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Recent progress on urban overheating and heat island research. Integrated assessment of the energy, environmental, vulnerability and health impact. Synergies with the global climate change

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ABSTRACT

Urban overheating is documented for more than 400 major cities in the world. Numerous experimental data show that the magnitude of the average temperature increase may exceed 4-5 C, while at the peak may exceed 10 C. Increased ambient temperatures cause a serious impact on the cooling energy consumption, peak electricity demand, heat related mortality and morbidity, urban environmental quality, local vulnerability and comfort. Synergies between urban heat island and heat waves increase further the amplitude of urban overheating The present paper reviews and reports the recent progress and knowledge on the specific impact of current and projected urban overheating in energy, peak electricity demand, air quality, mortality and morbidity and urban vulnerability. In parallel, it discusses new findings related to the characteristics and the magnitude of urban overheating, and reports and analyse the recent knowledge on the synergies between urban heat island and heat waves.

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1. Introduction

Cities present a higher ambient temperature than the surrounding suburban and rural areas. The phenomenon is known as 'Urban Heat Island Phenomenon', UHI, and is well documented in more than 400 cities around the world, [1]. Urban overheating is caused by numerous reasons as summarized in [2], including the thermal properties of the materials used in cities, the released anthropogenic heat, the canyon radiative geometry, the urban greenhouse effect, the reduction of the evaporative surfaces and the reduced turbulent transfer in the dense urban environment. Data on the magnitude and the characteristics of the urban heat island is available for hundreds of cities. Analysis of data collected using mobile traverses in 101 Asian and Australian cities, [3], shown that the UHI magnitude may vary between 0.5 to 11 C with an average value close to 4.1 C. A similar analysis performed using data from 110 European cities, [4], shown that the UHI magnitude, varies between 1 C to 10 C with an average maximum value close to 6 C.

Global climate change causes a serious increase of the frequency, magnitude and duration of extreme heat events, [5]. The important synergetic effects between regional and global climate change, seems to intensify the magnitude of the UHI phenomenon during the period of the heat waves, [6]. For many years, the identification of the magnitude of the UHI and the understanding of the reasons causing the phenomenon, were the main priorities in urban overheating research. The recent significant scientific developments on the appearance and the impact of heat waves, shifted research priorities towards the analysis and the understanding of the potential association between heat waves and urban heat island.

Higher urban ambient temperatures have a serious impact on citizen's life and the overall environmental quality of cities. It is well documented that urban overheating is causing a serious increase of the energy consumption for cooling purposes, a considerable rise of the peak electricity demand, affects in a negative way local vulnerability levels, increases heat related mortality and morbidity, while it augments the concentration of harmful pollutants, [7]. Numerous studies have examined the impact of urban overheating on the peak electricity demand during the warm period. An analysis of the existing studies reported in [8], concludes that for each degree of temperature increase, the corresponding rise of the peak electricity load varies between 0.45% and 4.6%. This corresponds to an additional electricity penalty of about 21 (±10.4) W per degree of temperature increase and per person.

The impact of the increased urban temperatures on the cooling energy demand depends on the magnitude of the urban overheating, the quantitative and qualitative characteristics of the building stock and the local climate characteristics. An analysis of the existing assessments reported in [9], concluded that in cooling dominated climates with an average summer ambient temperature above 27 C, urban overheating is causing a significant increase of the cooling demand. It is estimated that the additional energy penalty induced by the UHI phenomenon at the city scale is close to 0.74 kWh//m2/C, while the Global Energy Penalty per person, is close to 237, (±130) kWh/p. The study has also concluded that in heating dominated urban zones where the average summer ambient temperature is below 23 C, the decrease of the heating load is more significant than the corresponding increase of the cooling load. Important research is carried out aiming to assess the impact on energy load because of the local or/and global climate change. Most of the assessments conclude that during the next 30-40 years, the future energy needs for cooling will seriously exceed the corresponding heating demand, while they forecast a dramatic rise of the cooling needs for several countries under development like India, [10,11]. As reported in [11], the additional electricity consumption to cover the 2030 cooling demand in India is close to 239 TWh/year which corresponds to 300 new coal fired electricity power plants.

Although energy and peak electricity seems to be highly impacted by the urban overheating, the observed and the forecasted increase of the heat related morbidity and mortality caused by the global and local climate change, is highly alarming, and it seems to be one of the current and future peak scientific topic, [12,13]. According to the existing epidemiological records almost 59,114 persons passed away between 2000 and 2007 during 52 extreme heat events around the world, [14]. Overheating in cities combined with increased pollution levels rises significantly the levels of heat related mortality and morbidity, [15]. Recent research has shown that heat related mortality increases seriously above a temperature threshold that differs significantly between the various parts of the planet. Because of the human adaptation, threshold temperatures are much higher in cooling than in heating dominated climates, [16]. Current research aims to better document, the impact of changing climate on heat related mortality using longer time series of data for more cities. Projections of the future heat related mortality are very alarming although there is an important uncertainty in assessing the future health impacts, [17]. Issues related to the potential adaptation of the population to high temperatures under climate change, are of very high importance, while the impact of increased urbanisation on health is still an open question. In parallel, the combined impact of increased ambient temperature, humidity and air pollution is a research priority in hot humid and polluted cities.

Urban overheating has a serious impact on low income population while it seriously increases urban vulnerability, [18]. Vulnerable and low income population mainly live in low thermal quality houses in deprived urban zones presenting a significant overheating, [19]. As a result, low income households can be seriously exposed in higher indoor and outdoor ambient temperatures and pollution levels, while they have to consume more energy than the average to satisfy their energy needs, [20].

Higher urban temperatures increase seriously the concentration of harmful pollutants like the ground level ozone and particulate matter, [21]. The association between urban overheating and ground level ozone is well documented, and urban heat island seems to be the main cause increasing ozone concentrations above the accepted thresholds, [22]. Projected future concentration of the ground level ozone under climate change, are quite alarming and may be a serious threat for human life.

While numerous studies have focused on a specific impact of urban heat island like the increase of the cooling energy consumption, the peak electricity demand, mortality and morbidity issues and pollutants concentration, no studies have presented its global impact in an holistic and integrated way. Risk factors arising from urban overheating are strongly associated and interrelated and there is a need to shift away the focus from the specific associations of the ambient temperature with energy, electricity production, health and social issues, towards a more global and holistic approach highlighting the interdisciplinary nature of the subject. The present paper aims to present in a comprehensive and holistic way the current and future impact of urban overheating on urban population, Also, to report the recent developments on the topic and highlight the synergetic and interdisciplinary nature of the regional and global climate change.

2. Recent developments on the characteristics and magnitude of urban overheating

As cities expand their boundaries, agricultural land is transformed into urban space, anthropogenic activities and urban population are increasing, while ambient temperature in cities tends to increase significantly. Rapid urbanisation mainly in the developing world, intensifies urban overheating and causes serious energy, environmental, health and economic problems, boosting the scientific research aiming to document the magnitude and the characteristics of the urban overheating. The total number of cities, where urban heat island is documented is increasing rapidly. During the first months of 2019, urban heat island was documented experimentally in 14 new cities, ten out of which were in developing countries, (Paranavai Brazil, [23], Hanoi Vietnam, [24], Brisbane Australia, [25], Hiroshima, Japan [26], Tivissa Spain [27], Sofia Bulgaria [28], Rozario Argentina [29], Guayaquil Ecuador [29], Lima Peru [29], Antofagesta and Valparaiso, Chile [29], Tianjin China [30], Turin, Italy [31], and Kano Nigeria, [32]. The magnitude of the reported UHI intensity lies between the boundaries indicated in [3,4]. Several monitoring protocols, (mobile traverses, standard and non standard meteorological stations), have been employed, while the format of the reported results differed significantly. The lack of a standardized monitoring and reporting procedures and protocols is a source of serious inaccuracies and inconsistencies between the existing experimental works

Additional documentation of the magnitude and the characteristics of the urban heat island in cities provide useful information and contributes to better understand the extend of urban overheating in the world. However, apart of the new quantitative data, rarely new scientific information is reported as the causes and the characteristics of the UHI are quite well understood under the actual climatic conditions. However, a serious lack of knowledge is identified around the synergies between regional and global climate change, i.e. urban heat island, UHI, and heat waves, HW. Evidence from observational data shown that cities respond differentially to heat waves than rural areas and the urban heat stress during heat waves may be higher than the sum of the background stress caused by UHI and HW. The subject has recently gained increasing interest while the recent increase of the frequency, duration and magnitude of the heat waves, has provided enough data and evidence about the synergetic results of local and global climate change in cities. Several physical attributes determine the interaction between UHI and HW. Among them,

- the development of secondary air flows during heat waves may has a negative impact on the magnitude of the UHI as cool air from the surroundings may be transferred into the city,
- low wind speeds prevailing during HW may intensify the urban heat island, while,
- excess of the soil humidity in rural areas may increase the evaporation rates compared to the urban areas and result in higher temperature differences between the urban and rural environment, [33].

Several numerical and experimental analysis have been performed and it is well accepted that the synergies between the UHI and HW are strongly modulated by local dynamics. Using simulation it was found that in Klementinum, Check Republic, the intensity of the UHI during heat waves is decreasing, [34] while in Philadelphia, USA it is not modified mainly because of the city landscape characteristics, [35]. A non-intensification of the UHI intensity during heat waves is also observed in Bucharest, Romania using recorded climatic data, [36]. A numerical analysis performed in [35], for seven American cities concluded that the UHI is more amplified in upper tier cities like New York, Baltimore and Washington DC, than in smaller cities because of the sharper gradients in surface soil moisture along the urban-suburban-rural transect in large cities.

The magnitude of the intensification of the UHI can be significant. Simulations performed for New York city, US, shown that the daytime UHI intensity is intensified up to 4 C, [37], while a similar simulation study reported an increase of the daytime UHI intensity up to 2 C, [33]. Analysis of climatic data during several HW periods, in Athens, Greece, shown an intensification of the daytime UHI up to 3.5 C during heat waves compared to the background summer UHI intensity, [38]. In Washington and Baltimore, the intensity of the UHI has increased by 1.5 C to 2 C during the night period, [33]. An important intensification of the night time UHI intensity is also found in studies reported in [33,38–42], for Washington DC, Baltimore, Oklahoma, Shanghai, Beijing and Karachi Pakistan.

Intensification of Urban Heat islands during heat waves may has a severe impact on thermal comfort, cooling energy consumption, concentration of harmful pollutants and heat related mortality and morbidity. Further studies are necessary to better understand the complex synergies between UHI and HW mainly in upper tier cities where the intensity of the UHI phenomenon is high.

3. Impact of urban overheating on energy, peak electricity demand, vulnerability, health and concentration of pollutants

3.1. Impact of urban overheating on the energy consumption of buildings

Increase of the ambient temperature impacts adversely both the supply as well as the demand of electricity used for cooling purposes. It increases the cooling energy consumption of buildings, rises the peak electricity demand during the warm season and oblige utilities to built additional power plants, reduces the generation capacity of thermal and nuclear power plants, limits the currying capacity of electricity transmission lines, increases losses between substations and transformers, and in general puts the power generation systems under higher strain, [43–45]. Table 1, adapted from 43, presents the implications of ambient and urban overheating on demand and on supply-side components of electricity.

Six main types of studies are available to investigate and analyse the actual and future impact of urban overheating on the energy demand of buildings and cities as well as on the electricity supply systems. Most of the studies focus on the potential increase of the cooling energy demand induced by the regional and global climatic change, while the potential decrease of the heating demand is partly investigated:

A. Studies aiming to evaluate the energy impact of the urban heat island on reference - typical buildings. In most of these studies, climatic data from reference rural or suburban as well as from urban stations are used to perform comparative energy simulations
B. Studies aiming to evaluate the temporal evolution of the cooling energy demand of buildings caused by the urban overheating. These studies use long time series of past and recent climatic data collected from the same meteorological stations.
C. Studies aiming to evaluate the energy impact of regional and global climate change on the total building stock of a city
D. Studies aiming to evaluate the increase of the future cooling energy consumption of individual buildings, cities or countries caused by the global climate change.
E. Studies aiming to investigate the impact of the ambient temperature increase on the total electricity consumption of a city, region or country.
F. Studies aiming to evaluate the current and future impact of ambient overheating on the electricity supply systems

3.1.1. Energy impact of urban overheating on reference – typical buildings

To evaluate the energy penalty imposed by urban overheating in reference – typical buildings, thirteen relevant studies from Athens and Volos Greece, London UK, Munich Germany, Rome Italy, Boston, New York, California, Texas, USA, Melbourne Australia and Bahrain, [46–58], have been analysed in [9]. Ten out of the

Table 1
Implications of ambient and urban overheating on demand and supply side components of electricity, (Adapted from ([43]).

Implications of ambient and urban overheating on demand-side components of electricity		
Demand System Component	Ambient and Urban Overheating Effect	Implications
Cooling Load of Buildings	Higher ambient temperature in summer	Increase of the cooling demand of buildings
Peak Electricity Demand	Higher ambient temperature in summer	Increase of the peak electricity demand
Load Duration curves	Important change of air conditioning profile	Higher demand curve peaks and much greater load variability may Increase chances of breaching the market price cap
Non-Temperature Sensitive Demand	Increased cooling water temperatures	Generation curtailments and potential interruption of power to avoid blackouts
Implications of ambient and urban overheating on supply-side components of electricity		
Supply system component	Overheating Effect	Implications
Thermal Electricity Generation Plants and Components	Increased Ambient Temperatures Increased Water Temperatures	Decreased efficiency of electricity generating equipment like gas turbines, coal power plants, etc.
Transmission Network	Higher ambient temperatures and longer spells of dry weather	Power disruptions, increased cost of adaptation designs. Reduced equipment lifetime. Reduced power carrying capacity of transmission lines may cause disruptions because of the power line sagging
Substations and Transformers	High Ambient Temperatures	Increased losses within substations and transformers
Fuel Stock	High Ambient Temperatures	Coal stocks may spontaneously combust or self-ignite
Power Plants	Increased Ambient temperature and Extreme events	Utilities must built additional power plants to cover the peaks.
	Increase of the peak electricity demand	Increased cost of electricity production during the peak hours

thirteen studies were referred to residential buildings and the rest in offices. The average increase of the cooling demand caused by the urban overheating was found to be close to 13.1% compared to the load calculated using the data of the rural reference stations. It was also reported that the cooling penalty induced by the urban overheating may be as high as 7 kWh/m^2/y/C, while it increases as the absolute cooling demand rises. Recently, nine additional energy studies are published reporting comparative annual cooling energy data from Lima, Peru, Valparaisoand Antofagasta, Chile, Guayaquil, Equator, [59], Modena Italy, [60], Rome, [61–63], Athens Greece, [64], Singapore [65], Taichung, Taiwan, [66] and Manchester, UK, [67]. Three additional studies of similar nature but with different type of outputs are also reported in [68–70] In [68], comparative cooling energy data of one day are reported for Barcelona, Spain, [68], while [69], presented the power but not the energy needs of several typical buildings in Beijing, China, In [70], the energy penalty induced by the UHI in office buildings was calculated for 15 USA cities, but only information on the increase of the energy cost and not the absolute values of the energy consumption was reported, [70]. All three studies concluded that UHI is seriously increasing the cooling energy consumption and power, however, are not included in the present analysis because of the inconsistency of the reported data with the rest of the existing information. Six out of the nine considered studies, [59–67], refer to residential and the other 3 in tertiary buildings. Data and results reported in [46–67], are analysed to update the existing estimations regarding the cooling penalty induced by the urban overheating. For all cases, the reference cooling load varied between 0.5 kWh/m^2/y to 210 kWh/m^2/y, while the corresponding cooling demand under the impact of the UHI was between 2 kWh/m^2/y to 230 kWh/m^2/y. The increase of the cooling load per degree of UHI, Fig. 1a, found to vary between 0.5 to 8 kWh/m^2/C/y. Fig. 1, (b, and c), reports the cumulative frequency distribution of the reference and the final cooling demand. As seen, almost 90% of the reference and of the final cooling demand are below 45 and 50 kWh/m^2/y, respectively. The average intensity of the UHI varied between 0.5 to 7 C, Fig. 1d. Almost 90% of the data are below 4.5 C. The analysis has resulted in the following conclusions:

(a) Considering all existing studies, the average increase of the cooling energy demand induced by the urban overheating for all types of buildings, is close to 12%, Fig. 2. Surprisingly, the present value is similar to the one reported in [9], 13%, using limited inputs. For the tertiary buildings, the corresponding increase of the cooling energy demand is found close to 18%, very close to the estimated average increase of the cooling load of offices in 15 US cities, (17.5%), [70]. The present estimations are significantly lower than those predicted in [71], 19%. However, the results in [71], included additional data not considered by the present study because of serious inconsistency. The cooling penalty, as a percentage of the reference load is not a safe index to assess the energy impact of the urban overheating. It can be very high or very low for low or high reference cooling loads respectively. For example, in the considered database, for reference cooling loads up to 20 kWh/m^2/y, the percentage increase is close to 38%, while for loads between 20 to 50 kWh/m^2/y and 50 to 250 kWh/m^2/y it decreases down 25% and 9.5% respectively. Alternatively, it seems more reasonable and comprehensive to assess the cooling penalty induced by the UHI using an index counting the rise of the cooling demand per degree of UHI intensity, (kWh/m^2/y/C).
(b) The energy penalty induced by the urban overheating varies between 0.1 kWh/m^2/y/C to 20 kWh/m^2/y/C, Fig. 1a. The average and median energy penalty is found close to 2.3 and 2 kWh/m^2/y/C. The average penalty for the residential and tertiary buildings are 2.4 and 2.3 kWh/m^2/C respectively. While in [9], the maximum values of the cooling penalty per degree was estimated close to 7 kWh/m^2/y/c, the addition of the new data reporting a considerably higher cooling demands increased the upper boundary of the calculated penalty. However, almost 90% of the calculated values are below 4 kWh/m^2/y/C. In [9], the corresponding figures were 2,7 kWh/m^2/y/C for both the average and the median cooling penalty.
(c) As reported in [9], increased cooling penalties correspond to higher reference cooling loads, Fig. 3 reports the levels of the cooling penalty under low, average and high cooling loads of the reference buildings. The correlation between the reference cooling load and the corresponding cooling penalty per degree of overheating, was found less strong that in [9], as the new case studies added in the analysis, present quite different thermal balances and characteristics, affecting the variability of that part of the cooling load directly influenced by the urban overheating.

