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Introduction to eco-efficient materials to mitigate building cooling needs

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1.1 Climate change and urban heat islands (UHIs)

Climate change is one of the most important environmental problems on the planet (Garcia et al., 2014; IPCC, 2007; Rockström et al., 2009; Schellnhuber, 2008).

This is due to the increase of carbon dioxide (CO_{2eq}) in the atmosphere, for which the built environment is a significant contributor, with around one-third of global carbon dioxide emissions. In the early eighteenth century, the concentration level of atmospheric CO_{2eq} was 280 parts per million (ppm). At present it is 450 ppm (VijayaVenkataRaman et al., 2012).

Keeping the current level of emissions (which is unlikely given the high economic growth of less developed countries, with consequent increases in emission rates) will imply a dramatic increase in CO_{2eq} concentration to as much as 731 ppm in the year 2130, leading to a 3.7 °C global warming above pre-industrial temperatures (Valero et al., 2011).

As temperature increases, vector-borne illnesses, which rely upon organisms such as mosquitoes (*Aedes aegypti*, *Aedes albopictus*, *Aedes japonicus*) and other insects that have an active role in the transmission of a pathogen, have been projected to increase both in geographic reach as well as severity (IPCC, 2012; McMichael et al., 2006). Even northern latitudes in Europe will be reached (Githeko et al., 2000). West Nile fever is one that worries Europe (Hubalek and Halouzka, 1999; Sambri et al., 2013). The European Centre for Disease Control (ECDC, 2013) has reported several cases of West Nile fever in Europe and neighboring countries.

In addition to increased mean temperatures, climate change is likely to be responsible for more frequent heat waves, such as the 2003 European heat wave that claimed the lives of more than several thousand people (Table 1.1).

Heat waves also are associated with nonfatal impacts such as heat stroke and heat exhaustion (IPCC, 2007). Heat waves have a much bigger health impact in cities than in surrounding suburban and rural areas because urban areas typically experience higher—and nocturnally sustained—temperatures due to the urban heat island (UHI) effect (Hulley, 2012; IPCC, 2007).

UHIs are originated by heat generated in urban environments that is entrapped by urban structures being aggravated by greenhouse gases and the lack of green spaces. Dark-colored surfaces (like dark asphalt pavements) have low reflecting power

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Table 1.1 Excess mortality attributed to the 2003 heat wave in Europe

Location (date)	Excess mortality (% increase)
England and Wales (Aug 4–13)	2091 deaths (17%)
Italy (Jun 1–Aug 15)	3134 deaths (15%) in all Italian capitals
France (Aug 1–20)	14,802 deaths (60%)
Portugal (Aug)	1854 deaths (40%)
Spain (Jul–Aug)	4151 deaths (11%)
Switzerland (Jun–Sept)	975 deaths (6.9%)
Netherlands (Jun–Sept)	1400–2200 deaths (not reported)
Germany (Aug 1–24)	1410 deaths (not reported)

Haines et al. (2006).

(or low albedo characteristics). As a consequence they absorb more energy, and in summer can reach almost 60 °C, thus contributing to higher UHI effects. Some authors reported a 10 °C temperature increase in the city of Athens due to the UHI effect (Santamouris et al., 2001), and a 8.8 °C increase in London (Kolokotroni and Giridharan, 2008), while a recent three-year investigation in the city of Padua reported an increase up to 6 °C (Busato et al., 2014). According to Li et al. (2014), the waste heat discharged by air conditioners alone was responsible for an increase of almost 2 °C of Beijing's average air temperature in 2005. It's worth noting that since 2005, the population of Beijing has increased from 15 to 21 million people, and by 2020 it will reach 25 million.

According to Santamouris (2013), a renowned expert on energy and solar technologies, UHI is probably the most documented phenomenon of climate change for various geographic areas of the planet. As a result of the urbanization and industrialization of human civilization, UHI has become one of the major problems of the twenty-first century (Rizwan et al., 2008). A recent work published in *Nature/Letter* (Zhao et al., 2014) also addresses this position. If no adaptation measures are taken, the social cost of climate change can be significant. This could mean an additional 26,000 deaths per year from heat waves (and their synergic effects with air pollution) by the 2020s, rising to 89,000 deaths per year by the 2050s and 127,000 deaths per year by the 2080s. These predictions do not even take UHI effects into account.

