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Energy conservation and renewable technologies for buildings to face the impact of the climate change and minimize the use of cooling

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ABSTRACT

Facing the climate change is a common priority, due to ethical issues related to general concept of sustainability and livable future for the next generations. Moreover, ethical aims for contrasting energy poverty, heat-related diseases and deaths, availability of food and water, infections and viral-bacteriological risks, meteorological extreme phenomena, such as floods and intense and destructive precipitations, are stringent and pressing targets. All serious and independent investigations reveal future scenarios of an overall global warming that surely make worrying the evolution of quality of life on this earth. Each one has to do his part. In this study, the research is focused on renewable technologies for the passive cooling of buildings. Indeed, the space cooling is a strongly increasing use of energy and induces a vicious circle, being, at the same time, a cause and an effect of the anthropogenic overheating of the planet. The paper mainly reviews techniques for suitably governing the energy interaction between buildings and surrounding environment. The energy efficiency concerns the building envelope design, the use of efficient HVAC systems, adoption of renewable energy on-site. On the other hand, every energy conversion process determines waste heat, so that also a ‘free of operational cost' solar cooling system however causes dissipation of heat into the ambient. Finally, renewables cannot be the unique solutions for supplying the energy required for the building use. Conversely, strategies for reducing the building cooling are needed, and these are reviewed in this study. In thermodynamics terms, the building is seen as part of the system and not the mere control volume. Greenery of facades and roofs, phase change materials, nocturnal convective cooling, evaporative and ground cooling, solar systems such as chimneys for improving the building ventilation are here discussed, as well as emerging technologies such as breathing walls and dynamic insulation. The reviewed studies, selected on the basis of more recent progresses concerning the investigated technologies, revealed potentialities but also criticalities in the design.

1. Introduction overview on climate change, urban heat island effects and role of buildings and constructions

According to future worldwide targets aimed at a low-carbon future, during the last decades several protocols, energy acts and guidelines for contrasting the anthropogenic climate change have been shared at World level, starting from Copenhagen 2009 and arriving to the agreement of the 2015 United Nations Climate Change Conference, the COP21, hosted in Paris in December 2015 (Paris Agreements, 2015).

The same effort has been spent at European level, by taking into account several sectors of public life (Directive 2012/27/EU EU Commission and Parliament, 2012), with reference to general energy efficiency targets and, more specifically for the building sector, through the Directives on Energy Performance of Buildings (EPBD): the EPBD 2002/91/EU (EU Commission and Parliament, 2002) and the Recast version 2010/31/EU (EU Commission and Parliament, 2010). These last documents of the European Institutions have had an epochal impact. Indeed, for the first time in the world history, twenty-eight countries have decided to establish a common journey toward a better World. This is a common path of efficiency and not a mere declaration of intents, in relation to the sector that, at the EU level, is the one that mostly affects energy demand and pollution so closely connected to it. About it, two key points have to be underlined and thus the primary role that buildings have on the overall energy balance of European countries (around 35–40% of energy demand and a similar share of greenhouse emissions) and the consideration that policies aimed only at imposing new efficient buildings would not have significant impacts in the medium period. In detail, given the low turn-over rate characterizing the building sector (lower than 2%/year, in developed countries), many decades will be necessary for

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achieving some benefits if merely new efficient constructions would be built, without policies focused on the existing building stock.

Authoritative researches in matter of future scenarios of overall global warming and increasing use of cooling devices for contrasting the overheating due to the climate change testified a very worrying evolution of quality of life on this earth (Santamouris, 2016). Indeed, several factors will produce, in this century, an increasing of building cooling, mainly because of the development of countries, urban increase, desirable increasing of families income at world level, reduction of costs of technologies. About it, investigations revealed, for all world countries, also a generalized increase of cooling degrees-day (Warren et al., 2006; Benestad, 2008; Vautard et al., 2014).

Warren et al. (2006) developed a long report in which the impacts of climate change are studied with reference to several issues and, specifically, water resources, agriculture, coastal flooding, human health, energy requirements, ecosystems, vegetation. The investigation reveals tremendous scenarios, among which the diffusion of diseases, the increasing of deaths due to more frequent floods, and many more other negative events connected to the global warming, such as the reduction of biodiversity, losses of vegetal species, more frequent and intense extreme heat waves. Finally, an increment of temperature of about 2 °C (and this is a quite realistic scenario) would induce an increase of energy demand for cooling, at world level, between +20 and +170%.