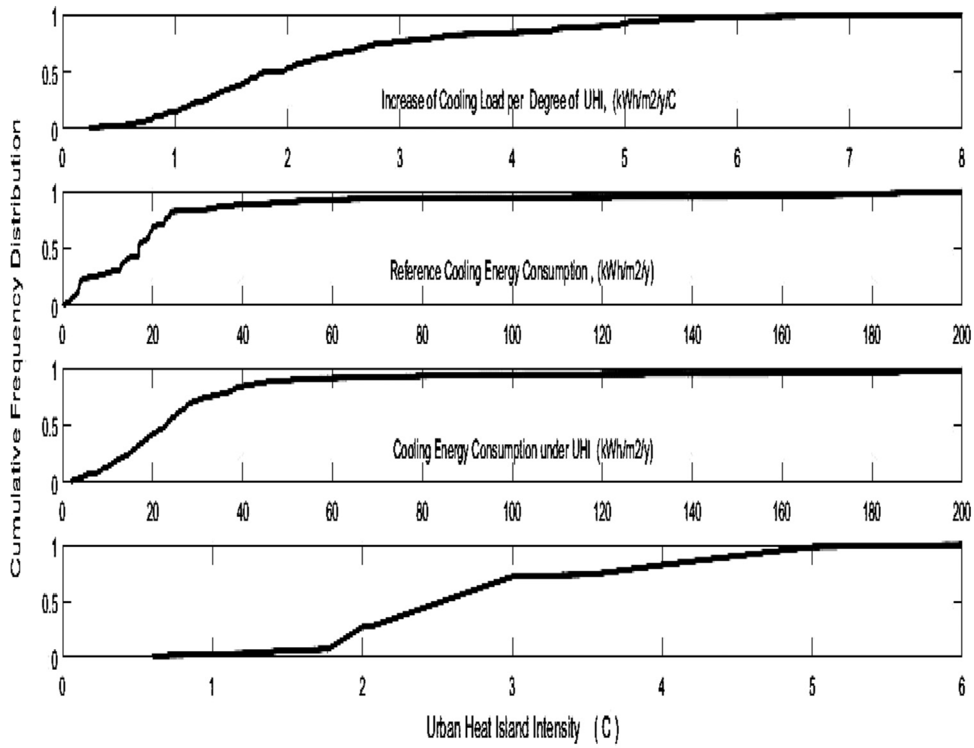

Fig. 1. Impact of urban overheating on reference – typical buildings. a) Cumulative frequency distribution of the increase of the Cooling load of the buildings per degree of UHI. b). Cumulative frequency distribution of the cooling energy consumption of the buildings under reference climatic conditions. c). Cumulative frequency distribution of the cooling energy consumption of the buildings under urban – UHI conditions. d). Cumulative frequency distribution of the UHI intensity for all considered cases.

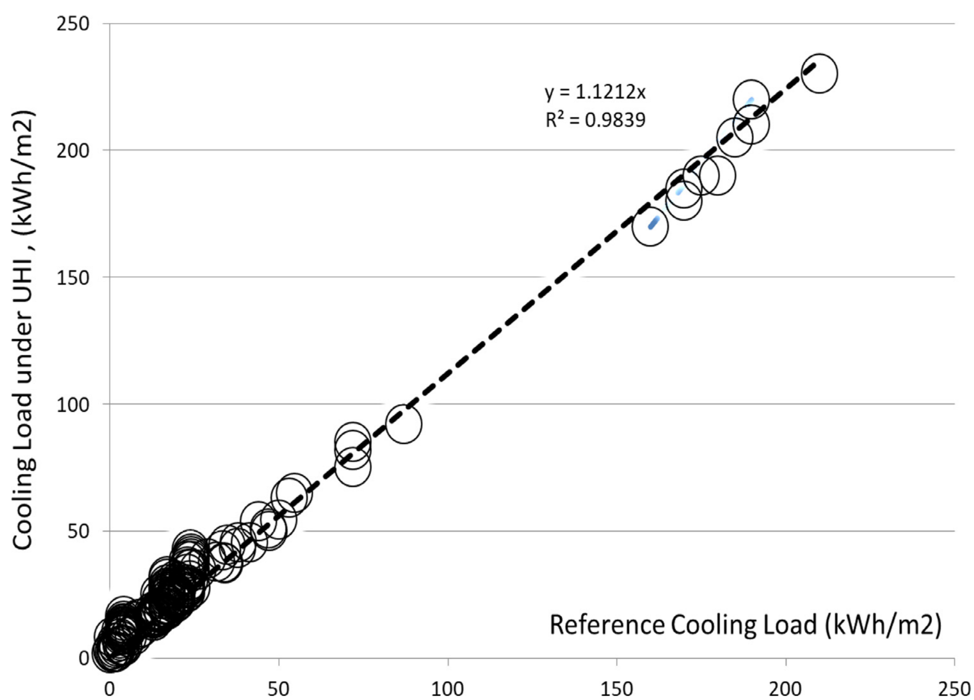

Fig. 2. Correlation between the calculated cooling energy demand under reference, rural, and UHI, urban, conditions.

(d) The potential decrease of the heating load of buildings caused by the urban overheating is analysed by several studies [9,46,48,52–57,70–72]. It is well accepted that in heating dominated climatic zones, urban overheating contributes to decrease substantially the heating needs of buildings. An average decrease of the heating demand close to 19% is reported in [71] for several cities of USA. However this depends on the characteristics of the projects, the climatic zones and the type of buildings considered. In [9], it is concluded that in zones with summer temperatures below 23 C, the potential increase of the cooling load is very low., while it starts to be very significant in climatic zones with a

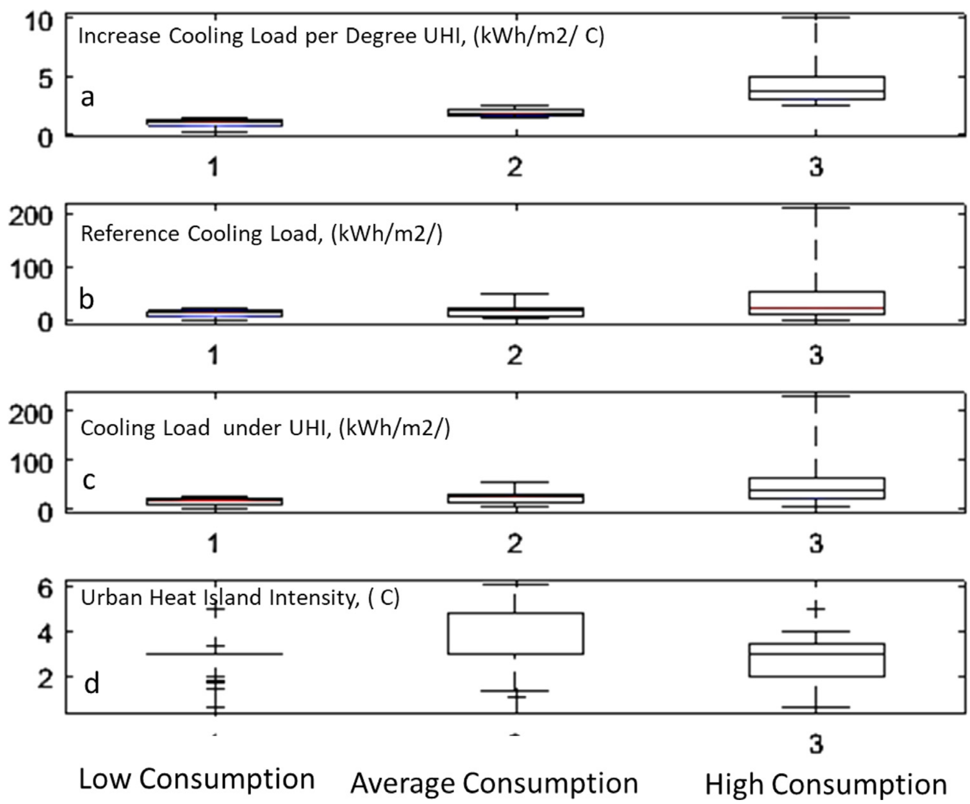

Fig. 3. a). Variability of the cooling penalty for low, average and high cooling loads of the reference building, b) Levels of the reference cooling load. c) Levels of the cooling load under UHI conditions, d) The corresponding urban heat island intensity.

summer temperature above 27 C. It is evident that the characteristics of the local climate define largely the potential of urban overheating to decrease/increase the heating and cooling demand of buildings. However, the specific thermal balance of buildings may strength further the impact of the increased ambient temperatures. Tertiary buildings with high internal gains, have a low balance point temperature over which cooling is needed, even in heating dominated zones. As shown in [52], office buildings in London with high internal gains exhibit a higher increase of the cooling load than the corresponding decrease of heating demand.

3.1.2. Temporal increase of the energy demand of reference buildings

The combined effect of urbanization, industrialization and global warming increases the temperature of cities. Analysis of multiyear ambient temperature time series shown that warming trends may be as high as 1 K per decade, [73]. Increased urban temperatures rises the cooling demand of buildings and may decrease their heating needs. To evaluate the temporal variation of the cooling and heating needs of representative buildings, energy simulation studies have been carried out using multiyear climatic data. Studies are available for eighteen cities, analysing the temporal variability of the cooling and heating needs of representative buildings. Studies refer to Athens, Larisa, Corfu and Heraklion in Greece, [73], Honk Kong, [74], Nicosia, Paphos, Limassol, Larnaca, Famagusta and Kerynia in Cyprus, [75], Zurich, Geneva, Lugano and Davos in Switzerland, 76,77, Phoenix, Washington DC, Puerto Rico in US, and Resolute in Canada, [78–80]. Both, residential and tertiary type buildings are considered.

A comparative assessment of the cooling energy needs in the 18 cities, for the period 1970-2010 is performed in [9]. The cumulative frequency distributions of the calculated cooling demand for 1970 and 2010, as well as the range of the overheating trend and the increase of the cooling demand per year and degree of overheating, are given in Fig. 4. As shown, the overheating trend in the considered cities varies between 0.1 to 0.94 K per 10 years, while the cooling load for 1970 varies between 14-100 kWh/m^2/y, and 20 to 125 kWh/m^2/y in 2010. The calculated increase of the cooling load per year and degree of temperature rise, varies between 67-161 kWh/m^2/y/C, with an average value close to 76 kWh/m^2/y/C. The average increase of the cooling load is calculated close to 11 kWh/m^2/y, which corresponds to about 23% increase of the 1970 cooling demand. In parallel, during the same period the heating needs of the considered buildings decreased by 19%, while the total heating and cooling demand increased by 11%.

3.1.3. Studies on the energy impact of regional and global climate change on the total building stock of a city

The magnitude of the energy penalty imposed by the regional and global climate to representative buildings is a useful knowledge and information. However, the levels of the additional energy consumption depend highly on the characteristics of the selected buildings and may not be fully compatible and representative of the global impact at the city scale. Several studies aiming to evaluate the impact of urban overheating on the global energy consumption of the whole city building stock, are already carried out, [46,47,81–84]. Studies refer to Athens Greece, [46,81], Western Athens, Greece, [47], Tokyo Japan, [82], Beijing China, [83] and Qingdao China, [84]. To evaluate the impact of the urban overheating on the total building energy consumption in a city, a set of indicators has been proposed [9]. In particular:

GEPS: The global energy penalty per unit of city surface (kWh/m^2).
GEPSI: The global energy penalty per unit of city surface and per degree of the UHI intensity (kWh/m^2/K).
GEPP: The global energy penalty per person (kWh/p).

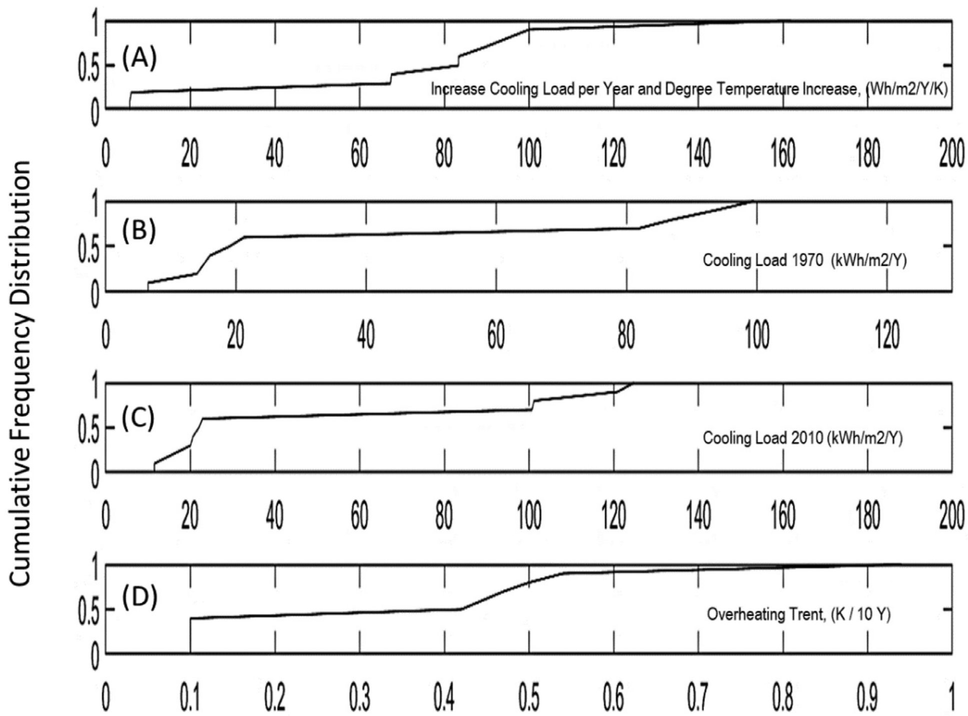

Fig. 4. Cooling energy consumption of representative buildings in 18 cities for the period 1970-2019. a) Cumulative Frequency Distribution of the Increase of the Cooling Load per Year and Degree of Temperature increase, b) Cumulative Frequency Distribution of the calculated cooling load for 1970, c) Cumulative Frequency Distribution of the calculated cooling load for 2010, d) Cumulative Frequency Distribution of the overheating Trent.

GEPPI: The global energy penalty per person and per degree of the UHI intensity (kWh/p/K)

Based on the analysis performed in [9], and the new data recently added, [84], GEPS is calculated to vary between 0.13 to 5.5 kWh/m^2, with an average value close to 2.3 $\pm$(1.5) kWh/m^2, while, GEPSI, varies between 0.12 to 2.22 kWh/m^2/C, with an average value close to 0.73$\pm$(0.64) kWh/m^2/C. In parallel, GEPP varies between 104 to 305 kWh/p, with an average value close to 230$\pm$(120) kWh/p, while GEPPI is between 20 to 154 kWh/p/C, with an average close to 78$\pm$(47) kWh/p/C. The above values are slightly different than the ones proposed in [9], because of the addition of the new data for the city of Xingdao. As already mentioned in [9], the reported values are indicative. More studies and data are necessary to provide a more accurate and concrete evaluation of the global of urban overheating on the total energy building consumption of buildings in a city.

3.1.4. Studies evaluating the impact of global climate change on the energy consumption of individual buildings, cities or countries

A high number of studies projecting the future cooling energy consumption of individual buildings, cities or even countries under climatic change conditions have been made available recently. Although most of those articles do not consider the impact of urban overheating, they provided useful information on the response of the building sector to the expected future overheating. About, 114 case studies, predicting to the future increase of the cooling demand of commercial buildings caused by the global climate change, are reviewed and analysed in [10]. The magnitude of the future increase of the cooling demand depends mainly on the characteristics of the reference building, the local climatic characteristics, the indoor set point temperature and the considered global climate, GCM and emission rate models to calculate the future climatic conditions An average increase of the cooling demand close 86 kWh/m^2/y is predicted. A strong non linear correlation between the current-reference cooling load and the absolute increase of the demand per degree of temperature increase is identified. For a reference cooling load close to 50 kWh/m^2/y, the average expected increase of the cooling demand per degree of temperature rise is found close to 6 kWh/m^2/C, and may increase up to 12 kWh/m^2/y when the reference load is as high as 150 kWh/m^2/y.

3.1.5. Studies investigating the impact of increased ambient temperature on the electricity consumption of a city, region or country

The magnitude of the electricity consumption during the summer period depends highly on the levels of the ambient temperature. Higher temperatures correspond to an increased use of air conditioning and also to a considerable rise of the electricity demand. The induced by the ambient overheating additional electricity penalty depends on the climatic characteristics of the place, the quality of the building stock, the penetration of the air conditioning in the building sector, the indoor set point temperatures, and the characteristics of the electricity network. Quantitative data on the impact of ambient overheating on the hourly, daily and monthly, electricity demand, is available for sixteen case studies, states or countries and in particular, Bangkok, Thailand [85], Spain [86], California, USA and part of the state [87], Athens, Greece [88,93], New Orleans, USA [89], Hong Kong [90,91, Ohio, USA and Louisiana, USA, [92], Chicago, USA [94] Maryland, USA [95], Massachusetts, USA [96], Singapore [97], The Netherlands [98] and Delhi India, [99]. The specific data provided in [85–99], are analysed and it is calculated that the hourly, daily or monthly variation of the electricity demand per degree of temperature increase varies between 0.5% to 8.5% with an average value close to 4.2%. The highest elasticity values are calculated FOR countries presenting a very high penetration of air conditioning in the building stock like the United States of America.

3.1.6. Impact of urban overheating on peak electricity demand

Higher ambient urban temperatures result in a higher use of air conditioning and rise the peak electricity demand in cities.

Additional electricity requirements during the warm period, oblige utilities to build additional power plants that result in a considerable increase of the electricity cost. Quantitative information on the association between the ambient temperature and the peak electricity demand of buildings is available for 13 cities or countries:Tokyo, Japan [100], Thailand [101], Ontario East Canada [102], Los Angeles, Washington, Dallas, Colorado Springs, Phoenix and Tuscon [103], Israel [104], Pert of Carolina USA [105], New South Wales in Australia, and Darwin Australia, [106–108]. All data of l the above case studies have been reviewed and analysed and It is calculated that the additional peak electricity demand per degree of temperature increase varies between 0.45% to 12.3% as a function of the levels of penetration of air conditioning in the city/country, the specific energy and thermal quality of the building stock, the indoor set point temperatures and the characteristics of the local electricity network. The calculated average additional electricity demand per person and temperature increase is estimated close to 21.9±(11.8) W/C/person, while the average increase of the peak electricity demand in cities is around 3.7% or 215 MW per degree of temperature increase. Results of a similar magnitude, 21 W/C/person and 226 MW per degree are reported in [8], using a reduced set of data, [100–105]. The threshold ambient temperature over which the electricity demand starts to increase varies between 13 C to 24 C, while in most of the studies the threshold temperature is higher than 18 C

3.1.7. Studies evaluating the current and future impact of ambient overheating on the electricity supply systems

It is well accepted that the adequacy of the electricity supply system depends on the following three factors: (a) realisable generation capacity, (b) capacity of the transmission and distribution subsystems, and (c) expected peak load, [44]. Higher ambient temperatures may affect significantly the efficiency and the generation capacity of thermal and nuclear power plants. The heating and cooling requirements of coal or gas based, thermal power generating systems operating under Rankine and Brayton cycles vary according to ambient temperature, humidity, pressure and water availability, [110]. Increased temperatures affect the maximum delivered power and heat rate, limit the electricity generation efficiency, increase the gas consumption and challenge the reliability of supply, [109–111]. According to [112], rise of the temperature by 1 C increases substantially the thermal efficiency losses and may reduce the power output of coal and gas power stations by 0.6%. In a similar way, [112], reported that increase of the ambient temperature by 1 F, in desert climates, result in 0.3-0.4% point reduction in electricity generation output. In a similar way, the power output of nuclear plants decreases by 0.8% per degree of temperature increase, [113], while higher ambient and water temperatures may decrease by 2030, the available capacity of nuclear plants worldwide by 6 GW, [114].

Ambient overheating reduces significantly the carrying capacity of electric transmission network due to power-line sagging, [44]. It is estimated that the projected increase of the ambient temperature by 2040-2060 may decrease the mean summertime transmission capacity in the USA by 1.9%–5.8% relative to the 1990–2010 period, [44]. In addition to the transmission and power generation problems, issues related to increased losses within substations and transformers should be considered as well, [115]

Given that by 2050, the peak per capita summertime electricity demand may increase between 4.2% - 15%, [44], the combined and coincident impacts of ambient and urban overheating on the power generation and transmission systems will affect the adequacy of the power supply network and will deteriorate its stability. As estimated, increased ambient temperatures and extreme phenomena, may cause 14-23% additional investments on electricity capacity in USA, relative to a non – climate change scenario for the years between 2010-2055, [116].