1.2 Adaptation to climate change and mitigation of UHI effects and of building cooling needs

Even if all the greenhouse gas emissions suddenly ceased, the amount already in the atmosphere would remain there for the next 100 years (Clayton, 2001). In other words, the rise in the sea level, ocean acidification, and extreme atmospheric events will continue.

Hansen et al. (2013) are even more pessimistic, believing that the climate has already been changed in an irreversible manner. This means that adaptation to climate change as well as mitigation of greenhouse gas emissions should be a priority to the built environment (Georgescu et al., 2014; Kwok and Rajkovich, 2010; Olazabal et al., 2014; Reckien et al., 2014).

The rapid increase of river floods and excessive hot days for the next decades is very worrying (EEA, 2012).

That is why the words of the European Commissioner for Climate Action, Connie Hedegaard, on the launch of the EU Strategy on Adaptation to Climate Change in Brussels on 29 April 2013, make a lot of sense: "*Investing now in adaptation will save lives and much greater costs later.*"

According to the COM 216 (2013), "*The minimum cost of not adapting to climate change in the EU is estimated to range from €100 billion a year in 2020 to €250 billion in 2050.*" On 25 June 2014, a study (Ciscar-Martinez et al., 2014) on the effects of climate change in Europe was released, stating that if no further action is taken, climate damages in the EU could amount to at least *€190 billion* and heat-related deaths could reach about 200,000.

The future of the built environment will therefore involve the adaptation towards climate-resilience. Unfortunately, a detailed study that analyzed the climate change adaptation and mitigation plans of more than 200 large and medium-sized cities across 11 European countries concluded that 35% of European cities studied have no dedicated mitigation plan, and 72% have no adaptation plan (Reckien et al., 2014).

Greening of the building envelope by using vegetation is a growing trend both in the adaptation to climate change and in the mitigation of UHIs. Green roofs date back to the fifth century in Babylon, when hanging gardens were implemented, and to ancient Mesopotamia, where they were used in the ziggurats (Berardi et al., 2014).

Though not an innovative technique (first attempts to quantify energy benefits occurred in the 1960s), the greening of the building envelope by using vegetation is a growing trend, and some countries show a remarkable acceptation of such "technology." For instance, Germany has almost 100 million m^2 of green roofs, and the state of Singapore intends to target 0.75 ha of green roofs per 1000 inhabitants (Pacheco-Torgal, 2014).

Green infrastructure is important enough to merit special attention in EU policy. On 6 May 2013, the EU adopted a new strategy for encouraging the use of green infrastructure (IP 404, 2013). The European Commission planned to develop guidance to show how green infrastructures could be integrated into the implementation of these policies from 2014 to 2020 for several areas, including adaptation to climate change. The green building envelope is particularly important, as recent investigations show a strong correlation between the lack of green infrastructures in the urban environment and the increase of allergy-related health problems (Hanski et al., 2012). This is the subject of Chapters 5, 11, 12, and 13 in this book.

An important consequence of climate change is the increase of building cooling needs. In the last two decades, building cooling needs have increased exponentially, from 6 TJ in 1990 to 160 TJ in 2010 (Balaras et al., 2007). According to Crawley (2008), "*the impact of climate change will result in a reduction in building energy* *use of about 10% for buildings in cold climates, an increase of energy use of up to 20% for buildings in the tropics, and a shift from heating energy to cooling energy for buildings in temperate climates.*" Other authors mention that, depending on the climate zone, cooling loads are likely to increase by 50–90% until the end of the century (Roetzel and Tsangrassoulis, 2012).

The synergistic effect between heat waves and air pollution causes worse outdoor air quality in the summer and will prevent natural ventilation, thus aggravating cooling needs. In the heavily polluted city of Beijing, Li et al. (2014) reported that 28.88% of the total air-conditioning energy consumption is due to the UHI effect.