More specifically for European climates, Benestad (2008) investigated past and future trends of heating and cooling degrees-day, HDD and CDD respectively. The author found that, for the next years, there will be a general reduction of heating demand and a significant increase of cooling needs. Conversely, the trends of rainfall are related to the specific area. In particular, for all example European cities - from Reykjavik to Thessaloniki, from Tallinn to Naples, and thus Mediterranean (e.g., Naples, Barcelona), continental (Berlin, Madrid) and northern areas (Vilnius, Stockholm) - the increasing trends of CDD is very impressive. In total, 62 cities have been studied according to an empirical statistical distribution of outdoor temperatures and the projection for the next future (the analyzed period is 1900–2100) provides a sensitive increase of CDD and a parallel lowering of HDD. Even if the COP21 (Paris Agreements, 2015) has identified a global warming of 1.5 °C compared to the pre-industrial climate as a kind of threshold of salvation, it does not mean that no significant changes will affect the European and World lives. For instance, Vautard et al. (2014), recently, have investigated what it will induce an increase of temperature of 2 °C; in detail, the authors performed many regional climate simulations and identified possible projected changes for this rate of environmental temperature change. Interesting (and worry) outcomes are provided. The regional warming will be higher compared to the global warming, with increases of about 2–3 °C in the winter temperatures in North-Eastern and Eastern areas of Europe, and analogue increments of summer temperatures in Southern Europe. In general, the increase of temperatures is more accentuated in winter. Mainly in the Iberian Peninsula and in the Mediterranean areas, the energy demand for cooling will increase significantly, with a 10–15% decrease of precipitations, while, in heating-dominated climates, the reduction of building heating will be significant. Southern Eastern Europe and Spain and Portugal could have an increase of maximum summer temperatures also of about 3–4 °C. At the same way, extreme minimum temperature in Northern and Central Europe will decrease of about 2–3 °C (Central and South Europe), of about 5–8 °C (North Europe and Scandinavia). The authors concluded that the generalized warming, more significant in Europe compared to the planet overheating, will have robust and important effects, among which the cooling costs for our buildings and, socially, the increase of heat-related mortality due to the summer extreme events. Furthermore, extreme floods and heavy precipitation events will occur.

Definitively, recent researches provide different specific outcomes, different investigated zones of the planet, but the last result is always the same: the temperature of the outdoor environment will increase, from 0 °C to 4 °C. This will determine highest temperature difference between outdoor and indoor-desired temperature for thermal comfort, so that a higher demand for cooling will be inevitable. These and many other issues and, more in general, several parameters affecting the increase of building cooling demand and diffusion have been largely discussed in Santamouris (2016).

Finally, it is expected a great and increasing diffusion of active cooling systems in some countries, with a low-rate increment in other ones, and it is undisputable that all countries have to establish, as soon as possible, effective policies for facing the climate change. Of course, the couple "global warming ↔ diffusion of mechanical cooling" is inseparable, a sort of vicious cycle, and everybody on this Earth has to do what he can do. Finally, even if strongly developed countries, such as North-America and Europe will have the lowest increase in terms of saturation of cooled buildings (e.g., when necessary, the equipment have been already installed many years ago), however a strong effort should be dedicated in reducing a further increase of cooling demand and active cooling use. This long premise, of course, would underline that the impact of energy policies will be not the same all around the world.

This study will focus on buildings, and more in detail on reduction of cooling in buildings of developed countries. Indeed, we have to discern two interconnected but also autonomous phenomena:

- the global increase of average temperature is mainly connected to the energy and anthropogenic factors of developing countries, being the developed ones already equipped with more-or-less efficient policies for facing the local climate change;
- the energy poverty, and all connected events, such as poor livability in buildings, poor quality of life, diseased and also mortality are event that affect also rich-considered countries, such as the European ones, where, of course, significant differences can be found. For instance, East countries suffer more fuel poverty compared to Scandinavian ones, with intermediate positions of middle European and Mediterranean nations (Santamouris and Kolokotsa, 2015).

Finally, in order to achieve significant benefits in terms of cleaner environment, contrasting the climate change, allowing a sustainable future for the next generations, it is needed to proceed 'in-parallel', by imposing new efficient constructions and strongly promoting the refurbishment of existing ones.

It is well-known that there are many levers for reducing the energy costs of a building, and thus:

(a) energy conservation measures for the thermal envelope,
(b) energy efficiency of active energy systems and technical equipment,
(c) integration of energy demands by means of on-site conversion from renewables.

Here there is a possible misunderstanding, which often involves Institutions and Governments. Indeed, reduction of energy costs and energy uses does not mean reduction of urban heat islands nor local warming. For instance, with reference to the more and more contingent topic of urban heat islands, the use of high-efficient cooling systems can contribute in reducing the electric energy demand for chillers (with benefits for the whole country), but there is not a complete lowering of the condensation heat at the urban scale. The same consideration is valid for the adoption of solar cooling system, by means of the coupling of solar thermal