Table 2, summarizes, the estimated current and future impact of ambient overheating on the demand and supply side components of electricity.

3.2. Impact of ambient overheating on outdoor air quality

Urban overheating affects seriously the air quality of cities. High temperatures speed up photochemical reactions in ambient air through chemical interactions with nitrogen oxides and hydrocarbons, resulting in the formation of tropospheric ozone. [117]. Additionally, urban overheating affects the turbulent exchange and the air flow in cities resulting in increased concentration of pollutants, [118], while in coastal zones it slows down sea breeze and favors the blocking of several pollutants in the urban zones, [119]. Finally, the high electricity demand during the warm summer period, results in an increased operation of the power plants rising the emission of pollutants, [120].

High temperatures accelerate the formation of ozone precursors like NOx and VOC's that combine photochemically to create tropospheric ozone, [121]. Formation of the ground ozone depends on the levels of ambient temperature, intensity of solar radiation, concentration of NOx and VOC's and the ratio of VOC's and NOx, [122]. Many studies concluded that there is a quite strong association between the formation of tropospheric ozone and high ambient temperature, [118,123,124]. Ozone is highly toxic and oxidant to human and plants, it affects the human cardiovascular and respiratory system by irritating the lungs and is strongly related to elevated heat related morbidity and mortality [125]. Given that it is strongly affected by the ambient temperature, it is classified as a causal intermediate in the heat related mortality association, [126]. Although the concentration of many atmospheric pollutants decreases as a result of the intensive environmental measures implemented in cities, ozone seems to rise as a result of the increased urbanisation and temperature increase. It is characteristic, that monitoring data from 74 Chinese cities between 2013 and 2015, shown an important temporal increase of the daily concentration, [127]. The average concentration in 2013 was close to 69 ppbv it raised to 75 ppbv in 2015.while the fraction of non-compliant cities to threshold ozone concentration levels, increased from 23% to 38% during the same period. Projections for several Chinese cities show a serious future increase of the ozone concentration, [127].

High ozone concentrations are strongly associated with the intensity of the urban heat island, [128–131]. Urban temperature profiles may enhance the transformation of the tropospheric ozone during the day or night time. Several studies have reported maximum ozone concentrations during the daytime, [123,124, caused by the high solar radiation intensity enhancing photochemical processes. Thermally induces air circulation and NOx dilution caused by the change of the boundary layer height may also increase the ozone concentration during the daytime, [132]. Higher night time ozone concentrations are reported in [133,134]. Because of the high surface temperature of cities, the atmospheric vertical stability during the night is reduced, resulting in increased boundary layer height that favors the vertical transport of pollutants, decrease of the NOx concentration at the ground level, reduction of the titration rate and increase of the ozone concentration.

Several theoretical and experimental studies have documented the impact of urban overheating on the concentration of ground level ozone, [21,121–124,128–147] A quite strong correlation is observed in polluted zones, where the ozone concentration exceeds 60 ppb, while no correlation is documented under low ozone concentrations, [147].

As reported in [135], the ozone concentration in much of the Eastern Unites States is increasing during heat waves by at least

Table 2
Quantified Implications of the ambient and urban overheating on demand and supply side components of energy and electricity demand.

Demand side component	Overheating effect	Average implications
Cooling demand of reference buildings	Urban Heat Island	Analysis of 22 studies shown: a) The average increase of the cooling demand induced by UHI, is 12% compared to the demand under reference-rural climatic conditions b) The average cooling penalty induced by UHI, is close to 2.3 kWh/m^2/y/ and per degree of temperature increase
Cooling demand of reference buildings	Combined Impact of Urban Heat Island and Global Climate Change	Analysis of 18 studies comparing the heating and cooling needs of reference buildings between 1970-2010, shown: c) The average Increase of the cooling demand is 23% or 11 kWh/m^2/y d) The average decrease of the heating demand is 19%. e) The average increase of the total heating and cooling demand is 11%.
Cooling demand of the total city stock.	Combined Impact of Urban Heat Island and Global Climate Change	Analysis of 6 studies evaluating the energy impact of regional and global overeating in cities, shown: f) The Global Energy Penalty per unit of city surface, GEPS varies between 0.13 to 5.5 kWh/m^2, with an average value close to 2.3 ±(1.5) kWh/m^2. g) The Global Energy Penalty per city surface and degree of temperature increase, GEPSI, varies between 0.12 to 2.22 kWh/m^2/C, with an average value close to 0.73±(0.64) kWh/m^2/C. h) The Global Energy Penalty per Person, GEPP, varies between 104 to 305 kWh/p, with an average value close to 230±(120) kWh/p. i) The Global Energy Penalty per person and degree of temperature increase, GEPPI, varies between 20 to 154 kWh/p/C, with an average value close to 78±(47) kWh/p/C
Future Cooling Load of Reference Buildings	Global Climate Change	Analysis of 114 studies forecasting the future cooling demand of buildings, shown: j) For actual reference cooling loads close to 50 kWh/m^2/y, the average expected future increase of the cooling demand per degree of temperature increase is close to 6 kWh/m^2/C, k) For actual reference cooling loads close to 150 kWh/^{m2}/y, the average expected future increase of the cooling demand is close to 12 kWh/^{m2}/y.
Peak Electricity Demand	Combined Impact of Urban Heat Island and Global Climate Change	Analysis of 11 studies evaluating the impact of temperature on peak electricity demand, shown: k) The additional peak electricity demand per degree of temperature increase varies between 0.45% to 12.3%. l) The average additional electricity demand per person and degree temperature increase is close to 21.9±(11.8) W/C/person, m) The average increase of the peak electricity demand is close to 3.7% or 215 MW per degree of temperature increase
Supply side component	**Overheating Effect**	**Average Implications**
Power output of coil and gas power plants	Combined Impact of Urban Heat Island and Global Climate Change	a) A temperature increase of 1 C reduces the power output of coal and gas power stations by 0.6%, [112]
Power output of nuclear plants	Combined Impact of Urban Heat Island and Global Climate Change	b) A temperature increase of 1 C, decreases their power output by 0.8%. [113]
Carrying capacity of electric transmission network	Combined Impact of Urban Heat Island and Global Climate Change	c) Rise of the ambient temperature by 2040-2060 may decrease the mean summertime transmission capacity in the USA by 1.9%–5.8% relative to the 1990–2010 period, [44]
Additional investments on electricity capacity	Combined Impact of Urban Heat Island and Global Climate Change	d) Increased ambient temperatures and extreme phenomena, may cause 14-23% additional investments on electricity capacity in USA, relative to a non – climate change scenario for the years between 2010-2055, [116],

20% compared to the summer average. Similar results for North Eastern United States are reported in [139]. Based on mesoscale simulations, it is estimated that in California, [135], a temperature increase by 1 F corresponds to an increase by 10% of the days exceeding the ozone thresholds. Measurements performed in Athens, Greece, found that because of the strong UHI, the number of summer days over the threshold ozone concentration increased by 18%, [122], while in Delhi, India, [138], a quite strong correlation between the average daily maximum temperature and the daily maximum ozone concentration is observed, [138]. The impact of urban overheating on the concentration of ground level ozone in Seoul Korea is studied in [129,133]. It is reported, that urban heat island affects significantly the structure of the boundary layer and local circulation resulting in a considerable increase of the ozone concentration during the night time, 16 ppb, and daytime 13 ppb. Analysis of ground ozone measurements in the central Kanto area of Japan, [140], concluded that during summer almost 84% of the long term variability of the peak ozone concentration is associated to the change of ambient temperature and wind speed. Almost similar conclusions are reported in [141,142]. It is found that about 70% of the temporal variability of the ozone concentration in Lovozero, Kola Peninsula, and 67% of the variability in Slavonia Croatia, is due to the changes of ambient temperature, wind speed and relative humidity. Using mesoscale simulations carried out for the city of Stuttgart it was found that there is almost a linear correlation between the ozone concentration and the ambient temperature in the city, [143]. While the ozone concentration was close to 40 ppb under 28 C, it has been doubled when the ambient temperature reached 37 C. Mesoscale simulations performed for the city of Phoenix, USA, [144], found that higher ambient temperatures and urbanisation leads to an increase of the ozone concentration during the night time between 10 to 30 ppb. In a similar way, it is reported that higher urban temperatures and urbanisation may increase the ozone concentration in New York, USA, between 1-5 ppb or up to 8 ppb at the maximum, [145], and up to 10 ppb and 14 ppb during day and night time correspondingly in the Pearl River Delta region in China, [146]. Finally, analysis of multiyear observations in the island of Cyprus shown that the ozone concentration presents a positive correlation with ambient temperature which increased under HW conditions by 9.6% during the day, [123].

Several studies have examined the impact of high urban temperatures on the concentration of the atmospheric PM's, [148–150]. It is generally concluded that the relation of the PM's with temperature depends on the specific PM component. While because of the faster SO_2 oxidation, the concentration of sulfate is increasing with increasing temperatures, [148–153], this is not the case for nitrate and organic volatile particles. According to [153], not a significant correlation between the PM concentration and the ambient temperature reported in literature.

The foreseen future increase of the urban and ambient temperature is expected to alter the concentration as well as the spatial and temporal distribution of air pollutants, [148–151]. It may also increase the concentration of the ground based ozone, and increase the intensity and the frequency of future ozone episodes through the modification of the chemical reaction rates and the influence of the synoptic flow patterns, [155]. In particular, it is predicted that the future production of ozone in the United States will increase up to 6 ppbv, [156], in Veszprém, Hungary by 12.1 μg/m3, and reach by 2100 summer concentrations close to 137.9 μg/m3, [152], while the average peak concentration of ozone may increase up to 16%, [153] Predictions of the potential increase of the future frequency of high ozone events in four Canadian cities show an increase close to 50% by 2050 and 80% in 2080, [157], while for the North-eastern USA it is predicted that the increase is between 10-30% by 2020, and doubling by 2050, [158]. Finally, estimations for the city of Tuscon, Arizona predict an increase of the high ozone events by 400% by the end of the present century, [159]. Given the high toxicity of the ozone, most of the studies predict a serious impact on human health in the upcoming years.

High demand of electricity for cooling during the summer period oblige utilities to extend the operation of the power plants increasing the emissions of pollutants like sulphur dioxide and nitrogen oxides, as well as the concentration of secondary pollutants like ozone and particulate matters, [119,160]. As calculated in [119], the summer electricity generation in the Eastern United States between 2007-2012, increased by 3.87% ±0.41% for each degree of temperature rise. Increased electricity generation resulted in a 3.32%/°C ± 0.36%/°C rise in CO_2 emissions, 3.35%/°C ± 0.50%/°C in SO_2 emissions, and a 3.60%/°C ± 0.49%/°C increase in NO_X emissions. Future predictions for the Eastern USA, considering a temperature increase between 1-5 C, is found to correspond to an average increase of the summer electricity demand by 7% while the increase of the non-coincided peak electricity demand is close to 32%, [119]. Considering that the future mixture of fuel used may change significantly, it is calculated that by 2050, NOx emissions will increase by 16%, and $S0_2$ emissions by 18%.

Table 3, summarizes the main impacts of ambient and urban overheating on air quality.

3.3. Impact of ambient and urban overheating on vulnerable and low income population

It is widely accepted that the spatial distribution of heat exposure in cities is highly associated to the corresponding levels of biophysical and socioeconomic vulnerability, [161–166]. A very significant overlap between the heat exposure in the various neighbourhoods of Philadelphia, USA, and the corresponding social sensitivity, during extreme heat events, is reported. [163]. In Georgetown NC, USA, [167], it is found that the most vulnerable districts were those combining medium levels of biophysical vulnerability with medium to high socioeconomic vulnerability. No- overlap is found between districts of the highest biophysical and social vulnerability. Several studies have examined the association of high ambient temperatures in cities with socioeconomic factors like income, education, racial characteristics, quality of housing, etc. Most of the studies concluded that low income population is living in deprived neighbourhoods characterised by excess heat stress and high urban heat island intensity, [19,166,168–173], Districts of high vulnerability levels are usually associated with a higher risk of heat related mortality, [168,169,171,172]. It is characteristic that during heat waves, the heat mortality risk in the most vulnerable districts of Barcelona, Spain was almost twice as high than the less vulnerable ones, [174].

Increased urban temperatures have a serious economic and environmental impact on low income and vulnerable population, [18,20]. Given that low income and vulnerable population is living in low thermal quality buildings, [175], it is evident that the cooling energy penalty induced by urban and ambient overheating is higher than that of the rest of the population, [176,177]. In fact, it is reported that the cost of air conditioning for low income population in Greece is to about 100% higher than the average value for the whole population, [4]. Given that the cost of air conditioning is a serious additional burden for low income population, most of the households cannot afford to satisfy their cooling needs. Studies comparing data of real summer electricity consumption against the simulated cooling needs, for low income population in Portugal, shown that only 2% of electricity needs are covered, [177].

Multiple studies have shown that vulnerable and low income households experience highly discomfort indoor conditions during the summer period. A study carried out by the World Health Organisation in eight European countries shown that almost 9% of the population lives in houses with important overheating problems during the summer period, [178]. Several experimental studies have assessed the potential overheating of low income houses in the UK, [179–187]. All studies concluded that overheating occurs in most of the dwellings causing serious thermal comfort and health problems. Maximum indoor temperatures may reach 35-40 C, during the hot days, while the average maximum indoor temperatures were found close to 29-30 C. Indoor thermal comfort conditions were out of the accepted comfort conditions for most of the time, while in many cases, indoor environmental conditions exceeded the health protection thresholds. Much higher indoor temperatures recorded during a heat wave in fifty low income houses in Athens, Greece, [188]. Indoor temperatures were above 28 C for the whole period of the heat wave while the indoor maximum temperature reached values close to 40 C. Compared to the period before the heat wave, indoor temperatures were in average almost 4.2 C higher. Spells above 30 C for more than 215 continuous hours are recorded while in highly overheated houses spells of six continuous days above 33°C are found. Table 4,presents in a tabulated form the main impact of ambient and urban overheating on low income and vulnerable population.

3.4. Impact of urban and ambient overheating on health

It is widely accepted that exposure to high ambient temperatures is a serious health hazard, [189–191]. When exposed to temperatures beyond a certain threshold, the human's thermoregulation system cannot offset the impact of extreme heat resulting in increased global mortality and morbidity. Most of studies investigating the characteristics of heat related vulnerability, concluded that elderly is the most vulnerable population group, [192,193], followed by those with pre-existing health problems, like respiratory, cardiovascular or mental health problems, [194,195], those using medication that affects thermoregulation, [175], and 'those "lacking in economic assets and access to public support systems, with diminished physical or cognitive capacities to respond to warnings and missing strong and enduring social support systems", [196], like social isolated people, [197], and those living in hazardous places, [198]. A recent meta-analysis of 26 articles on the relation

Table 3
Quantified implications of ambient and urban overheating on ambient air quality.

Air quality component	Overheating effect	0Implication
Ozone concentration	Global Overheating – Heat Waves	a) Increase of the ozone concentration between 9.6 - 20% during heat a) waves, [122,139]
Ozone concentration	Combined Impact of Urban Heat Island and Global Climate Change	b) Increase of the ambient temperature by 1% increases the number of days exceeding the threshold of ozone concentration by 10%. [135] c) Urban Heat island increases the number of days exceeding the threshold ozone concentration by 18%, [122] d) Urban overheating increases the ozone concentration between 10-30 ppb and 1- 13 ppb during the night and day time, [129,133,144–146] e) About 67-84% of the annual variability of the ozone concentration is due to the change of temperature and other meteorological parameters, [140] f) Predicted future concentration of the ozone ranges between 6 to 12 ppb, [148–159] g) Predicted percentage future increase of the concentration between 20-60% in 2050, 80% in 2080, and 400% by 2100, [153–159],
Emissions of pollutants by power plants	Combined Impact of Urban Heat Island and Global Climate Change	h) Increased emission of pollutants by power plants per degree of temperature increase: 3.32%/°C ± 0.36%/°C increase in CO_2 emissions, 3.35%/°C ± 0.50%/°C increase in SO_2 emissions, and a 3.60%/°C ± 0.49%/°C increase in NO_X emissions [119]
Future emissions of Pollutants by power plants	Combined Impact of Urban Heat Island and Global Climate Change	i) Estimated increase of emissions by power plants: Plus 16% NOx emissions and plus 18% SO_2 emissions by 2050, [119].
Component	Overheating ambient Effect	Implication
Cooling energy cost	Combined impact of Global and Regional Climate Change	a) The cost of air conditioning of low income households may increase up to 100% relative to the average conditions, [4]
Indoor temperature	Combined impact of Global and Regional Climate Change	b) Indoor peak temperatures in low income houses during heat waves may exceed 40 C, [179-178]
Cooling needs	Combined impact of Global and Regional Climate Change	c) Low income households cover a very small part, (even 3%), of their cooling needs, [177]
Urban heat island and vulnerability	Combined impact of Global and Regional Climate Change	d) Low income population is living in deprived neighbourhoods characterised by excess heat stress and high urban heat island intensity, [19,166,168–173] e) Districts of high vulnerability levels are usually associated with a higher risk of heat related mortality, [168,169,171,172].

between the heat exposure and the risk of cardiovascular mortality, concluded that it increases by 1.3% for the heat exposure of total population and 8.1% for the elderly population, [199]. Heat related mortality and morbidity rises the same day or several days after the exposure to heat and the associated risk is considerably higher in cities than in rural areas because of the UHI phenomenon that increases the ambient temperature, [173], and the specific socioeconomic, demographic and biophysical factors that determine deprivation and vulnerability, 171,200.

Analysis of the intra – urban variability of heat related health problems presents important interest as cities are characterised by spatial variabilities in the exposure and spatial variabilities related to the distribution of vulnerable population, [201]. Urban heat island intensity is heterogenous with some urban zones presenting substantially higher ambient temperature than others, while socioeconomic, demographic and health problems determining the levels of deprivation and urban vulnerability vary substantially between the neighbourhoods in a city. To better understand the characteristics of the intra urban mortality and design more efficient prevention policies, an increasing number of studies have investigated the impact of place and urban neighbourhoods on heat related health outcomes, [19,161,163–165,168–171,173,174,198,201–223]. Although the characteristics and the outcomes of the studies vary substantially, it is agreed that urban neighbourhoods influence heat related health outcome through four main pathways: The stresses in the physical and social environment, the availability of neighbourhood institutions and resources and the relative influence and impact of the local networks, [224]. The association between the local thermal environment and demographic and socioeconomic risk factors is found to be significant. Lower socioeconomic groups were more likely to live in neighbourhoods of a higher UHI intensity, with limited vegetation cover and high density, experiencing an increased exposure to heat stress, [225]. Thus, the heat related health outcome in cities may be investigated as the aggregated impact of thermal, social, economic and demographic risk factors.

3.4.1. Intra urban heat stress and mortality- identity of the studies and results

We analysed twenty-eight studies investigating the association between the intra - urban thermal quality and heat related mortality, HRM, [19,170–174,202,204,207–213,215,218,220,222,223,226–231]. Six different parameters and proxies were used to characterise the thermal quality of the cities: a] The intra-urban distribution of the near surface ambient temperature or a combination of it with other climatic parameters, [19,170,172,177,202,210,217,220,222,226–228], b) The distribution of the surface temperature in the city as obtained by remote sensing monitoring, [171,207,211,215,218,220], c) the density of vegetation in the neighbourhood, [172,174,208,209,211–213,215,223,229,231], d) the density of buildings in the various neighbourhoods, [204,212,213,223,230], e) The percentage of impervious surfaces, [172,204], and f) the proximity to water surfaces, [209]. Twenty studies evaluated the total risk of heat related mortality considering the aggregate impact of the thermal quality of a city in combination with the corresponding socioeconomic, demographic and health covariates. Statistical methods were used to calculate the specific risk of heat related mortality associated and attributed

Table 4
Quantified implications of ambient and urban overheating on low income and vulnerable population.

