics of the raw material (monolithic and translucent granular) are illustrated. The chapter includes general information about the production process, the main chemical and physical properties, and a market overview. Thermal, visual and acoustic performances of silica aerogel windows are highlighted. A numerical analysis review confirms the contribution of these windows for energy building efficiency.

Chapter 4 contains the state of the art about thermochromic glazings. These high-performance glazings have temperature-dependent properties being able to control the quantity of solar heat and light entering a building by changing its optical properties, thus reducing energy consumption. A review on different chromogenic materials (photochromic, thermocromic and electrochromic) is introduced. A special attention is dedicated to vanadium oxide (VO_2)-based thermochromic glazings including fabrication and performance. A review on energy modelling of buildings with thermochromics glazings is presented.

The use of an optically transparent, thermal energy adsorbing glass is the subject of Chap. 5. A review on vasculature networks is included. The importance of biomorphic responsive glass for energy building efficiency is highlighted. Investigations on glass with embedded microvascular networks are reviewed as promising research field for future development of photosynthetic composite glass.

Chapter 6 provides an overview of the requirements for product development of adaptive nanobased materials and technologies. The role of building simulation in the development of innovative adaptive materials and technologies is discussed. State-of-the-art advanced methodologies and the characteristics of the tools to support the product development for building-integrated adaptive materials and technologies are presented. A case study concerning the evaluation of the performance of future-generation adaptive glazing and adaptive insulation is also presented.

Chapter 7 addresses the use of nanotech-based vacuum insulation panels (VIPs) for building applications. It includes VIP concepts, the state of the art on VIP products as well as some case studies. Future research pathways for VIP technologies are also included.

The use of nanomaterial-based phase-change materials (nanoPCMs) for thermal energy storage is the subject of Chap. 8. It reviews PCM, nanomaterial and nanoPCM composites. The enhancement of the thermal energy storage capabilities of NanoPCM composites and its role on achieving improved energy efficiency in buildings is highlighted.

Chapter 9 addresses the case of nanotech-based cool materials and its contribution in reducing energy building cooling needs. Recent nanoscale developments are addressed, and the main applications of cool materials are discussed including cool roofs, cool walls, cool shading devices and cool paving materials. The durability performance of cool materials is also covered.

Chapter 10 covers the performance of semi-transparent photovoltaic (STPV) facades. A methodology that quantifies the building energy demand reduction provided by STPV constructive solutions is presented, and the design parameters of STPV solution are analysed.

Chapter 11 reviews the use of organic photovoltaics for building energy efficiency. The functioning principles of hybrid and organic (HOPV) devices that include dye-sensitized solar cells (DSCs) and polymeric cells are described. A description of the actual studies carried on HOPV and energy efficiency in buildings is included. Some showcases that involve the use of HOPV integrated into buildings are also included.

Investigations on biobased polyurethane foam for thermal insulation materials are the subject of Chap. 12. A review on the insulating properties of polyurethane foam is included. Raw materials, synthesis and properties of bio-polyurethane foams are covered.

Chapter 13 is related to the development of biorefinery-derived bioplastics as promising low embodied energy building materials. While current materials based on petrochemical-based plastics produce hazardous non-biodegradable wastes when buildings are demolished. Materials made from the renewable organic sources are biodegradable and can be left in soil or composted after the building demolition. Bioplastics also have the potential to lead to the rise of new building materials with low embodied energy, thus contributing to energy building efficiency.

Chapter 14 addresses the bio-inspired lightweight structural materials as low embodied energy-based materials. Several examples were reviewed including water lily leaves, bird's bones and trunk trees.

Chapter 15 is related to nanocellulose aerogels as promising thermal insulation materials and covers cellulose aerogel produced from bacterial cellulose and from paper pulp, and even aerogel prepared from paper wastes. It includes fabrication methods, mechanical and thermal properties.

Chapter 16 covers photobioreactor-based energy sources. The characteristics of the different industrial-scale photobioreactors are reviewed. A discussion on cost limitations are included.

Several case studies on the architectural integration of photobioreactors in building façades constitute the subject of Chap. 17.

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