In Europe, this could complicate the implementation of the ambitious nearly zero-energy building target set by the European Energy Performance of Buildings Directive (EPBD) recast (Directive 2010/31/EU). It could also put at risk the EU strategy to tackle climate change, especially the goal to cut greenhouse gas emissions by 80–95% below 1990 levels by 2050, as well as savings of at least €100 million per year by 2050 (COM (2011) 885/2, Pacheco-Torgal et al., 2013).

Actually, the energy costs represent 12% of the European GDP, and an increase to 14% is expected by 2050 in both scenarios (BAU and decarbonisation) (Figure 1.1). However, the decarbonisation scenario involves a 1.9% increase in infrastructure and energy efficiency investments and a 1.4% reduction of energy imports. This increase in the GDP, despite huge investments, has to do with the increase in energy demand. Of course, a better performance could be obtained if an indicator capable of measuring long-term sustainable use of natural ecosystems and resources was used, like the Genuine Progress Indicator (Constanza et al., 2009; Daly and Cobb, 1989).

Since the urban population will increase dramatically in the next decades, building cooling needs due to UHI effects will also increase dangerously (Allegrini et al., 2012).

According to the World Health Organization (WHO, 2014), around half of all urban dwellers currently live in cities; however, by 2050, cities will hold 70% of

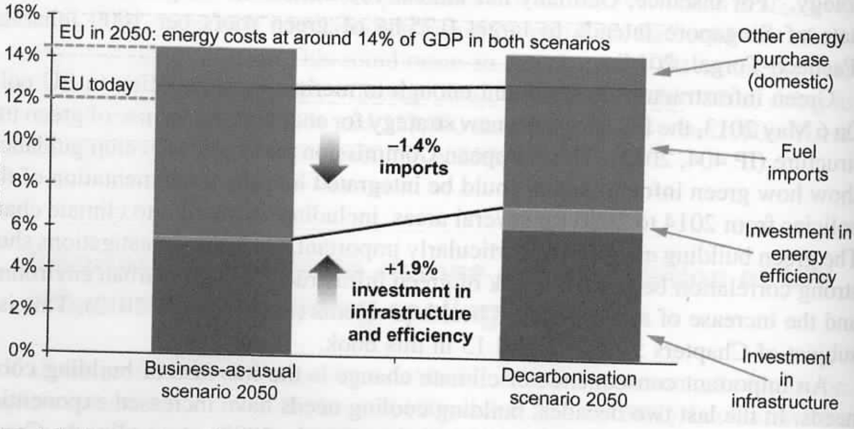

Figure 1.1 Forecasting of energy costs for Europe by 2050.
Barroso (2013).

the world population. This represents an alarming increase of about 3000 million people in the next 40 years (WHO, 2014).

If current trends in population density continue, urban land cover will increase by 1.2 million km^2 by 2030. This is equivalent to an area about the size of South Africa (Seto et al., 2012).

Therefore, it is very important that new eco-efficient materials and technologies capable of mitigating UHI effects and building cooling needs be developed. It is the purpose of this book to make a contribution in this area.

Other books have already been written about mitigation of UHI effects. However, some are short on material for the mitigation of building cooling needs, and others have almost nothing on UHIs. And almost all have nothing on chromogenic smart materials, to which this book dedicates three chapters (16, 17 and 18). Those three chapters, along with the three chapters related to the greening of the building envelope, constitute an important part of this book. With the special contribution of a team of international experts, the book provides an updated state of the art on eco-efficient materials to mitigate UHI effects and building cooling needs.

1.3 Outline of the book

This book provides an updated, state-of-the-art review on the eco-efficiency of materials to mitigate UHI effects and building cooling needs. The first part of the book encompasses an overview on pavements for mitigation of UHI effects (Chapters 2–4). In Chapter 2, different coating overlays of pavements for heat island phenomenon mitigation are introduced. Three types of materials as the main components of the coating materials for pavement to mitigate the heat island effect are provided. Organic polymers applied as the main part of the overlay coating materials, inorganic metal oxide powders used as the solar energy reflective fillers, and fine aggregates used to increase the durability of the reflective coatings are systematically introduced. The advantages and disadvantages of the current coating materials are analyzed. Chapter 3 addresses concrete pavements with high solar reflectance. Materials and methods used and their relative effectiveness for increasing solar reflectance are examined. The basic heat transfer problem relating solar reflectance to pavement surface temperature is explained. Modeling of a hypothetical scenario where high solar reflectance concrete replaces conventional concrete and both concrete and asphalt surfaces in several large cities shows that huge energy savings could be realized. Chapter 4 discusses the albedo and thermal performance of concrete and asphalt-based materials. The performance of different pavement materials, including pavement surface temperature, near-surface air temperature above pavement, thermal impact of pavement on nearby building surfaces, and heat flux from pavement are analyzed.