Location	Population Concerned	Exposure Period	Climate Data to Assess Spatial Variability	Outcome	Temperature Proxy	Considered Covariates	Results	Reference
London, UK	All Population	Hot Spell: 26th of May to 19th of July 2006.	Twelve stations in London + meso scale simulations	All cause mortality	A composite parameter with the Mean Maximum T, the UHI temperature anomalies and the dwelling thermal quality.	Quality of Housing	Spatial variability of HRM follows the background mortality rates due to population age. Estimated UHI attributable deaths between 6.1 to 8.14 deaths per million of population. Dwelling characteristics cause a larger variation in temperature exposure and risk, than UHI	[173]
Hong Kong China	All Population	June – September 2001-2009	Ambient T from several stations	All cause Mortality	Mean Ambient T and calculated UHI index	Meteorological parameters and concentration of PM10	Average T above 29 C and low wind speeds associated with higher mortality. Stronger impact in areas with high UHI Index. A 1 C rise above 29 C caused a 4.1% and 0.7% increase in mortality in high and low UHI zones correspondingly.	[207]
London – UK	All Population	June – August 1993-2006	Simulated Ambient T data	All cause Mortality	Mean ambient T	Age, Socioeconomic deprivation score	1°C UHI anomaly multiplied the risk of heat death by 1.004 and 1.070 when acclimatisation or no acclimatisation is considered.	[210]
St Louis Missouri, USA	Older than 65 years old	Heat wave days 1980, 1983,1988 and 1995	Measured Ambient Temperature in one station	All cause mortality	Mean ambient T	Socioeconomic, Demographic	The cooler suburbs presented much lower heat related mortality than the warmer ones. Heat wave mortality rates were higher in warmer, less stable IN socioeconomically disadvantaged areas.	[19]
Sydney, Australia	Older than 65 years old	Warm months 1993-2004	Measured Ambient T	All cause Mortality	Mean and maximum temperature	Socioeconomic factors	Zones of higher Temp had a higher mortality risk, 0.8 – 30% for 10 C temperature increase. No statistically significant correlation between socioeconomic factors and HRM.	[221]
Vancouver, Canada	All population	Selected days 1998-2014	Ambient and Surface T	All cause Mortality	Humidex, Ambient and Surface Temp.	Socioeoeconomic, emographic, Health	The OR for a 1°C increase in daily mean humidex was 1.13 and 1.04 for data above and below 34.2 C respectively. t.	[201]
Kaohsiung Taiwan	All population	May-October 1999-2008	Measured Ambient T	All cause mortality	A composite thermal load index	Socioeconomic factors	Mortality increases per 1°C rise, increases by 2.8%, 2.3% and -1.3% for the very warm, less warm and cool urban zones respectively. Above 29.0°C increase rates were 4.2%, 5.0% and 0.3% respectively	[170]
West Midlands, UK	All Population	Heat Wave: 1-10 August 2003	Mesoscale simulations for urban and rural zones	All cause mortality	Mean Daily Temperature above 17.7 C	None	The relative risk of death above17.7 average daily temperature, was 1.023 per degree of temperature increase. UHI contributes 50% of the total heat related mortality in the city	[226]
Sao Paolo, Brazil	All Population	1993-1994	Ambient T from 3 stations	Cardiovascular and Respiratory	Urban Heat Island Intensity	None	Significant correlation of the intensity of the UHI and the annual mortality rates. HRM 30% higher in zones of 2-4 C higher Temp.	[227]
Shanghai China	All Population	Heat Waves 1975-2004	Measured ambient T data	All cause mortality	Urban Heat Island Intensity	None	HRM between 1 to 27 deaths/million following the intensity and length of the heat wave	[217]

(*continued on next page*)

Table 4 (*continued*)

Location	Population Concerned	Exposure Period	Climate Data to Assess Spatial Variability	Outcome	Temperature Proxy	Considered Covariates	Results	Reference
Several USA Cities	All Population	2006-2010	Measured Temperatures	All cause mortality	Not clear	None	The impact of the UHI in the death rate is 1.1 people per million.	[72]
Texas USA	Older than 65 years	2006-2001	A high number of meteo-stations	All cause mortality	Heat Index, HI, combining Temp and humidity	None	Risk of mortality is increasing for higher HI. Significantly higher RR of heat on mortality for HImax over 90th percentile	[222]
Paris France	Older than 65 years	Heat Wave 11-13 August 2003	61 images from (NOAA -AVHRR)	All cause mortality	Min, max, mean and the diurnal daily surface temperatures	Age, gender	Mortality risk very well associated with the min and max surface Temp. Elderly population exposed to high night surface Temp, has a double risk of death than less exposed people.	[202]
Maricopa, Arizona, USA	All Population	July of 2000-2008	Satellite data Surface T	Heat Related Mortality	Mean Daily Surface Temperature	Socioeconomic factors	Increase of the mean surface temperature by 1 C caused a 32% increase in the odds of death from heat exposure	[211]
Montreal Canada	All Population	June- August 1990-2003	Satellite derived surface T plus one ambient T station	All cause mortality	Surface Temperature to classify urban zones. Mean ambient T	Ozone, Residential property values	The odd ratios comparing mortality on days with a mean ambient T of 26 C against that on days at 20 C, was 1.21 in the "hot" urban zone and 1.11 in the cooler zone.	[171]
New York, USA	Older than 65 years	Extremely hot days, May – Sept1997-2006	LANDSAT surface T data	All cause mortality	Surface T to classify urban zones	Socioeconomic, health and other parameters	The mean Mortality Rate Ratios, MRR, in zones with high and low surface T were 1.223, and 1 respectively.	[172]
Paris, France	Older than 65 years	Heat wave: 8-13 August 2003	LANDSAT surface T data	All cause mortality	Mean Daily Surface Temp.	Social factors + Housing	The Odd ratio concerning the surface temperature around the dwelling was high, 1.82	[215]
Philadelphia, USA	All Population	Heat Wave July 3rd to July 14th	LANDSAT surface T data	All cause mortality	Mean and Maximum Daily Surface T	Socioeconomic and Demographic factors	For each Degree increase in the mean LST, risk of death increases by a factor of 6, while for each degree decrease in maximum LST the odds of death increase by a factor of 2.84.	[218]
11 cities *	Various	Various	Measured Ambient T and Surface T	All cause mortality + Cardiovascular and Respiratory	Daily mean T, mean apparent T, max T, UTCI, Min T,Daily mean Humidex,	Many(***).	Population living in warmer areas within cities have almost 6% higher risk of mortality / morbidity compared to those living in cooler areas of cities. The estimated risk varied between the 11 studies from 0 to 13%.	[169]

to urban heat island. Six studies analysed the association between the thermal quality in the cities and heat related mortality without to consider the impact of other covariates, [208,213,222,226–228]. The characteristics as well as the results and the conclusions of all the considered studies are given in Tables 5a and 5b. Most of the studies concluded that there is a considerable correlation between the quality of the thermal environment in the various districts of a city and the risk of heat related mortality. The degree of association between the considered thermal proxies and HRM depends on the magnitude and the intra urban distribution of the thermal stress. It depends also on specific socioeconomic, demographic and health factors. A systematic metanalysis of eleven articles analysing the impact of local microclimate on heat related mortality, HRM, [169], concluded that population living in warmer neighbourhoods within cities have almost 6% higher risk of mortality compared to those living in cooler urban districts. The estimated risk in the 11 studies found to vary between 0.0 to 13%. It is also concluded that population living in less vegetated areas had 5% higher risk compared t those living in greener neighbourhoods areas. The risk for all the studies varied between 0 to 30%. A detailed presentation of the analysed studies and the major conclusions are presented in the following.

3.4.1.1. Studies associating heat related mortality risk with the distribution of the ambient temperature in cities. Twelve studies have analysed the association between the spatial distribution of heat island and heat related mortality risk. Studies refer to the city of London in the UK, [173,210], Hong Kong, China, [207], Sydney Australia, [220], Kaohsiung, Taiwan [170], West Midlands UK, [226], Sao Paolo Brazil, [227], Shanghai China, [217], several USA cities, [228], Texas USA, [222], St Louis Missouri USA, [19] and Vancouver, Canada, [201] Three studies, (Texas, Sydney, St Louis), estimated the impact of excess heat on elderly population, (> 65 years old), while the rest covered all urban population. Five studies were focusing on excess mortality during heat waves or during seriously hot weather, (London, St Louis, West Midlands, Vancouver and Shanghai), and seven studies extended the analysis during the whole warm summer period.

3.4.1.2. Studies associating heat related mortality risk with the distribution of the surface temperature in cities. Previous research has shown that the use of the local surface temperature, LST, as a proxy to delineate the risks of urban overheating on heat related mortality is quite inconsistent as it fails to describe all issues of human exposure to urban heat, [232], However, given the lack of appropriate ambient temperature data describing the thermal conditions in the neighbourhoods of a city, LST is an interesting proxy used in many relevant studies.

Six studies have analysed the impact of urban overheating on heat related mortality risk using as a proxy the surface temperature distribution. Studies concern the cities of Paris, France [201,215], Maricopa, Arizona, USA, [198], Montreal, Canada, [171], New York, USA [214], and Philadelphia, USA, [218]. Three studies, Paris, [202,215] and NY, [214], analysed the impact of excess urban heat on elderly population, (> 65 years old), while the rest of the studies extended the analysis for all the population groups. Four studies were focusing on excess mortality during heat waves or seriously hot weather, (Paris, NY and Philadelphia, and two studies extended the analysis during the whole warm summer period.

3.4.1.3. Studies associating heat related mortality risk with landscape characteristics. The thermal quality of the urban environment is highly determined by the presence of heat sources and heat sinks. Heat sinks like water and vegetation contribute highly to decrease the ambient temperature and improve thermal comfort in cities, [233], while heat sources like the generated anthropogenic heat increase the urban temperature. Landscape and urban quality parameters like the level of vegetation, the proximity to the water surfaces, the density in the city, land cover and imperviousness are used as proxies to investigate the association of the thermal quality of cities with heat related mortality

Vegetation is used by 11 studies, as a proxy to evaluate the association of urban thermal quality with heat related mortality. Studies refer to nine cities or agglomerations: Paris, France, [215,223], Barcelona Spain [174], Seoul Korea [208], Lisbon Portugal [209], Maricopa, Arizona, USA, [108], Worcester USA [212], eight cities in Michigan, USA [213], Sydney Australia [220] 106 USA cities, [231], and NY USA [214]. Four studies, Barcelona, Paris and New York 174,214,215,223, have analysed HRM under heat waves or very hot summer weather, while the rest covered the whole summer period. Six studies, Lisbon [209], Paris, [215,223], Sydney [220] and New York, [214], 106 USA cities, [231], investigated HRM of elderly population, (> 65 years old) while all the rest covered the whole urban population.

The type of land cover influences the thermal balance of cities. Sealed impervious surfaces of high thermal absorptivity and thermal capacitance, absorb more solar radiation during the day and release it during the afternoon and night time, [234]. Once the term of heat convection from the city land cover is significant compared to the other terms of the thermal balance, the degree of imperviousness may be used as a proxy to associate HRM with the thermal quality in a city. Two relevant studies performed in Berlin, Germany, [204], and New York, USA, [214], found a significant association between the degree of impervious surfaces in the city with HRM.

In a similar way the density of cities affects the convective gains from buildings and open spaces, the magnitude of advective flow and the escape of the emitted infrared radiation to the sky. Although the intensity of the UHI is usually higher in dense urban zones, a study performed in St Louis Missouri, [19], concluded that HRM was higher at urban neighbourhoods of lower density. The lack of association between urban density and HRM risk indicates that other socioeconomic and demographic factors may have a stronger impact than density and finally determine the distribution of deaths in a city. In contrast to the above findings, three studies performed in Berlin, Germany, [204], Paris France, [171], and several USA cities, [230], found a significant correlation between the density of neighbourhoods and heat related mortality and higher density was associated with higher risk of mortality. In a similar way, another study performed in Worcester, USA, [212], concluded that people living in more dense urban areas were more likely to suffer from an acute myocardial disease on hot period than those living in less dense zones.

Evaporation of water contributes to decrease the ambient temperature in cities, [233]. Proximity to the water may enhance evaporative losses and improve the quality of the urban thermal environment. A study performed in Lisbon, Portugal, [209] concluded that in urban districts > 4 km from water, increase of the UTCI by 1 C, above a threshold, resulted in an increase of the mortality by 7.1%, while in districts ≤ 4 km from water, the corresponding increase of mortality was only 2.1%.

3.4.1.4. Discussion and analysis. The main conclusions and results arising from the eleven studies associating the intra city distribution of temperature with the corresponding HRM, studies are:

(a) When the ambient urban temperature exceeds a threshold, heat related mortality increases considerably, [16]. Acclimatisation and adaptation of the local population affect the levels of the threshold temperature which is considerably higher in warm than in cold climate cities [235]. Threshold

Table 5a
Main Characteristics and results of existing studies associating intra – cities heat related mortality with ambient and surface temperature.

Location	Population Concerned	Exposure Period	Outcome	Considered Covariates	Results	Reference
10 cities*	Various	Various	All cause Mortality + Cardiovascular, Respiratory	Many***	Those living in less vegetated areas had 5% higher risk compared to those living in more vegetated areas. The risk varied between 0 to 30%.	[169]
Barcelona, Spain	All population	Warm seasons 1999-2006	All cause Mortality	Socioeconomic Housing quality	No modifying effects related to Percent Tree Cover HRM was higher in zones where residents perceiving little surrounding greenness (RR=1.29).	[174]
Seoul, Korea	All population	2000-2009	All-cause mortality	None	Mortality risk increase per degree of Temp rise above 25.1 C was 4.1%,3.0% and 2.2% in low, medium, and high NDVI group, respectively.	[208]
Lisbon, Portugal	Above 65 years old	1998-2008	All-cause mortality	None	For UTCI > 19.9°C, mortality was higher in areas of the lowest quartile of NDVI by 3.9%/deg. In the 2nd, 3rd and 4th quartiles ware 2.2, 2.2 and 1.2% respectively. Above 24.8 C mortality was 14.7, 5.4, 5.1%, and 3.0%/deg.	[209]
Maritopa, Arizona,	All Population	July of 2000-2008	Heat Related Mortality	Socioeconomic factors	Lack of vegetation had a weak but significant positive association with the odds of at least one heat death in a census block, (1.19)	[211]
Worcester, MA, USA	Patienjts > 25 years	April October 1995, 1997, 1999, 2001, 2003	Mortality from Acute MI	Socioeconomic factors	No relation between greenery levels and mortality	[212]
Michigan, USA	All Population	May- Sept 1990-2007	Cardiovascular Mortality	Socioeconomic factors	The odds of cardiovascular mortality during extreme heat events were higher by 39% in urban zones without green spaces.	[213]
Paris, France	Older than 65 years	Heat wave 8-13 August 2003	All-cause mortality	Socioeconomic factors	A strong negative correlation between mortality and Vegetative index, VI. Mortality increases by a factor of 2.8 per unit of decrease of the VI	[215]
Sydney, Australia	Older than 65 years old	Warm months 1993-2004	All cause mortality	Socioeconomic factors	No correlation between mortality and level of vegetation	[221]
England	Non retired population	2001-2005	All cause mortality, Circulatory, Lung cancer,	Socioeconomic factors	The incidence rate ratio (IRR) for all-cause mortality for the most income deprived quartile compared with the least deprived was 1·93 and 1.43 in the least and most vegetated zones respectively. For circulatory diseases, it was 2·19 and 1.54 respectively.	[229]
New York, USA	Older than 65 years	Hot days, May – Sept 1997-2006	All-cause mortality	Socioeconomic+ health factors	Non important correlation between the percentage of vegetated surfaces and mortality, (r=0.3)	[172]
Paris France	Older than 65 years	Heat Wave 2003	All-cause mortality	Socioeconomic factors	The density of vegetation has a protective effect with a beta coefficient of −0.005	[223]
109 USA Cities	Older than 65 years old	May-Sept 1992-2006	Renal Heat Respiratory	Socioeconomic factors	A weak correlation between HRM and vegetation levels	[231]
Berlin Germany	All Population	Heat waves 1990-2006			Significant correlation between the number of deaths and the proportion of land covered by impervious surfaces during very high temperature periods	[304]
New York, USA	Older than 65 years	Hot days, May – Sept1997-2006	All-cause mortality	Socioeconomic, +health factors	Significant correlation between the area of impervious surfaces and mortality is found, (r=0.3)	[214]
Berlin Germany	All Population	Heat waves 1990-2006			Important relationship between the mortality rate and the density of urban structures within the city area	[204]
Worcester, MA, USA	Patients > 25 years	Summer 1995, 1997, 1999, 2001, 2003	Mortality from Acute MI	Socioeconomic factors	Population living in more urban areas were more likely to suffer from an acute MI on hot period than those living in less dense zones.	[212]
7 US Cities*i	All population	22 years data	All cause mortality	Socioeconomic factors	In most of the cities higher density was associated with higher risk of mortality	[169]
Paris France	Older than 65 years	Heat Wave 2003	All cause mortality	Socioeconomic factors	Urban density increased the risk of dying	[223]
St Louis Missouri	Older than 65 years old	Heat wave 1980, 1983, 1988 1995	All cause mortality	Socioeconomic, Demographic	Densities were higher, rather than lower, in tracts with low heat wave mortality rates.	[19]
Lisbon, Portugal	Above 65 years old	1998-2008	All cause mortality	None	In zones > 4 km from water, rise of UTCI by 1 C above the 99th percentile increased mortality by 7.1%. In zones ≤ 4 immortality increased by 2.1%.	[209]

*Montreal Canada, Hong Kong China, Kaohsing City Taiwan, Worcester MA, USA, Barcelona Spain, Lisbon, Spain, 8 cities in Michigan, US, Vancouver Canada, London, UK, Seoul Korea.
**Atlanta, Georgia; Boston, Massachusetts; Minneapolis-St. Paul, Minnesota Philadelphia, Pennsylvania; Phoenix, Arizona; Seattle, Washington; St. Louis, Missour.
***Residential property values, Climate, Concentration of pollutants, percent of old population, density, education level, reception of social benefits, proximity to water, family status, age, race, age of dwellings.

Table 5b
Main Characteristics and results of existing studies associating intra – cities heat related mortality with landscape parameters.

