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Regulating the damaged thermostat of the cities—Status, impacts and mitigation challenges

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ABSTRACT

Increase of the urban ambient temperature caused by local and global phenomena is probably the more incontestable incident of climate change. Urban warming has a very significant impact on human life increasing the energy consumption, deteriorating the comfort levels, increasing the pollution concentration, threatening the human health and affecting the urban economy. Mitigation technologies aiming to countermeasure the impact of the phenomenon are rapidly developed and applied in real scale projects. The present paper aims to present in a critical and comprehensive way the recent scientific knowledge on the causes of urban warming and also stress the main problems and inconsistencies concerning the experimental and the theoretical findings and analysis. In parallel, it classifies and summarizes the main knowledge on the energy, environmental, health and economic impacts of urban warming. Quantitative information on the energy penalties, mortality rates and environmental degradation induced by urban warming is presented. Finally, it presents the main developments regarding urban mitigation techniques and technologies and in particular, urban greenery and planted roofs, cool pavements, cool roofs and increase of the urban albedo, decrease of the anthropogenic heat and use of the ground as a sink for heat dissipation.

Contents

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1. Introduction

Cities are centers of significant size where the population is living in an organized way, consumes and develops commercial and cultural activities. Cities are supposed to improve the quality of life of human beings. As pointed out in [1], 'a city comes into being for the sake of life, but exists for the sake of living well'. Expectations for a better life created by the urban economic growth and industrialization, local conflicts in rural areas, mechanization of the agriculture and lack of resources in the rural areas are the main causes of the massive migration of the rural population into the cities and the unprecedented growth of urban population. Although in the fifties, only 30% of the world's population lived in cities, in our day urban population has reached 3.9 billion of citizens, almost 54%, and future projections show that by 2050 around 66% of the earth's population will be urban [2]. It is characteristic that urban population increases with a rate of almost 1.5 million people per week because of the migration from rural areas and childbirth [3].

Increase of the urban population has resulted in a serious territorial urban expansion, spatial growth or sprawl that affected in a direct way the consumption patterns. Although cities occupy 0.5% of the earth's surface, they consume about 75% of the global resources [3]. In most of the cases, urban sprawl and the implied change of land use resulted in a serious climatic and environmental degradation like air pollution, noise, poor water quality and temperature increase and thermal stress. In fact, urban expansion and sprawl led to a reduction of the green areas, sealing of urban surfaces through intensive paving and building construction and increase of the anthropogenic heat released to the atmosphere [4].

Urban climate is the result of urban, local and regional geographical features [5]. Changes in land cover at the regional and local scale, increased heat storage by the urban structure, higher anthropogenic heat liberated, lowered evaporative cooling and increased sensible heat released by buildings and pavements affect highly the urban heat balance and contribute to higher urban temperatures. The effect is known as urban heat island and it is the most documented phenomenon of climate change [6]. Its magnitude is a function of the urban layout, its morphological, physical and structural characteristics, the synoptic weather conditions, the local meteorological factors and finally the intensity of the anthropogenic heat produced and liberated in the city [7]. Intensive experimental studies performed in numerous cities of the world report urban heat island intensities as high as 10 K, however, almost every city has a heat island.

Furthermore, the actual urban warming cannot be contributed solely in terms of the urban heat island. Global climate changes resulting from the increase of the greenhouse gases in the atmosphere caused by human activity increase urban temperature as well. In fact, the IPCC suggested projections on the average ambient temperature increase, 0.15 K to 0.3 K per decade for 1990 to 2005, are verified by recent measurements [8]. Depending on the scenario chosen, the most recent estimates of IPCC suggest a worldwide increase of 1.8 K to 4 K to occur between 1990 and 2100 [8]. Thus, urban warming should be attributed to both of the phenomena. The relative contribution and the synergy between the two phenomena is for the time being a quite gray scientific zone. Evidence from numerous experimental studies shows that in many locations, climate effects attributed to urban heat island are of similar or of a greater magnitude than that caused by global climate change [9–11]. Future projections based on advanced simulation techniques are quite contradictory. According to [4], the intensity of the urban heat island may remain the same even if the magnitude of the global warming is intensified, while in [12] it is predicted that urban heat island may decrease if global warming is intensified due to the increase of the vertical instability conditions and the corresponding dissipation of the heat in the cities. Simulations reported in [13] using global climatic models, shown that in urban zones of high population growth urban heat island may be intensified. In general a stronger global climate change may cause an average reduction of the urban heat island by 6%, however, in some locations the magnitude of the urban heat island may increase up to 30%. In particular, it is predicted that for specific urban zones of the planet the impact of urbanization will be similar as the impact of double CO_2 concentration and will increase the difference in extreme hot nights between the urban and rural zones. However, the future magnitude of the urban heat island depends highly on the frequency of the weather types and the prevailing synoptic conditions as it is well known that heat island is better developed under anticyclonic conditions [14].

Higher urban temperatures and frequent extreme events have a serious impact on various domains of the human life. Numerous studies have documented that UHI increases the concentration of specific urban pollutants and affects the urban air quality, increase the energy consumption for cooling purposes as well as the peak electricity demand, raises the CO_2 emissions and the ecological footprint of cities while it has a serious impact on human health, thermal comfort and economy [15].

Increased urban ambient temperatures facilitate the formation of tropospheric ozone, a harmful pollutant created as nitrogen oxides react with VOC's during the day time. Evidence from numerous observational and numerical studies, show a strong positive correlation between the urban heat island intensity and the concentration of tropospheric ozone [16–18]. Important research is carried out to identify the energy penalty induced by the urban warming. It is commonly accepted that higher urban temperatures increase the peak electricity demand as well as the energy spent for cooling purposes while the heating energy demand is decreased [19,20]. Urban warming has a serious impact on indoor and outdoor thermal comfort. Several studies have correlated the levels of outdoor thermal comfort in cities against the corresponding increase of the urban temperature. In most of the cases a significant degradation of the outdoor comfort conditions is observed [21]. In parallel, studies investigating indoor environmental conditions during extreme events report very warning results. Extensive monitoring of low income houses shows that indoor temperatures are significantly higher than the defined allowed levels, putting in threat the health and the well being of citizens [22,23].

It is widely accepted that exposure to substantially high temperatures is a health threat [24]. Medical research has shown that high ambient temperatures cause serious respiratory, cardiovascular and cerebrovascular problems [25]. Recent research has proven that increase of the ambient temperature up to a threshold is associated with a significant increase of the mortality rates and hospital admissions [26].

Counterbalancing the impact of urban warming is a serious challenge for scientists. Mitigation technologies aiming to reduce the strength of the sources and enhance the sinks of temperature anomaly in the urban environment were developed and already