Façade materials for reducing building cooling needs are the subject of Part Two (Chapters 5–8). Chapter 5 is concerned with green façades. It reviews different types of green façades and living walls and analyzes the individual processes of a vegetated layer that contribute to the cooling effect. It also includes an assessment of energy savings that can be achieved in buildings with vegetated façades and summarizes additional benefits of green walls. Chapter 6 covers the performance of different façade materials. The thermal behavior of 96 façade materials—claddings and coatings evaluated by means of their solar reflectance index (SRI)—is analyzed. A simulation of relative impact of the appropriate selection of materials as a strategy for building and urban rehabilitation is presented. Chapter 7 analyzes innovative new materials for passive evaporative cooling walls. The chapter includes a description of the performance of porous mullite ceramics with unidirectionally oriented pores, prepared by an extrusion method using rayon fibers with various diameters as the pore formers; their capillary rise properties are investigated with a view to developing materials applicable for counteracting UHI effects. Chapter 8 addresses the performance of innovative evaporative cooling walls. A state-of-the-art review is included. The most important approaches currently adopted, namely direct and indirect cooling, are presented. A review of some numerical models relative to the simulation of evaporative cooling components is also presented.

Part Three (Chapters 9–13) deals with roofing materials for reducing building cooling needs. Chapter 9 reviews high albedo coatings for building roof application including its threefold benefits—at building, urban, and global climate scale. Specific characteristics of such coatings are discussed. The physical properties determining their cooling potential, solar reflectance, thermal emittance, and the final overall Solar Reflection Index are presented. Benefits of high albedo coating for roofs through the analysis of recent research demonstrating their effect in reducing building energy requirements for cooling are also presented. Chapter 10 discusses the solar evaporative cooling of roofs with hydrophilic (hydroscopic) porous materials. Urban passive cooling methods of building roofs are briefly presented. The interaction of solar spectrum with the porous materials through reflection and absorption, with or without adsorbed water vapor, is also presented. The concept of solar cooling through the water vapor adsorption–condensation–evaporation–desorption cycle and the experiment for the efficiency of the technique with low-cost materials are analyzed. Chapter 11 looks at cool green roofs. It summarizes three types of green roof systems and gathers materials and properties of each layer, according to maintenance requirements. A green roof design and construction process is presented step-by-step. Design principles for reducing cooling needs are suggested. Chapter 12 is concerned with the influence of damaged vegetation on the reduction of building cooling needs. Suggestions for damage prevention are included. Chapter 13 reviews the technical and economic aspects of green roofs. Economic indicators are described, as well as the physical set of equations for evaluating the energy performance of green roofs. Some case studies are shown, describing the various considered climates, energy and water costs, efficiency of power systems, emissions factors, and all parameters necessary for suitable feasibility studies. Considerations for improving the profitability of green roof by adopting rainwater harvesting systems are presented.

Finally, Part Four concerns phase change materials (PCMs) and chromogenic smart materials (Chapters 14–18). Chapter 14 is concerned with the performance of PCMs. A description of the use of PCMs in passive and active systems is included. Chapter 15 deals with nanomaterials—embedded PCMs for reducing building cooling needs. A review on nanomaterials for thermal energy storage is presented. A simulation on the thermal energy storage properties of nanomaterials is included. Chapter 16 deeply reviews chromogenic glazings based on thermochromic and electrochromic materials for reducing building cooling needs. Chapter 17 covers electrochromic walls, which encompass the innovative use of electrochromic glazing in the opaque partition of the building envelope. Chapter 18 closes Part IV with a case study on the influence of electrochromic windows' impact on the energy performance of buildings located in Mediterranean climates.

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