Location	Population Concerned	Exposure Period	Climate Data to Assess Spatial Variability	Outcome	Temperature Definition	Covariates	Results	Reference
Brisbane Australia	All population	October – March 2007-2011	Local ambient T from 2 stations	All type of morbidity	Daily Maximum Temperature	Socioeconomic factors	During summer, increase in daily maximum temperature by 10 C was associated with a 7.2% increase in hospital admissions on the following day. A significant variability of morbidity with neighbourhood ranging from a 55% decrease in admissions per 10°C increase in temperature to 102% increase.	[205]
Toronto Canada	All population	Summer 2002-2005	Local Ambient T	All type of morbidity	Mean Average T	Socioeconomic Factors	There is clear geospatial heterogeneity in the burden of HRI in Toronto. Areas within the downtown core experienced high rates of HRI medical dispatch calls. While the reasons for proportio- nately higher rates are unclear, possible explanations may include spatial risk factors like poorer housing type, lack of air condition- ing, and particular local heat islands. It also appears that areas with high rates of HRI include low income inner-city neighbor- hoods, areas with high rates of street-involved individuals such as the homeless. Further analysis using indicators of socioeconomic status would provide added information to explore the possible ecological association between socioeconomic factors and rate of HRI, as has been suggested in other studies. Areas along the waterfront also have a particularly high rate of HRI as compared with other neighborhoods. A plausible explanation for this is that these areas have a high rate of outdoor activities and therefore include a large temporary population exposed to hot weather. This is consistent with previous work that considered increases in all 911 medical dispatch calls in Toronto on heat alert days (Dolney and Sheridan, 2005).	[265]
NY, USA	Old population	Extreme hot days Summer 2005-2013	Local climate data	Cardiovascular deseaces	Average T	none	a 7% increased risk of ischemic heart disease on the day of extreme heat, and increased risks of hypertension (4%) and cardiac dysrhythmias (6%) occurred on lag days 5 and 6, respectively. Important increase in some neigborhoods see health	[244]
Mekong Delta River, Vietnam	All population	January 2002–December 2014 period	Local Ambient T	all causes, and for infectious, cardiovascular, and respiratory diseases	Average Temperature	Socioeconomic fattors	For 1°C increase in average temperature, the risk of hospital admissions increased by 1.3% (95% CI, 0.9–1.8) for all causes, 2.2% (95% CI, 1.4–3.1) for infectious diseases, and 1.1% (95% CI, 0.5–1.7) for respiratory diseases. However the resultwas inconsistent for cardiovascular diseases	[245]
Mekong River Delta, Vietnam	All population	2010-2013	Local ambient T from 12 local stations	All type of Heat Related morbidity	Daily Average T	Sociodemographic factors	The result of the first model indicated that an increase of 5°C in average temperaturewas associatedwith a statistically significant 6.1% increase (95%CI: 5.9, 6.2) in total hospital admissions across districts. High variability of morbidity per district. 55.2% decrease (95%CI: −54, −56) to 24.4% (24.3–24.6) increase in admissions per 5°C increase in average temperature.	[259]
Mekong River Delta, Vietnam	All population	Heat waves2-12 years	Local Ambient Temperature	All cause hospital admissions	Average Ambient T	Socioeconomic factors	The risk of admissions was higher in the North (5.4%, 95%CI: _0.1e11.5; 11.2%, 95%CI: 3.1e19.9; 7.5%, 95%CI: 1.1e14.4; 2.7%, 95%CI: _5.4e11.5) than in the South (1.3%; 95%CI: 0.1e2.6; 3.2%, 95%CI: 0.7e5.7; _1.2%, 95% CI: _2.6e2.3; 2.1%, 95%CI: _0.8e1.2) for all causes, infectious diseases, cardiovascular, and respiratory diseases respectively	Morbidity [11]
114 USA Cities	Older than 65 years old	1992-2006	Local Ambient Temperature	All cause hospital admissions	Apparent T	Socioeconomic factors	When comparing the effects of extreme heat by climate zone, we found significant heterogeneity between climate zones in the cumulative 8-day effect estimates for admissions for respiratory diseases, with pooled increases of 11.8% (95% CI: 2.3%, 22.2%) in climate zone 1 and –0.5% (95% CI: –4.0%, 3.1%) in climate zone 5 (Table 3). For admissions for both respiratory and renal diseases, we found significant heterogeneity in effect estimates within climate zones 1, 2, 3, and/or 4. Climate zone 5 is the hot one	Morbidity [5]
12 European Cities	all ages, 65–74 age group, and 751 age group	Heat Waves: 1990-2001	Local Ambient Temperature	cardiovascular, cerebrovascular, and respiratory causes	Apparent Temperature	none	For respiratory admissions, there was a positive association that was heterogeneous between cities. For a 18C increase in maximum apparent temperature above a threshold, respiratory admissions increased by 14.5% (95% confidence interval, 1.9–7.3) and13.1%(95%confidence interval, 0.8–5.5) in the 751age group inMediterranean and North-Continental cities, respectively. In contrast, the association between temperature and cardiovascular and cerebrovascular admissions tended to be negative and did not reach statistical significance.	Morbidity [9]

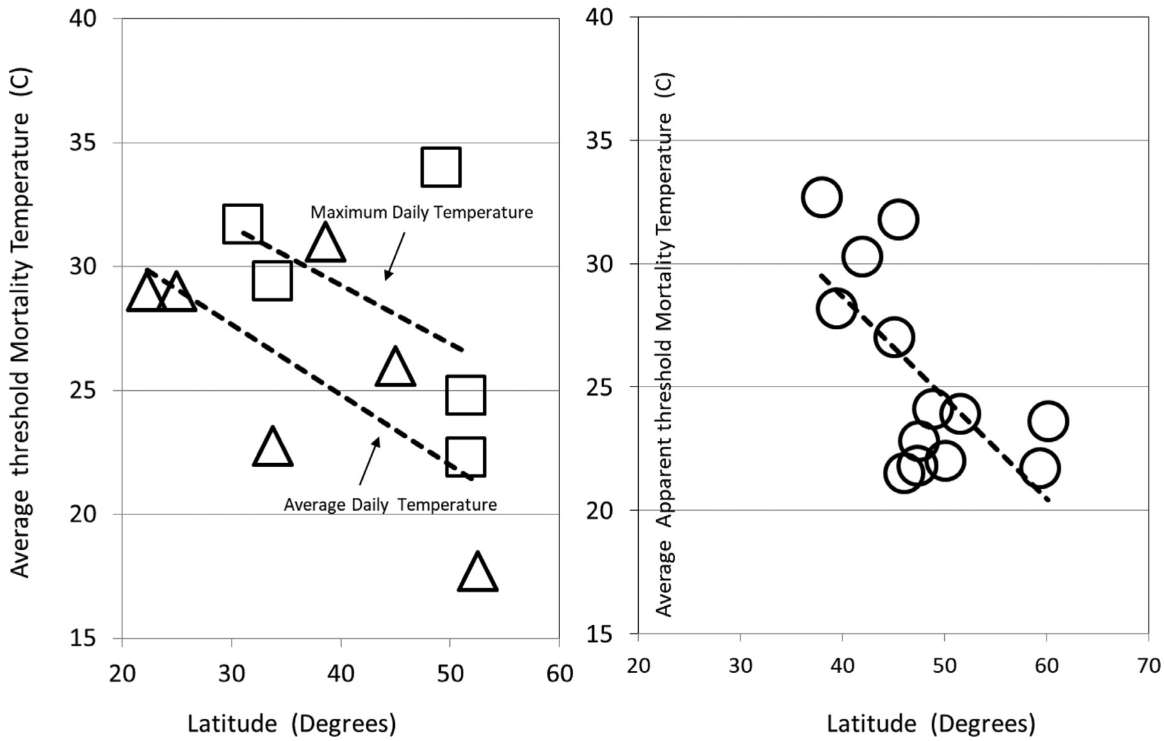

Fig. 5. (a) left: Correlation between the Average Threshold Mortality Temperature and Latitude, Data from [19,170,173,201,207,210,218,220,222,226–228]. (b) Correlation between the average apparent threshold Mortality Temperature and Latitude, Data from [16]. Squares refer to the Maximum daily Temperature and triangles to the average daily temperature.

mortality temperatures, reported by the analysed articles, are plotted against the corresponding geographic latitude, Fig. 5a. Also, a similar plot of the apparent threshold mortality temperatures reported in [16], is given in Fig. 5b. A clear decreasing trend of the daily maximum, daily average and maximum apparent threshold mortality temperature is found with increasing latitudes. A similar trend is also found between latitude and heat related mortality in 236–239,245], and also between cold related mortality and latitude, [199]. The correlation of the data in Fig. 5a, is not statistically significant and the R^2 is much higher for the average ambient temperature, (0.45). Although, the threshold mortality temperature depends on many other socioeconomic and demographic factors, the observed association between the latitude and the threshold mortality temperature levels is quite significant and informative regarding the potential association of heat related mortality, local climate and adaptation capacity

(b) Several proxies are used to analyse the intra-urban variability of the heat related mortality. The selection of the most appropriate proxy to describe the spatial variability of HRM in a city, depends on the characteristics of the local climate and the corresponding socioeconomic and demographic factors. Different proxies applied at the same city may result in completely different results, correlations and conclusions. Most of the studies use the average daily temperature as a proxy to identify the potential association with HRM, while many articles found that the use of the daily maximum temperature is more appropriate and describe in a more precise way the spatial distribution of HRM. The use of composite and aggregate climatic factors as the operative temperature, UTCI, SET, Humidex index, may or may not consist a more suitable proxy option depending on the climatic parameters affecting the local HRM. Given the importance of the specific socioeconomic and demographic factors, the use of aggregate proxies involving climatic, socioeconomic and demographic factors may be more appropriate than the use of simple or composite climatic parameters.

(c) All studies examining the intra – urban variability of the HRM using the ambient temperature as a proxy, have concluded that there is a significant association between the mortality risk and the intensity of the heat island in the city. It is a general conclusion that warmer neighbourhoods present a relatively higher mortality risk than the cooler ones. In addition, community attributes are correlated with demographic and socioeconomic factors, and differences between the various neighbourhoods affect highly the levels of mortality risk. In Sao Paolo, Brazil, heat related mortality was about 30% higher in urban zones with 2-4 C higher ambient temperature, [227], In Hong Kong, [207], the variability of the additional mortality above 29 C in the neighbourhoods with a high and low UHI index was very significant, 4.1% and 0.7% respectively. In a similar way, in Kaohsiung, Taiwan, the additional mortality above 29 C, in the warmer and cooler neighbourhoods, was 4.2% and 0.3%, respectively. [170]. Finally, in Texas, [222], the relative risk of mortality in the neighbourhoods belonging to the upper quartile of the Heat Index was 1.12, while for the lower quartile it was close to zero.

(d) Urban heat island is responsible for an additional to the background, heat related mortality ranging between 1.0 additional death/ million up to 27 deaths per million of population. The highest additional heat mortality, (27 deaths/million), was reported in Shanghai during the 1998 heat wave and for a heat island intensity close to 3 C, [217]. During the same period, in neighbourhoods with a lower UHI intensity, 0.5 C, the additional deaths were limited to 6 per million. Much lower additional mortality, (1-6 deaths per million), was reported in Shanghai for the heat waves of 2000-2004 and for a similar range of UHI intensity. Slightly higher levels of UHI induced mortality, 6.1 to 8.1 deaths per million, were estimated during the 2006 heat wave in London, [173]. In fact, additional mortality during heat waves may vary substantially as a function of the maximum observed temperature, the duration of the heat wave and the spatial extend of the urban zones presenting extreme temperatures. The additional mortality induced by the urban heat island, during the non-heat waves periods, seems to be much lower. Using mortality data from several US cities, it is reported that the additional HRM in the center of the large cities, is close to 1.1 death per million, [228].

(e) Most of the existing studies on the intra-urban variability of the mortality risk caused by the UHI are carried out in developed countries where epidemiological and climatic data are systematically monitored. Because of the lack of appropriate data, very few studies from developing countries are available, [240]. Existing information on Urban Heat Island intensity shows that major cities in the developing countries experience a very high amplitude of urban overheating, [241]. High ambient temperatures in combination with the lack of appropriate health networks, low housing quality and poverty, may result in much higher levels of HRM than those reported in developed countries. It is evident that there is an urgent need for additional information of the health burden caused by urban overheating in the developing world.

(f) The specific patterns of mortality associated to temperature, vary substantially between the cities and population groups as a function of the specific demographic factors. The relative risk, RR, of the heat related mortality per degree of temperature increase, varies between 1.004 to 1.07. Different threshold temperatures are considered to calculate the relative risk of mortality in the various cities, and thus the reported results may not be fully comparable. The highest RR value, RR=1.07, was calculated for London, [210], when acclimatization of the local population was not considered. A quite high RR value, RR=1.041 was calculated in Hong Kong for the neighborhoods suffering from a strong UHI intensity, [207], and West Midlands 1.023, [226], without however to consider any physiological and institutional adaptation at the specific urban conditions. When acclimatization of the population was considered, the relative risk of mortality, was substantially reduced, RR=1.004, [210], and was quite similar to the RR value calculated in the urban zones of Hong Kong non affected by the UHI, RR=1.007, [207]. Much higher RR values are reported for elderly population above 65 years, [220].

(g) Although in Sydney, [220], Kaohsiung, [170], and London, [210], the warmer neighbourhoods are associated with high deprivation level, heat related mortality in the neighbourhoods was not significantly associated with socioeconomic factors. Lack of significant association between the socioeconomic status and the heat related mortality may be attributed to the extended use of air conditioning in the specific urban zones and other adaptation factors like the good quality of housing. For all other cities, socioeconomic and demographic determinants were strongly associated with the corresponding thermal parameters and determined synergistically the levels of heat related mortality in the city. The association of thermal and socioeconomic parameters is found to be more consistent in all American studies. In Hong Kong, the increase rate of heat related mortality per degree of temperature above 29 C, was 5.6% for the population of low socioeconomic status, SES, living in warm neighbourhoods, 3,0% for the population of high SES living in warm urban zones, 2.6% for those of low SES living in cooler places and -1.2% for the high SES population in the cooler neighbourhoods, [207]. In St Louis Missouri, [19], urban zones of low socioeconomic status and high UHI intensity, presented significantly higher heat related mortality during heat waves. In Philadelphia, USA, [218], the probability of heat related mortality, for elderly population increased by a factor of 1.82, when poverty increased by one standard unit. In parallel, the odds ratio of HRM for the low education population and the African Americans were significantly higher 1.53 and 1.657 respectively. In Maricopa, Arizona, USA, [198], the OR of HRM related to the socioeconomic vulnerability was 1.5, and the percentage of deaths in neighbourhoods of high and low vulnerability was 25% and 9.6% respectively. In Paris, France, [215], the OR of the HRM for manual workers and farmers working outdoors were almost the double than for the indoor working employees. Finally, in NY, a significant association between HRM and socioeconomic factors is identified only for the neighbourhoods of very high poverty.

(h) Increase of the city's surface temperature above a threshold, is associated with a higher risk of heat related mortality. In Paris, increase of the minimum night time surface temperature by 0.41 C corresponded to a mortality odd ratio of 2.17, [202], while for the same city, the odd ratio between surface temperature and mortality was equal to 1,21, [215]. In Philadelphia, USA, the risk of death increased by a factor of 6, per unit of increase of the mean LST [218]. Finally, in Maricopa, Arizona, USA, rise of the LST by 1 C, corresponded to an increase of the odds of death from heat exposure by 32%, [198].

(i) Urban neighbourhoods presenting a higher LST, usually are associated with an important increase of the heat related mortality. In Montreal, the odd values, defined as the ratio of mortality above 26 C to the mortality at 20 C, were 1.21 and 1.11 in the warmer and cooler neighbourhoods respectively, [171]. In NY, USA, the corresponding Mortality Rate Ratios in the warmer and cooler districts were 1.225 and 0.998 respectively, [214]. In Paris, those living in urban zones with higher night LST presented almost a double mortality risk than those living in low LST zones, [202].

(j) People is living most indoors than outdoors and the overall thermal quality of the indoor environment may affects health more than the outdoor thermal conditions. This is clearly shown in the study evaluating the impact of UHI and housing quality in London, [173]. It is found that the type and quality of dwellings have a higher influence on exposure risk than the UHI and ranges the higher of temperature anomalies across London, The estimated UHI-attributable and dwelling-attributable deaths during the whole period were 6.1 and 23.5, deaths per million of population, respectively. In Paris, the OR value for the well and badly insulated houses was 0.4 and 1.0 respectively.

(k) Urban vegetation can be a suitable proxy to characterise the thermal quality of cities if it contributes substantially to the urban thermal balance and determine the magnitude of the local temperature. When other thermal processes, like advection of heat, are the dominant heat transfer mechanisms determining the local microclimate, vegetation may not be the most appropriate proxy to describe the quality of urban zones. For example, in Western Sydney, Australia, although the levels of vegetation are quite high, advection of warm air from the desert determines largely the thermal balance and the temperature of these neighbourhoods, [242]. Under these conditions, the association between the vegetation cover and HRM is not significant, In fact, four of the studies for Sydney, NY, Barcelona and Worcester have not found any significant correlation between the vegetation cover and HRM, while in Barcelona the perception of surrounding vegetation is found to have a weak association with HRM. A weak association between urban greenery cover and HRM is also found in Maricopa, USA, RR=1.19, [198], and 106 USA cities, (RR=1.03), [231]. Contrary to the above findings, for the rest of the studies, vegetation found to has a strong association with HRM. A study considering the impact of urban greenery in several cities of England, [229], found that the incidence rate ratio (IRR) for all-cause mortality for the most income deprived quartile of cities compared with the least deprived ones, was close to 1·93 and 1.43 in the least and most vegetated neighbourhoods respectively. In Seoul Korea, [208], the increase of the HRM per degree of temperature rise above 25.1 C was 4.1%, 3.0% and 2.2% in the low, average and high vegetated urban zones. In Paris, [215], decrease by one unit of the vegetation index, resulted in a increase of the HRM by a factor of 2.8, while in 8 cities of Michigan, [213], HRM was almost 39% higher in the non green zones of the cities. Finally, in Lisbon, Portugal, the levels of HRM per degree of UTCI increase, above 24.8°C, were 14.7%, 5.4%, 5.1%, and 3.0%, for the urban zones in the lowest, 2nd, 3rd, and 4th quartiles of vegetation cover, respectively

3.4.2. Ambient overheating and morbidity

Heat related morbidity is a research area of very high importance as it relates to a significant part of the population suffering from a kind of illness while it affects highly the costs of public health, [243]. The association between ambient temperature – heat related morbidity is not so well explored as the corresponding association with heat related mortality. Much fewer studies are available and there is a significant lack of knowledge on the impact of high ambient temperatures on heat related illnesses. Existing studies have investigated with mixed results, the impact of high ambient temperatures on hospital admissions. Many studies documented a positive association of extreme ambient temperature with illnesses related to cardiovascular, [243–249], and respiratory problems [250–253], heat stroke, dehydration and electrolyte imbalance 251,254, acute renal failure, [251,252,254], nephritic syndromes, [254], mental illnesses and diabetes, [168,254]. However, not all studies on heat related morbidity have found a strong or even significant association between excess ambient temperature and hospital admissions, [191,251,255,256].

The quantitative association of ambient temperature and heat related morbidity presents a high heterogeneity between the studies. During the summer period, an increase of the all causes heat related morbidity between 0.05 – 3.6% per degree of temperature rise in reported for Vietnam, [245], 4.6% for Madrid, Spain, [257], while for Brisbane, Australia the corresponding increase was 7.2% per 10 C of temperature increase, [205]. During heat waves, the all causes heat related morbidity increases between 1% to 11%. In England, an 1% excess mortality per degree of temperature rise is reported for the 2003 heat wave, [191], while in Vietnam and London, UK, hospital admissions increased by 2,5% and 2.6%, respectively [245,258], and 3% in 114 USA cities, [259]. In Toulouse, France, the corresponding increase rate was 5.5%, [260], in Adelaide, Australia, between 7.0 and 7.3%%, [261,262], while in Chicago, USA, close to 11%, [251]. The observed heterogeneity of the association between urban temperature and heat related morbidity is attributed to four main factors, [253]: a) The variable degree of acclimatisation and adaptation as well as the demographic differences between the various places, b) the diveristy of the temperature indicators used to describe heat exposure, like the average, the minimum of the maximum ambient temperature, the diurnal temperature range and the apparent temperature, c) The consideration of different measures of heat related morbidity like hospital admissions, practitioners visits and emergency department visits, and d) the methodological differences between the studies.

The temperature threshold above which heat mortality is increasing, varies between the cities and the type of heat related illness. Several inter city comparisons of the heat related morbidity, shown that acclimatisation and adaptation of the local population seems to determine the temperature – morbidity thresholds. For example, while the threshold for respiratory deceases in London is close to 23 C, [191], it increases up to 28.6 C in San Diego California, [213], 28.9 C in NY, [246], and 44.4 C in Phoenix Arizona, [213]. A study on the threshold maximum apparent temperature corresponding to respiratory morbidity in 12 European cities, [255], shown a clear increase of the threshold temperature for decreasing geographic latitudes. It varies between 17.7 C in Dublin, Ireland, up to 36.4 C in Valencia, Spain, while it is 22.8 C in Stockholm, Sweden, 24.6 C in London, UK, 27.3 in Ljubljana, Slovenia, 27.8 C in Paris, France, 28.9 C in Budapest, Hungary, 30.8 C in Barcelona, Spain, 31.2 In Turin, Italy and 33.8 in Milan, Italy. In parallel, the threshold temperature for renal problems was as low as 18 C in London [191], while the threshold temperature for all causes morbidity in Vietnam was 21 C, [245].

As a result of the positive thermal balance of cities, and the existence of the UHI, cities exhibit a much higher heat related morbidity than rural or suburban areas, [264]. The relative risk of heat related morbidity in the urban zones of Chicago during the 1995 heat wave was almost the double, 3.86, that the corresponding relative risk in the suburban zones, 1.89, [168]. There is an open question if the heterogeneity of the temperature distribution in cities caused by the urban heat island, affects and possibly increases the heat related morbidity in a similar way as the heat related mortality. Unfortunately, not enough information is available about the intra-cities morbidity and the impact of UHI, There are three studies investigating the intra-city morbidity, [205,244,263]. All studies reported a serious variability of the heat related morbidity among the different neighbourhoods. In Brisbane, morbidity in the various neighbourhoods during the hot period was ranging between a decrease of 55% to a 102% increase per 10°C of temperature rise, [205], In Toronto, low income neighbourhoods and lower housing quality is found to present a relatively higher heat related morbidity, [263]. Unfortunately, none of the studies assessed the impact of the urban heat island on morbidity as the specific heat related morbidity in the neighbourhoods was not correlated against the corresponding local temperatures.

3.4.3. Future higher temperatures and mortality

Ambient temperature may increase considerably during the future years, [264]. According to the estimations of the IPCC, the global average temperature may increase between 1.6 C to 2.6 C by 2050, compared to the preindustrial period, [264]. In urban environments, regional climate models predict a more significant temperature rise than the average one, because of the positive thermal balance of cities, [266,267]. In addition, to the important background temperature rise, future extreme heat events heat waves, are projected to increase significantly in terms of duration, frequency and intensity, [268]. As already analysed, higher ambient temperatures increase significantly heat related mortality and morbidity, [250]. Given the projected temperature increase serious concerns are raised about the levels of future heat related mortality, [269,270].

Numerous models are developed aiming to forecast the future mortality rates under conditions of considerably higher ambient temperature, [271–278]. Very large increases in the projected heat related mortality as compared to the actual levels, are reported by most of the studies. The predicted relative increase depends on the assumptions and the characteristics of the studies and covers a very wide spectrum of values up to 1000%, [269]. A review of the existing studies projecting the future heat related mortality, is presented in [269]. Predictions of the future heat related mortality entails a very complete understanding of the past and current relation between temperature and mortality and a precise forecast of the future climate, human adaptation and demographic conditions. Projections differ substantially between the various models as a result of the important uncertainties on the prediction of the future climatic, acclimatisation and demographic conditions, [17].

As analysed in [17], uncertainty in the prediction of the future heat related mortality originates from four major sources: a) The considered climate model and the corresponding emission scenario, b) the mortality model and the calibration process followed, c) the considered adaptation model and d) the future change of the population. Equally to the four previously sources of uncertainty, the increasing urbanisation may affect significantly the magnitude of the heat related mortality and is a serious source of additional uncertainty.

Prediction of the future climate is performed using Global Climate Models, GCM, combined with a greenhouse gas emission scenario, [279]. Several greenhouse gas emission scenarios are developed by IPCC. The so called SRES, (Special Report Emission scenarios), are developed for the needs of the second and third assessment reports of IPCC and included scenarios assuming a considerably higher emission rate, A1F1 and A2, medium emission A1B, B2 and low emission rates, B1, [280]. At a later phase, a new family of emission scenarios, Representative Concentration Pathways, RCP, are proposed, [281], also including high emission, RCP8.5, medium RCP 6.0 and low emission RCP 4.5, scenarios. Estimation of the future climatic heat related mortality was performed using one or more of the above mentioned emission scenarios, or by assuming a different pattern of the future concentration of the greenhouse gases. Models were calibrated or not using actual climatic data to decrease of avoid biases. Several downscaling methods are also used to estimate future temperatures in a more dense spatial grid. An analysis of the specific GCM and emission scenarios, as used by 63 articles providing a quantitative estimation of the future heat related mortality, is given in [17]. About half of the estimations were based on the use of the SRES scenarios while 13 studies used the RCP scenarios to generate future climatic data. Most of the studies considered a high or medium emission scenario, (B2,A1B,A1F1,A2,RCP8.5 and RCP6), few studies used climatic data calculated using low emission scenarios, (B1, RCP4.5), while some articles are based on a combination or the average of several emission scenarios. Although projections may not refer to the same period, the forecasted future temperature levels present very significant differences increasing the prediction uncertainty of heat related mortality. It is characteristic that projections of heat related mortality for 12 USA cities, shown that the use of the high or low emission scenario results in about 22,000 additional deaths, [276]. Projections of the heat related mortality in the UK using a Low, Medium High and High emissions scenarios, estimated that the corresponding increase by 2050 will be 71%, 253% and 307% respectively, [282] Similar conclusions are drawn in [283], when the future mortality is calculated for ten Australian cities considering several emission scenarios.

As already discussed, models associating ambient temperature and heat related mortality are based on the use of the minimum, maximum, or average daily temperature, comfort parameters or a combination of several climatic parameters. Given that the prediction accuracy by the climatic models of considered temperature proxies may differ substantially, the choice of climatic proxy is of important significance and may affect the accuracy of the mortality model and/or increase the uncertainty of the predicted future mortality levels.

According to United Nations the global population by 2050 may increase up to 76% compared to the 2000 levels, [284]. In parallel, the number of the elderly population increases constantly and it is projected to reach almost 2.1 billion by 2050, [285]. As a result of the important population increase and the higher proportion of older people, the future number of deaths is projected to increase significantly, [286]. A review of the considered future population scenarios considered by the various mortality estimation models is provided in [17]. It is characteristic that the projected increase of the mortality rate by 2050 in the UK is 169% or 257% when population was held constant or when demographic changes are considered respectively, 17,287.

According to IPCC adaptation is defined as '"Adjustment in natural or human systems to a new or changing environment. Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation.", [288]. Autonomous adaptation is related to physiological acclimatisation and some behavioural changes of individuals, while planned adaptation involves governmental actions to decrease the vulnerability of the population, involving financial assistance to live under air conditioned spaces, implementation of health warning systems, buildings of better quality, life expectancy increase, and more efficient health services. There is significant and growing evidence that human beings are becoming more tolerant to higher temperatures, [17,289,290]. A meta-analysis of 11 papers analysing the temporal variation of the heat related mortality in different parts of the world, concluded that there is a significant decrease of the susceptibility to ambient heat, [291]. It is characteristic that the Relative Risk, RR, of mortality in New York, USA, was 1.3, at the beginning of the previous century, and has decreased to 1.26 in 1970 and 1.09 in 2000, [292], while heat related mortality in 105 cities in USA declined by 63% between 1987 and 2005, [293]. In parallel, threshold mortality temperatures have increased by 1.5-3 C between 1972 and 1994 in Tokyo, [294], by 0.7 C in France, from 1968 to 1996 – 2009, [295], and about 10 C in Stockholm between 1901 and 2009, [296]

However, analysis of the existing time series shows that the magnitude of adaptation varies considerably between the different parts of the world and population groups, [290]. A higher decrease of susceptibility to heat is found for the older age groups, [292], and in cities with a higher penetration of air conditioning, [293]. However, the relative impact of air conditioning in decreasing heat related mortality rates is not confirmed by many studies, [297].

Models predicting the future heat related mortality either consider or neglect human adaptation to heat, [17,290]. Several adaptation methodologies are proposed to quantify future mortality, [17]. Some studies propose an arbitrary increase of the mortality temperature threshold not based on a specific scientific evidence, [298,299], while other studies considered a reduction of the gradient of the relationship between temperature and mortality, [300,301], It is also proposed to use the mortality model of a current warmer city to the city under consideration, the 'analogue city approach', [302], while some studies ignored mortality during the first days of a future heat wave, [273], Given the lack of data, all proposed methods to consider future adaptation are not supported by empirical evidence and the considered assumptions are quite arbitrary.

Neglecting the impact of adaptation when forecasting the future heat related mortality, results in serious overestimations Projections of deaths in Canada, foreseen a five times increase for the period 2070-2090, [303], while projections of the future mortality in the UK estimated that the relative increase for 2020, 2050 and 2080 could be 66%, 257% and 535%, respectively, compared to 2000 levels, [272]. A projection of the future mortality of elderly population in Washington State, USA, predicted an increase between 4-22.3 times by 2045, [304]. Modelling of the heat related mortality in three cities in North-Eastern USA predicted a six to nine times increase by 2080 under the high emission scenario, RCP 8.5, [276], while a similar study foreseen almost 200,000 heat related deaths in USA between 1970 and 2099 under the A2 emission scenario, [305]. Finally, projections of heat related mortality for Manhattan, USA, under the A2 scenario predicted an increase of 22.2, 49.4 and 91% for 2020, 2050 and 2080 respectively compared to the 1989 levels, [306].

Substantially lower future heat related mortality rates are estimated when adaptation is considered by the epidemiological models. For example, projections of the increase of mortality by 2050, in the Netherlands, concluded that it may vary between 1.56 to 2.52%, when adaptation is not considered, or between 0.94-2.52, when adaptation is taken into account, [307]. Studies assessing the impact of land cover modifications, like increase of the vegetation and increase of the albedo, found that can counterbalance the increase of heat related mortality between 40-99% in 2050 in three American cities, [308], while may reduce by almost 66% heat related deaths in Manitoba Arizona for the period 2045-2055, [203]. Considering a potential increase of the threshold mortality temperature in Beirut, Lebanon, it is estimated that the projected increase of mortality may be lowered from 8.4% to 2.5% by 2095, [309]. When, early heat related mortality during heat waves is removed, then the projected increase of the mortality in California lowered by 37-56% for 2090., [273]. A study evaluating the levels of heat rerated mortality in 14 European cities, for the period 2070-2099, has simulated the impact of six different adaptation methods combined with five climatic models and two emission scenarios, [310]. It is calculated that irrespective of climate model and emission scenario, the average difference between the calculated heat related mortality including or not adaptation was varying between 28% to 103% as a function of the model used. The uncertainty related to adaptation was found to be larger than the uncertainty associated to the selection of the climate model and emission scenario, [310]. For Example, the range of impacts due to the uncertainty of the adaptation levels, (maximum minus minimum value), for Athens, Greece was 88, the corresponding range in impacts due to climate modelling uncertainty is 46 and the range in impacts due to emissions uncertainty is 54.

Humanity is facing an unprecedent urbanisation, [311]. Urban population, mainly in developing countries is increasing fast and by 2050 it is predicted that 68% of the world population will live in cities, [311]. Cities experience an important overheating because of the urban heat island phenomenon that increases significantly heat related mortality. Projections of the future heat related mortality are rarely considering the impact of the future urbanisation. Most of the GCM models do not simulate urban climates and this may result in a serious underestimation of the future levels of mortality. A study, examining the future mortality in London, concluded that when the specific climate of cities is considered, then the magnitude of mortality may increase up to 15%, [312].

It is evident that the magnitude of the projected heat related mortality under climatic change is quite uncertain. However, the scientific progress achieved is very significant and permits a better understanding of the impact of overheating on health, but many advances remain to be made. Further research should concentrate: to improve the accuracy of future climate predictions, investigate and analyse the specific health and climatic conditions in developing countries, better clarify the impact of an urbanised built environment, study in depth the specific impact of the socioeconomic and demographic factors, and develop a stronger theoretical background to describe and predict adaptation processes in a more accurate and precise way.

4. Discussion and conclusions

Increase of the temperature in cities is mainly attributed to their positive thermal balance causing the urban heat island phenomenon. Numerous studies shown that global climatic change generating serious heat wave events may act synergistically to urban heat island and increase further the magnitude of urban overheating during extreme climatic events. The important current increase of the magnitude and frequency of heat waves and the projected intensification of the phenomena, highly affect urban overheating conditions, alter significantly its spatial and temporal variability and ask for a more integrated and holistic analysis combining both regional and global climate issues in cities.

It is well documented that urban overheating causes a serious impact on humanity affecting in multiple ways our wellbeing. Energy demand and generation, pollution and environmental quality, vulnerability and health are among the most affected sectors. Numerous studies have investigated the individual association between ambient temperature and parameters related to energy generation and demand, energy poverty and vulnerability, concentration of pollutants and heat related mortality and morbidity. Additionally, several studies investigated the future impact of ambient overheating on energy, pollution and health based on projected data of urban and global climate and on modelling of the future correlation between temperature and the related parameters.

Current studies examining the impact of urban overheating on energy, pollution, vulnerability and health,provide information and quantified knowledge among other, on the specific increase of the cooling energy consumption, the rise of the peak electricity demand, the decrease of the efficiency of the power plants, the increase of the concentration of the ground level ozone, the higher emission of power plants, the increase risk of vulnerability because of the extreme indoor and outdoor temperatures and the rise of heat related mortality and morbidity. While the provided information is rich in terms of quantified data, it is highly fragmented among the different scientific disciplines and fails to consider the problem of ambient overheating impact in an integrated and holistic way.

In fact, it is constantly understood that there is a very strong interrelationship between the different sectors affecting highly the specific assessments. The whole data and analysis reported in the previous chapters documents the strong synergies between energy, health, pollution and vulnerability. Not an exhaustive list of the main synergies is listed below:

- the provision of energy to operate air conditioning keeps indoor temperatures in appropriate levels and may decrease the levels of heat related mortality,
- lack of energy resources in low income households increases dramatically indoor temperatures during heat waves, rises vulnerability levels and skyrockets heat related mortality.
- Prolonged operation of power plants to satisfy the additional electricity demand during heat waves, increases significantly the emission of harmful pollutants and may exacerbate respirational and other health problems.
- The significant increase of the peak electricity demand obliges utilities to built additional power plants operating just for a fraction of time, resulting in a significant increase of the electricity prices and a serious increase of vulnerability in cities.
- Serious disruptions in electricity generation result in blackouts, limiting the potential of air conditioning to provide protection from extreme indoor temperatures and resulting in a significant increase of heat related mortality and morbidity

- The serious decrease of the efficiency of power plants during the warm season increases the cost of electricity and put an additional burden to the vulnerable population
- Low income population facing health problems need to maintain reasonably low indoor temperatures for health reasons increasing their energy bill
- The thermal quality of housing determines the level of indoor temperature during the warm period and affects highly heat related mortality, more than the increase of the outdoor temperature.
- High ground level ozone concentrations affect directly health and increase the cost ventilation and filtration systems in tertiary buildings
- Increased needs for comfort and health protection indoors, skyrockets the penetration of air conditioning rising the global energy consumption and the peak electricity demand

The serious heterogeneity of the quantitative and qualitative conclusions drawn by the existing studies can be mainly attributed to the differentiation of the synergetic association of energy, pollution, health and vulnerability in the considered cases. The need to adopt a more extended and interdisciplinary frame for impact studies considering all possible synergies is quite evident.

Projections of the future impact of urban and ambient overheating present a serious confidence problem. The scientific uncertainty of the proposed emission scenarios, adaptation mechanisms, and technological developments is still very high despite the tremendous improvements achieved in the recent years. Existing projections, of the future energy needs and generation requirements, pollutants concentration, vulnerability levels and mortality and morbidity magnitude offer very significant information and knowledge asking for a more proactive agenda. However, quantitative projections although rapidly converge, may differ by a significant factor. Global and integrated future impact scenarios considering all the existing associations and synergies between climate, energy, health, pollution and vulnerability combined with forecasts of the projected technological, socioeconomic and demographic developments, may offer more holistic and less uncertain predictions.

Declaration of competing interest

None.

References

[1] M. Santamouris, Minimizing Energy Consumption, Energy Poverty and Global and Local Climate Change in the Built Environment Minimizing to Zero the Building Sector, Published by Elsevier (2018).
[2] T.R Oke, G.T. Johnson, D.G. Steyn, I.D. Watson, 'Simulation of Surface Urban Heat Islands under 'Ideal' Conditions at Night - Part 2: Diagnosis and Causation', Boundary Layer Meteorol. 56 (1991) 339–358.
[3] M. Santamouris, Analyzing the heat island magnitude and characteristics in one hundred Asian and Australian cities and regions, Sci. Total Environ. 512–513 (2015) 582–598.
[4] M. Santamouris, Innovating to zero the building sector in Europe: Minimising the energy consumption, eradication of the energy poverty and mitigating the local climate change, Solar Energy 128 (April 2016) 61–94.
[5] E. Sarah Perkins, A review on the scientific understanding of heatwaves—Their measurement, driving mechanisms, and changes at the global scale, Atmosph. Res. 164–165 (2015) 242–267.
[6] A. Pyrgou, P. Hadjinicolaou, M. Santamouris, Urban-rural moisture contrast: regulator of the urban heat island and heatwaves' synergy over a Mediterranean city, Sci. Rep. 7 (2017) 10973.
[7] M. Santamouris, Regulating the damaged thermostat of the Cities – Status, Impacts and Mitigation Strategies, Energy and Buildings, Energy Build. 91 (2015) 43–56.
[8] M. Santamouris, C. Cartalis, A. Synnefa, D. Kolokotsa, On The Impact of Urban Heat Island and Global Warming on the Power Demand and Electricity Consumption of Buildings–A Review, Energy Build. 98 (1) (July 2015) 119–124, doi:10.1016/j.enbuild.2014.09.052.
[9] M. Santamouris, On The Energy Impact of Urban Heat Island and Global Warming on Buildings, Energy Build. 82 (2014) 100–113 October 2014.
[10] M. Santamouris, Cooling of Buildings. Past, Present and Future, Energy Build. 128 (2016) 617–638 2016.
[11] A. Phadke, N. Abhyankar, N. Shah, Avoiding 100 New Power Plants by Increasing Efficiency of Room Air Conditioners in India: Opportunities and Challenges, Lawrence Berkeley National Laboratory, Berkeley, USA, 2014.
[12] A. Gasparrini, Y. Guo, F. Sera, A.M. Vicedo-Cabrera, V. Huber, S. Tong, M. de Sousa Zanotti Stagliorio Coelho, P.H.N. Saldiva, E. Lavigne, P.M. Correa, N.V. Ortega, H. Kan, S. Osorio, J. Kyselý, A. Urban, J.J.K. Jaakkola, N.R.I. Ryti, M. Pascal, P.G. Goodman, A. Zeka, P. Michelozzi, M. Scortichini, M. Hashizume, Y. Honda, M. Hurtado-Diaz, J.C. Cruz, X. Seposo, H. Kim, A. Tobias, C. Iñiguez, B. Forsberg, D.O. Åström, M.S. Ragettli, Y.L. Guo, C.-F. Wu, A. Zanobetti, J. Schwartz, M.L. Bell, T.N. Dang, D. Do Van, C. Heaviside, S. Vardoulakis, S. Hajat, A. Haines, B. Armstrong, Projections of temperature-related excess mortality under climate change scenarios, Lancet 1 (December 2017).
[13] J.A. Patz, D. Campbell-Lendrum, T. Holloway, J.A. Foley, Impact of regional climate change on human health, Nature 438: (2005) 310–317.
[14] S.N. Gosling, J.A. Lowe, G.R. McGregor, M. Pelling, B.D. Malamud, Associations between elevated atmospheric temperature and human mortality: a critical review of the literature, Climatic Change 92 (2009) 299–341, doi:10.1007/s10584-008-9441-x.
[15] J. Paravantis, M. Santamouris, C. Constantinos, E. Chrysanthi and K. Nikoletta: Mortality Associated with High Ambient Temperatures, Heatwaves, and the Urban Heat Island in Athens, Greece, Sustainability, 9, 606; doi:10.3390/su9040606, 2017
[16] M. Baccini, A. Biggeri, G. Accetta, T. Kosatsky, K. Katsouyanni, A. Analitis, H.R. Anderson, L. Bisanti, D. D'Ippoliti, J. Danova, et al. Heat effects on mortality in 15 European cities, Epidemiol. 19 (2008) 711–719.
[17] M. Sanderson, K. Arbuthnott, S. Kovats, S. Hajat, P. Falloon, The use of climate information to estimate future mortality from high ambient temperature: A systematic literature review, PLoS ONE 12 (7) (2017) e0180369.
[18] M.S.D. Kolokotsa, On the Impact of Urban Overheating and Extreme Climatic conditions on Housing Energy Comfort and Environmental Quality of Vulnerable Population in Europe, Energy Build. 98 (2015) 125–133, doi:10.1016/j.enbuild.2014.08.050.
[19] K.E. Smoyer, Putting Risk in its Place: Methodological Considerations for Invetsigating Extreme Event Health Risk, Soc. Sci. Med. 47 (11) (1998) 1809–1824.
[20] D. Kolokotsa, M. Santamouris, Review of the indoor environmental quality and energy consumption studies for low income households in Europe, Sci. Total Environ. 536 (2015) 316–330.
[21] L.-W. Lai, W.-L. Cheng, Air quality influences by urban heat island coupled with synoptic weather patterns, Sci. Total Environ. 407 (2009) 2724–2732.
[22] H. Yoshikado, M. Tsuchida, High levels of winter air pollution underthe influence of the urban heat island along the shore of Tokyo Bay, J. Appl. Meteorol. Climatol. 35 (1804).
[23] L.P. Dorigon, M. Amorim, Spatial modeling of an urban Brazilian heat island in a tropical continental climate, Urban Climate 28 (June 2019).
[24] T.M. Nguyen, T.-H. Lin, H.-P. Chan, The environmental effects of urban development in Hanoi, Vietnam from satellite and meteorological observations from 1999–2016, Sustainability 11 (2019) 1768, doi:10.3390/su11061768.
[25] S. Chapman, M. Thatcher, A. Salazar, J.E.M. Watson, C.A. McAlpine, The impact of climate change and urban growth on urban climate and heat stress in a subtropical city, Int. J. Climatol. 39 (6) (May 2019) 3013–3030.
[26] K. Matsuo, T. Tanaka, Analysis of spatial and temporal distribution patterns of temperatures in urban and rural areas: Making urban environmental climate maps for supporting urban environmental planning and management in Hiroshima, Sust. Cities Soc. 47 (May 2019) Article number 101419.
[27] M. Dienst, J. Lindén, Ò. Saladié, Esper, J.: Detection and elimination of UHI effects in long temperature records from villages – A case study from Tivissa, Spain, Urban Clim. 27 (March 2019) 372–383.
[28] R. Evgeniev, K. Malcheva, Long-term air temperature variations in some urban areas of Sofia Valley in the context of climate change, in: AIP Conference Proceedings, 2075, February 2019 Article number 12001210th Jubilee Conference of the Balkan Physical Union, BPU 2018; Sofia; Bulgaria; 26 August 2018 through 30 August 2018; Code 145692.
[29] P. Sarricolea, O. Meseguer-Ruiz, Urban climates of large cities: Comparison of the urban heat Island effect in Latin America (Book Chapter), in: Urban Climates in Latin America, 23, Springer, February 2019, pp. 17–32.
[30] H. Huang, Y Yun, H. Xu, T. Liu, Influence of the mega-urban heat Island on spatial transfer of summer thermal comfort: Evidence from Tianjin, China, Tehnicki Vjesnik 26 (1) (February 2019) 183–192.
[31] D. Garzena, F. Acquaotta, S. Fratianni, Analysis of the long-time climate data series for Turin and assessment of the city's urban heat island, Weather (2019).
[32] M.U. Mohammed, N.I. Hassan, M.M. Badamasi, In search of missing links: urbanisation and climate change in Kano Metropolis, Nigeria, Int. J. Urban Sust. Develop. (2019) In Press.
[33] D. Li, E. Bou-Zeid, Synergistic interactions between urban heat islands and heat waves: The impact in cities is larger than the sum of its parts, J. Appl. Meteorol. Climatol. 52 (9) (2013) 2051–2064.
[34] R. Brázdil, M. Budíková, An urban bias in air temperature fluctuations at the Klementinum, Prague, the Czech Republic, Atmos. Environ. 33 (1999) 4211–4217.
[35] P. Ramamurthy, E. Bou-Zeid, Heatwaves and urban heat islands: A comparative analysis of multiple cities, J. Geophys. Res. Atmos. 122 (2017) 168–178, doi:10.1002/2016JD025357.

[36] S. Cheval, A. Dumitrescu, A. Bell, Te urban heat island of Bucharest during the extreme high temperatures of July 2007, Teor. Appl. Climatol. 97 (2009) 391–401.
[37] L.E. Ortiz, J.E. Gonzalez, W.U. Wei, M. Schoonen, K.J. Tongue, R. Borstein, New York City Impacts on a Regional Heat Wave, J. Appl. Meteorol. Climatol. 57 (2018) 837–851.
[38] D. Founta, M. Santamouris, Synergies between Urban Heat Island and Heat Waves in Athens (Greece), during an extremely hot summer, Sci. Reports – Nature 7 (1) (December 2017) 1 Article number 10973, doi:10.1038/s41598-017-11407-6.
[39] B.J. Basara, H.G Basara, B.G. Illston, K.C. Crawford, The impact of the urban heat island during an intense heat wave in Oklahoma City, Adv. Meteorol. (2010) Article ID 230365.
[40] J. Tan, et al., The urban heat island and its impact on heat waves and human health in Shanghai, Int. J. Biometeorol. 54 (2010) 75–84.
[41] D. Li, et al., Contrasting responses of urban and rural surface energy budgets to heat waves explain synergies between urban heat islands and heatwaves, Environ. Res. Lett. 10 (2015) 054009.
[42] S.H. Rizvi, K. Alam, M.J. Iqbal, Spatio -temporal variations in urban heat island and its interaction with heat wave, J. Atmosph. Solar-Terrestrial Phys. 185 (April 2019) 50–57.
[43] S.N. Chandramowli, F.A. Felder, Impact of climate change on electricity systems and markets – A review, of models and forecasts, Sust. Energy Technol. Assess. 5 (2014) 62–74.
[44] M. Bartos, et al., Impacts of rising air temperatures on electric transmission ampacity and peak electricity load in the United States, Environ. Res. Lett. 11 (2016) 114008.
[45] J.A. Dirks, et al., Impacts of climate change on energy consumption and peak demand in buildings: a detailed regional approach, Energy 79 (2015) 20–32.
[46] M. Santamouris, N. Papanikolaou, I. Livada, I. Koronakis, C. Georgakis, A. Argiriou, D.N. Assimakopoulos, On the impact of urban climate to the energy consumption of buildings, Solar Energy 70 (3) (2001) 201–216.
[47] S. Hassid, M. Santamouris, N. Papanikolaou, A. Linardi, N. Klitsikas, C. Georgakis, D.N. Assimakopoulos, The effect of the Athens heat island on air conditioning load, Energy Build. 32 (2) (2000) 131–141.
[48] D.K. Papanastasiou, D. Fidaros, T. Bartzanas, C. Kittas, Impact of urban heat island development on buildings' energy consumption, Fresenius Environ. Bullet. 22 (7A) (2013) 2087–2092.
[49] M. Zinzi Fanchiotti, Impact of cool materials on urban heat islands and on buildings comfort and energy consumption, in: Proc. ASES Conference, 2012.
[50] T.J. Chandler, The Climate of London, Hutchinson & Co Publishers Ltd., London, UK, 1965.
[51] M. Kolokotroni, Y. Zhang, R. Watkins, The London heat island and building cooling design, Solar Energy 81 (2007) 102–110.
[52] M. Kolokotroni, X. Ren, M. Davies, A. Mavrogianni, London's urban heat island: impact on current and future energy consumption in office buildings, Energy Build. 47 (2012) 302–311.
[53] W. Briindl, P. Hoppe, Advantages and disadvantages of the urban heat island an evaluation according to the hygro-thermic effects, Archives for Meteorology, Geophysics, and Bioclimatology, Series B 35 (1984) 55–66.
[54] M. Street, C. Reinhart, L. Norford, J. Ochsendorf, Urban heat island in Boston an evaluation of urban air-temperature models for predicting building energy use, in: Proceedings of BS2013: 13th Conference of International Building Performance Simulation Association, August 26–28, Chambry, France, 2013.
[55] H. Rong, Impact of Urban Sprawl on U.S. Residential Energy Use (Dissertation), Faculty of the Graduate School of the University of Maryland, 2006.
[56] D. Chen, Z. Ren, C.-H. Wang, M. Thatcher, X. Wang, Urban Heat Island on Australian Housing Energy Consumption, Healthy Buildings, Brisbane, Queensland, 2012.
[57] Aecom: Economic Assessment of the Urban Heat Island Effect, Prepared by AECOM Australia Pty Ltd., Level 9, 8 Exhibition Street, Melbourne VIC 3000, Australia, 2012.
[58] S.S. Radhi, Quantifying the domestic electricity consumption for airconditioning due to urban heat islands in hot arid regions, Appl. Energy 112 (2013) 371–380 [26].
[59] M. Palme, L. Inostroza, G. Villacreses, A. Lobato-Cordero, C. Carrasco, From urban climate to energy consumption. Enhancing building performance simulation by including the urban heat island effect, Energy Build. 145 (2017) 107–120.
[60] S. Magli, C. Lodi, L. Lombroso, A. Muscio, S. Teggi, Analysis of the urban heat island effects on building energy consumption, Int. J. Energy Environ. Eng. 6 (2015) 91–99, doi:10.1007/s40095-014-0154-9.
[61] M. Zinzi, E. Carnielob, B. Mattoni, On the relation between urban climate and energy performance of buildings.A three-years experience in Rome, Italy, Appl. Energy 221 (2018) 148–160.
[62] M. Zinzi, E. Carnielo, Impact of urban temperatures on energy performance and thermal comfort in residential buildings. The case of Rome, Italy, Energy Build. 157 (2017) 20–29.
[63] C. Calice, C. Clemente, A. Salvati, M. Palme, L. Inostroza, Urban Heat Island Effect on the Energy Consumption of Institutional Buildings in Rome, WMCAUS IOP Publishing IOP Conf. Series: Materials Science and Engineering, 245, 2017, doi:10.1088/1757-899X/245/8/082015.
[64] H.S. Bagiorgas n, G. Mihalakakou, On the influence of the urban heat island on the cooling load of a school building in Athens, Greece, J. Atmosph. Solar-Terr. Phys. 138-139 (2016) 179–186.
[65] M. Ignatius, W.N. Hien, S.K. Jusuf, The significance of using local predicted temperature for cooling load simulation in the tropics, Energy Build. 118 (2016) 57–69.
[66] R.-L. Hwang, C.-Y. Lin, K.-T. Huang, Spatial and temporal analysis of urban heat island and global warming on residential thermal comfort and cooling energy in Taiwan, Energy Build. 152 (2017) 804–812.
[67] C.P. Skelhorn, G. Levermore, S.J. Lindley, Impacts on cooling energy consumption due to the UHI and vegetation changes in Manchester, UK, Energy Build 122 (2016) 150e9.
[68] A. Salvati, H.C. Roura, C. Cecere, Assessing the urban heat island and its energy impact on residential buildings in Mediterranean climate: Barcelona case study, Energy Build. 146 (2017) 38–54.
[69] X. Xua, J.E. Gonzálezc, S. Shena, S. Miaob, J. Dou, Impacts of urbanization and air pollution on building energy demands — Beijing case study, Appl. Energy 225 (2018) 98–109.
[70] Y. Sun, G. Augenbroe, Urban heat island effect on energy application studies of office buildings, Energy Build 77 (2014) 171e9.
[71] X. Li, Y. Zhou, S. Yu, G. Jia, H. Li, L. Wenliang, Urban heat island impacts on building energy consumption: A review of approaches and findings, Energy 174 (2019) 407e419.
[72] S.A. Lowe, An energy and mortality impact assessment of the urban heat island in the US, Environ. Impact Assess Rev. 56 (2016) 139–144.
[73] J. Kapsomenakis, D. Kolokotsa, T. Nikolaou, M. Santamouris, S.C. Zerefos, Forty years increase of the air ambient temperature in Greece: the impact on buildings, Energy Convers. Manage. 74 (2013) 353–365.
[74] J.C. Lam, C.L. Tsang, D.H.W. Li, Long term ambient temperature analysis and energy use implications in Hong Kong, Energy Convers. Manage. 45 (2004) 315–327.
[75] M.A. Lange, P. Hadjinicolaou, M. Santamouris, G. Zittis, Assessment of increasing electricity demand for space cooling under climate change condition in the Eastern Mediterranean, 2nd Conference on Power Options for the Eastern Mediterranean Region (POEM 2013), 2013.
[76] M. Christenson, H. Manz, D. Gyalistras, Climate warming impact on degree–days and building energy demand in Switzerland, Energy Convers. Manage. 47 (2006) 671–686.
[77] T. Frank, Climate change impacts on building heating and cooling energy demand in Switzerland, Energy Build. 37 (2005) 1175–1185.
[78] S. Doddaballapur, Analysis of the impact of urban heat island on building energy consumption, in: Proc. 2012 ACES Solar Conference, World Renewable Energy Forum (WREF), 2012.
[79] J.S. Golden, A. Brazel, J. Salmond, D. Laws, Energy and water sustainability the role of urban climate change from metropolitan infrastructure, J. Green Build. 1 (3) (2006) 124–138.
[80] D.B. Crawley, Estimating the impacts of climate change and urbanization on building performance, J. Build. Perform. Simul. 1 (2) (2008) 91–115.
[81] M. Santamouris, K. Paraponiaris, G. Mihalakakou, Estimating the ecological footprint of the heat island effect over Athens, Greece, Clim. Change 80 (2007) 265–276.
[82] Y. Hirano, T. Fujita, Evaluation of the impact of the urban heat island on residential and commercial energy consumption in Tokyo, Energy 37 (2012) 371–383.
[83] C. Li, J. Zhou, Y. Cao, J. Zhong, Y. Liu, C. Kang, Y. Tan, Interaction between urban microclimate and electric air-conditioning energy consumption during high temperature season, Appl. Energy 117 (2014) 149–156.
[84] F. Ding, H. Pang, W. Guo, Impact of the urban heat island on residents' energy consumption: a case study of Qingdao, EEEP2017 IOP Publishing IOP Conf. Series: Earth and Environmental Science, 121, 2018, doi:10.1088/1755-1315/121/3/032026.
[85] K. Wangpattarapong, S. Maneewan, N. Ketjoy, W. Rakwichian, The impacts of climatic and economic factors on residential electricity consumption of Bangkok Metropolis, Energy Build. 40 (Jan. (8)) (2008) 1419–1425.
[86] Pardo, V. Meneu, E. Valor, Temperature and seasonality influences on Spanish electricity load, Energy Econ. 24 (1) (2002) 55–70.
[87] G. Franco, A.H. Sanstad, Climate change and electricity demand in California, Clim. Change 87 (2007) 5883–5891.
[88] C. Giannakopoulos, B.E. Psiloglou, Trends in energy load demand for Athens, Greece: weather and non-weather related factors, Clim. Res. 31 (1) (2006) 97–108.
[89] A.H. Rosenfeld, H. Akbari, S. Bretz, B.L. Fishman, D.M. Kurn, D. Sailor, H. Taha, Mitigation of urban heat islands: materials, utility programs, updates, Energy Build. 22 (3) (1995) 255–265.
[90] W.Y. Fung, K.S. Lam, W.T. Hung, S.W. Pang, Y.L. Lee, Impact of urban temperature on energy consumption of Hong Kong, Energy 31 (2006) 2287–2301.
[91] S.L. Wong, K.K.W. Wan, D.H.W. Li, J.C. Lam, Impact of climate change on res-idential building envelope cooling loads in subtropical climates, Energy Build. 42 (Nov. (11)) (2010) 2098–2103.
[92] D.J. Sailor, J.R. Mũnoz, Sensitivity of electricity and natural gas consumption to climate in the U.S.A.—methodology and results for eight states, Energy 22 (1997) 987–998.
[93] S. Mirasgedis, Y. Sarafidis, E. Georgopoulou, D.P. Lalas, M. Moschovits, F. Karagiannis, D. Papakonstantinou, Models for mid-term electricity demand forecasting incorporating weather influences, Energy 31 (2006) 208–227.
[94] K. Hayhoe, M. Robson, J. Rogula, M. Auffhammer, N. Miller, J. VanDorn, D. Wueb-bles, An integrated framework for quantifying and valuing climate change impacts on urban energy and infrastructure: a Chicago case study, J. Great Lakes Res. 36 (2010) 94–105.

[95] M. Ruth, A.C. Lin, Regional energy demand and adaptations to climate change: methodology and application to the state of Maryland, USA, Energy Policy 34 (2006) 2820–2833.
[96] A.D. Amato, M. Ruth, P. Kirshen, J. Horwitz, Regional energy demand responses to climate change: methodology and application to the Commonwealth of Mas-sachusetts, Climatic Change 71 (2005) 175–201.
[97] T.K. Doshi, P. Fellow, A. Rohatgi, N. Bin Zahur, E. Analyst, Y.K. Hung, E. Analyst, Impact of climate change on electricity demand of Singapore (2014) 1–15, Available through: https://editorialexpress.com/cgi-bin/conference/download.cgi?dbname=SERC2013&paper id=405.
[98] M. Hekkenberg, R.M.J. Benders, H.C. Moll, A.J.M. Schoot Uiterkamp, Indications for a changing electricity demand pattern: the temperature dependence of electricity demand in the Netherlands, Energy Policy 37 (2009) 1542–1551.
[99] N. Yadav, C. Sharma, S.K Peshin, Renu Masiwal, Study of intra-city urban heat island intensity and its influence on atmospheric chemistry and energy consumption in Delhi, Sust. Cities Soc. 32 (2017) 202–211.
[100] K. Yabe, Evaluation of energy saving effect for the long-term maximum power forecast (title only in original language), in: Proceedings of National Conventionof the Institute of Electrical Engineers of Japan (IEEJ), 2005
[101] S.J. Parkpoom, G.P. Harrison, Analyzing the impact of climate change on futureelectricity demand in Thailand, IEEE Trans. Power Syst. 23 (2008) 1441–1448.
[102] A.F. Colombo, D. Etkin, B.W. Karney, Climate variability and the frequency of extreme temperature events for nine sites across Canada: implications for power usage, J. Climate 12 (1999) 2490–2502.
[103] H. Akbari, S. Davis, S. Dorsano, J. Huang, S. Winnett, Cooling our communities: a guidebook on tree planting and light-colored surfacing, Cooling Our Communities: A Guidebook on Tree Planting and Light-Colored Surfacing, Environmental Protection Agency, EPA, USA, 1992.
[104] M. Segal, H. Shafir, M. Mandel, P. Alpert, Y. Balmor, Climatic-related evaluations of the summer peak-hours' electric load in Israel, J. Appl. Meteorol. 31 (1992) 1492–1498.
[105] H Franco, A.H. Sanstad, Climate change and electricity demand in California, Climatic Change 87 (2007) 5883–5891.
[106] S. Haddad, R. Paolini, A. Synnefa, M. Santamouris, Mitigation of urban overheating in three Australian cities (Darwin, Alice Springs and Western Sydney), in: P. Rajagopalan, M.M. Andamon (Eds.), Engaging Architectural Science: Meeting the Challenges of Higher Density, The Architectural Science Association (ANZAScA), Melbourne, Australia, 2018, pp. 577–584. https://www.asa2018conference.com/proceedings. ISBN: 978-0-9923835-5-8. Online at:.
[107] S.G. Synnefa, S. Haddad, R. Paolini, M. Santamouris, Impact of the mitigation of the local climate on building energy needs in Australian cities, in: P. Rajagopalan, M.M. Andamon (Eds.), Engaging Architectural Science: Meeting the Challenges of Higher Density, The Architectural Science Association (ANZAScA), Melbourne, Australia, 2018, pp. 277–284. https://www.asa2018conference.com/proceedings. ISBN: 978-0-9923835-5-8. Online at:.
[108] R. Paolini, S. Haddad, A. Synnefa, S. Garshasbi, M. Santamouris, Electricity demand reduction in Sydney and Darwin with local climate mitigation, in: P. Rajagopalan, M.M. Andamon (Eds.), Engaging Architectural Science: Meeting the Challenges of Higher Density, The Architectural Science Association (ANZAScA), Melbourne, Australia, 2018, pp. 285–294. https://www.asa2018conference.com/proceedings. ISBN: 978-0-9923835-5-8. Online at:.
[109] R. Schaeffer, A.S. Szklo, A.F.P. de Lucena, B.S.M.C. Borba, L.P.P. Nogueira, F.P. Fleming, A. Troccoli, M. Harrison, M.S. Boulahya, Energy sector vulnerability to climate change: A review, Energy 38 (2012) 1e12.
[110] F.R.P. Arrieta, E.E.S. Lora, Influence of ambient temperature on combined-cycle power-plant performance, Appl. Energy 80 (2005) 261–272.
[111] H. Paeth, A. Scholten, P. Friederichs, A. Hense, Uncertainties in climate change prediction: El-Niño southern oscillation and monsoons, Global Planetary Change 60 (2007) 265–288.
[112] K. Linnerud, G. Eskeland, T. Mideksa, The impact of climate change on thermal power supply, CICERO Mimeo. (2009).
[113] C. Davcock, R. DesJardins, S. Fennell, in: Generation of Cost Forecasting Using Online Thermodynamic Models, Proceedings of Electric Power, Baltimore, MD, 2004.
[114] D. Rubbelke, S. Vogele: Impacts of climate change on European critical infrastructures: the case of power sector. Environ Sci Policy 2011:53–63.
[115] C.V. Mikellidou, L.M. Shakou, G. Boustras, C. Dimopoulos, Energy critical infrastructures at risk from climate change: A state of the art review, Safety Sci. 110 (2018) 110–120.
[116] K. Linder, M. Inglis, The Potential Impact of Climate Change On Electric utilities, Regional and National Estimates, US Environmental Protection Agency, Washington DC, 1989.
[117] J. Coates, K.A. Mar, N. Ojha, T.M. Butler, The influence of temperature on ozone production under varying NOx conditions - A modelling study, Atmos. Chem. Phys. 16 (2016) 11601–11615.
[118] H. Yoshikado, M. Tsuchida, High levels of winter air pollution underthe influence of the urban heat island along the shore of Tokyo Bay, J. Appl.Meteorol. Climatol. 35 (1804).
[119] P. Meier, T. Holloway, J. Patz, M. Harke, D. Ahl, D. Abel, S. Schuetter, S. Hackel, Impact of warmer weather on electricity sector emissions due to building energy use, Environ. Res. Lett. 12 (2017) 064014.
[120] C.P. Lo, D.A. Quattrochi, Land-use and land cover change, urban heat island phenomenon, and health implications: a remote sensing approach, Photogrammetric Eng. Remote Sens. 69 (9) (2003) 1053–1063, doi:10.14358/PERS.69.9.1053.
[121] M.C. Penache, M. Zoran, Temporal Patterns of Surface Ozone Levels in Relation with Radon (222Rn) and Air Quality, in: AIP Conference Proceedings, 2075, 2019 Published Online: 26 February 2019, doi:10.1063/1.5091279.
[122] E. Stathopoulou, G. Mihalakakou, M. Santamouris, H.S. Bagiorgas, Impact of temperature on tropospheric ozone concentration levels in urban environments, J. Earth Syst. Sci. 117 (3) (June 2008) 227–236.
[123] A. Pyrgou, P. Hadjinicolaou, M. Santamouris, Enhanced near-surface ozone under heatwave conditions in a Mediterranean island, Sci. Rep. 8 (1) (2018) 9191.
[124] B. Brunekreef, ST. Holgate: Air pollution and health. Lancet. 360(9341):1233–1242.
[125] C.E. Reid, J.M. Snowden, C. Kontgis, I.B. Tager, The role of ambient ozone in epidemiologic studies of heat-related mortality, Environ. Health Perspect. 120 (12) (2012) 1627–1630 PMID: 22899622, doi:10.1289/ehp.1205251.
[126] T. Wang, L. Xue, P. Brimblecombe, Y.F. Lam, L. Li, L. Zhang, Ozone pollution in China: A review of concentrations, meteorological influences, chemical precursors, and effects, Sci. Total Environ. 575 (2017) 1582–1596.
[127] Y. Wang, L. Shen, S. Wu, L. Mickley, J. He, J. Hao, Sensitivity of surface ozone over China to 2000–2050 global changes of climate and emissions, Atmos. Environ. 75 (2013) 374–382.
[128] G. Swamy, S.M.S. Nagendra, U. Schlink, Urban heat island (UHI) influence on secondary pollutant formation in a tropical humid environment, J. Air Waste Manage. Assoc. 67 (10) (2017) 1080–1091, doi:10.1080/10962247.2017.1325417.
[129] Y.H. Ryu, J.J. Baik, S.H. Lee, Effects of anthropogenic heat on ozone air quality in a megacity, Atmos.Environ. 80 (2013) 20–30.
[130] C. Sarrat, A. Lemonsu, V. Masson, D. Guedalia, of urban heat island on regional atmospheric pollution, Atmos. Environ. 40 (10) (2006) 1743–1758, doi:10.1016/j.atmosenv.2005.11.037.
[131] M.E. Jenkin, K.C. Clemitshaw, Ozone and other secondary photochemical pollutants: chemical processes governing their formation in the planetary boundary layer, Atmos. Environ. 34 (16) (2000) 2499–2527, doi:10.1016/S1352-2310(99)00478-1.
[132] M. Li, Y. Song, Z. Mao, M. Liu, X. Huang, of thermal circulations induced by urbanization on ozone formation in the Pearl River Delta region, China, Atmos. Environ. 127 (2016) 382–392, doi:10.1016/j.atmosenv.2015.10.075.
[133] Y.H. Ryu, J.J. Baik, K.H. Kwak, S. Kim, N. Moon, Impacts of urban land-surface forcing on ozone air quality in the Seoul metropolitan area, Atmos. Chem. Phys. 13 (4) (2013) 2177–2194.
[134] A. Hashem, in: Cooling Our Communities: A Guidebook On Tree Planting Andlight Colored Surfaces, Lawrence Berkeley National Laboratory, Heat Island Group LBNL, 1992, p. 31587.
[135] J.E. Diem, C.E. Stauber, R. Rothenberg, Heat in the southeastern United States: Characteristics, trends, and potential health impact, PLoS ONE 12 (5) (2017) e0177937, doi:10.1371/journal.pone.0177937.
[136] C.M. Atkinson-Palombo, J.A. Miller, R.C. Balling, Quantifying the ozone "weekend effect" at various locations in Phoenix, Arizona, Atmosph. Environ. 40 (39) (2006) 7644–7658, doi:10.1016/j.atmosenv.2006.05.023.
[137] D. Kley, M. Kleinmann, H. Sanderman, S. Krupa, Photochemical oxidants: State of the science, Environ. Poll. 100 (1–3) (1999) 19–42, doi:10.1016/S0269-7491(99)00086-X.
[138] N. Yadav, C. Sharma, S.K. Peshin, R. Masiwal, Study of intra-city urban heat island intensity and its influence on atmospheric chemistry and energy consumption in Delhi, Sust. Cities Soc. 32 (2017) 202–211.
[139] G. Zhang, S.T. Rao, S.M. Daggupaty, Meteorological processes and ozone exceedances in the Northeastern United States during the 12-16 July 1995 episode, J. Appl. Meteorol. 37 (1998) 776–789.
[140] R. Ooka, M. Khiem, H. Hayami, H. Yoshikado, H. Huang, Y. Kawamoto, Influence of meteorological conditions on summer ozone levels in the central Kanto area of Japan, Procedia Environ. Sci. 4 (2011) 138–150.
[141] Tarasova, A.Y. Karpetchko, Accounting for local meteorological effects in the ozone time-series of Lovozero (Kola Peninsula), Atmosph. Chem. Phys. 3 (2003) 941–949.
[142] E.A. Kova??, J. Brana, V. Gvozdi??, mpact of meteorological factors on ozone concentrations modelled by time series analysis and multivariate statistical methods, Ecol. Inf. 4 (2009) 117–122.
[143] F. Joachim, F. Renate and E. Stefan: Cool Cities—Clean Cities? Secondary Impacts of Urban Heat Island Mitigation Strategies on Urban Air Quality. In D.G. Steyn and N. Chaumerliac (eds.), Air Pollution Modeling and Its Application XXIV, Springer Pro
[144] M.G. Li, P. Hyde, A. Mahalov, M. Moustaoui, Achieving accurate simulations of urban impacts on ozone at high resolution, Environ. Res. Lett. 9 (2014) 114019 11 pp.
[145] K. Civerolo et al 2007 Estimating the effects of increased urbanization on surface meteorology an ozone concentrations in the New York city metropolitan region Atmos. Environ. 41 1803–18
[146] X. Wang, W. Lin, L. Yang, R. Deng, H. Lin, A numerical study of influences of urban land use change on ozone distribution over the Pearl River Delta region, China Tellus 59B (2007) 633–641.
[147] S. Sillman, P.J. Samson, The impact of temperature on oxidant formation in urban, polluted rural and remote environments, J. Geophys.Res. 100 (1995) 11497–11508.
[148] J. Aw, M.J. Kleeman, Evaluating the first-order effect of intra-annual temperature variability on urban air pollution, J. Geophys. Res. 108 (2003) 4365.

[149] J.P. Dawson, P.J. Adams, S.N. Pandis, Sensitivity of PM2.5 to climate in the Eastern US: a modeling case study, Atmos. Chem. Phys. 7 (4) (2007) 295 –4, 309.

[150] M.J. Kleeman, A preliminary assessment of the sensitivity of air quality in California to global change, Climatic Change 87 (2007) S273–S292.

[151] J. Mika, P. Forgo, L. Lakatos, A.B. Olah, S. Rapi, Z. Utasi, Impact of 1.5 K global warming on urban air pollution and heat island with outlook on human health effects, Current Opinion Environ. Sust. 30 (2018) 151–159.

[152] A.J. Trájer, G. Nagy, E. Domokos, Exploration of the heterogeneous effect of climate change on ozone concentration in an urban environment, Int. J. Environ. Health Res. 29 (3) (2019) 276–289, doi:10.1080/09603123.2018.1539703.

[153] D.J. Jacob, D.A. Winner, Effect of climate change on air quality, Atmosph. Environ. 43 (2009) 51–63.

[154] K. Knowlton, J.E. Rosenthal, C. Hogrefe, B. Lynn, S. Gaffin, R. Goldberg, C. Rosenzweig, K. Civerolo, J.Y. Ku, P.L. Kinney, Assessing ozone-related health impacts under a changing climate, Environ. Health Perspect. 112 (15) (2004) 1557–1563.

[155] C. Hogrefe, B. Lynn, K. Civerolo, J.Y. Ku, J. Rosenthal, C. Rosenzweig, R. Goldberg, S. Gaffin, K. Knowlton, P.L. Kinney, Simulating changes in regional air pollution over the eastern United States due to changes in global and regional climate and emissions, J. Geophys. Res. Atmos. 109 (D22301) (2004) 1–13.

[156] K. Murazaki, P. Hess, How does climate change contribute to surface ozone change over the United States? J. Geophys. Res. Atmos 111 (D05301) (2006) 1–16.

[157] C.S. Cheng, M. Campbell, Q. Li, G. Li, H. Auld, N. Day, D. Pengelfly, S. Gingrich, D. Yap, A synoptic climatological approach to assess climatic impact on air quality in south-central Canada. Part II: future estimates, Water Air Soil Pollut. 182 (2007) 117–130.

[158] C.-Y.C. Lin, L.J. Mickley, K. Hayhoe, E.P. Maurer, C. Hogrefe, Rapid Calculation of Future Trends in Ozone Exceedances Over the Northeast United States: Results From Three Models and Two Scenarios, Presented at the Consequences of Global Change For Air Quality Festival, EPA, Research Triangle Park, NC, 2007 February 20–21.

[159] E.K. Wise, Climate-based sensitivity of air quality to climate change scenarios for the southwestern United States, Int. J. Clim 29 (1) (January 2009) 87–97.

[160] D. Abel, T. Holloway, R. Kladar, P. Meier, D. Ahl, M. Harkey, S. Schuetter, J. Patz, Response of power plant emissions to ambient temperature in the Eastern United States, Environ. Sci. Technol. 51 (2017) 5838–5846.

[161] W.L. Filho, L.E. Icaza, A. Neht, M. Klavins, A. Edward, Morgan: Coping with the impacts of urban heat islands. A literature based: study on understanding urban heat vulnerability and the need for resilience in cities in a global climate change context, J. Cleaner Prod. 171 (2018) 1140e1149.

[162] S.L. Harlan, D.M. Ruddell, Climate change and health in cities: impacts of heat and air pollution and potential co-benefits from mitigation and adaptation, Curr. Opinion Environ. Sust. 3 (2011) 126–134.

[163] S. Weber, N. Sadoff, E. Zell, A.d. Sherbinin, Policy-relevant indicators for mapping the vulnerability of urban populations to extreme heat events: A case study of Philadelphia, Appl. Geograph. 63 (2015) 231–243.

[164] C.E. Reid, M.S. O'Neill, C.J. Gronlund, S.J. Brines, D.G. Brown, A.V. Diez-Roux, J. Schwart, Mapping Community Determinants of Heat Vulnerability, Environ. Health Perspect. 117 (11) (November 2009).

[165] D.M. Ruddell, S.L. Harlan, S. Grossman-Clarke, A. Buyantuyev, Risk and Exposure to Extreme Heat, in: M. Phoenix, A.Z.P.S. Showalter, Y. Lu (Eds.), Geospatial Techniques in Urban Hazard and Disaster Analysis, 2, C_Springer Science+Business Media B.V., 2010, p. 179, doi:10.1007/978-90-481-2238-7_9. Geotechnologies and the Environment.

[166] S.L. Harlan, A. Brazel, L. Prashad, W.L. Stevanov, L. Larsen, Neighborhood microclimates and vulnerability to heat stress, Soc. Sci. Med. 63 (2006) 2847–2863.

[167] S.L. Cutter, J.T. Mitchell, M.S. Scott, Revealing the vulnerability of people and places: a case study of Georgetown County, South Carolina, Ann. Assoc. Am.Geogr. 90 (4) (2000) 713e737.

[168] J.R. Robert, P.R. Dino, C.S. Julio, M.H. Teresita, and M. K. Linda: The Rate and Risk of Heat-Related Illness in Hospital Emergency Departments During the 1995 Chicago Heat Disaster J. Med. Syst., Vol. 23, No. 1, 1999

[169] L.H. Schinasi, T. Benmarhnia, A.J.D. Roos, Modification of the association between high ambient temperature and health by urban microclimate indicators: A systematic review and metaanalysis, Environ. Res. 161 (2018) 168–180.

[170] W.B. Goggins, C. Ren, E. Ng, C. Yang, E.Y.Y. Chan, Effect modification of the association between meteorological variables and mortality by urban climatic conditions in the tropical city of Kaohsiung, Taiwan, Geospatial Health 8 (1) (2013) 37–44.

[171] A. Smargiassi, M.S. Goldberg, C. Plante, M. Fournier, Y. Baudouin, T. Kosatsky, Variation of daily warm season mortality as a function of micro-urban heat islands, J. Epidemiol. Commun. Health 63 (2009) 659–664, doi:10.1136/jech.2008.078147.

[172] J. Klein Rosenthal, P.L. Kinney, K.B. Metzger, Intra-urban vulnerability to heat-related mortality in New York City, 1997-2006, Health Place 30 (2014) 45–60, doi:10.1016/j.healthplace.2014.07.014.

[173] J. Taylor, P. Wilkinson, M. Davies, B. Armstrong, Z. Chalabi, A. Mavrogianni, P. Symonds, E. Oikonomou, I. Sylvia, Bohnenstengel: Mapping the effects of urban heat island, housing, and age on excess heat-related mortality in London, Urban Climate 14 (2015) 517–528.

[174] Y. Xu, P. Dadvand, J. Barrera-Gómez, et al., J. Epidemiol. Commun. Health 67 (2013) 519–525.

[175] M. Santamouris, S. Alevizos, L. Aslanoglou, D. Mantzios, P. Milonas, I. Sarelli, C.C. S.Karatasou, J.A. Paravantis, Freezing the poor—indoor environmentalquality in low and very low income households during the winter period in Athens, Energy Build. 70 (2014) 61–70.

[176] D.A. Asimakopoulos, M. Santamouris, I. Farrou, M. Laskari, M. Saliari, G. Zanis, G. Giannakidis, K. Tigas, J. Kapsomenakis, C. Douvis, S.C. Zerefos, T. Antonakaki, C. Giannakopoulos, Modelling the energy demand projection of the buildingsector in Greece in the 21st century, Energy Build. 49 (2012).

[177] J.P. Gouveia, J. Seixas, G. Long, Mining households' energy data to disclose fuel poverty: Lessons for Southern Europe, J. Cleaner Prod. 178 (2018) 534–550.

[178] World Health Organization, Large Analysis and Review of European Housingand Health Status (LARES), World Health Organization, DK-2100 Copenhagen,Denmark, 2007.

[179] A.J. Wright, A.N. Young, S. Natarajan, Dwelling temperatures and comfort during the August 2003 heat wave, Build. Serv. Eng. Res. Technol. 26 (2005) 285–300, doi:10.1191/0143624405bt136oa.

[180] A.J. Summerfield, R.J. Lowe, H.R. Bruhns, J.A. Caeiro, J.P. Steadman, T. Oreszczyn, Milton Keynes Energy Park revisited: changes in internal temperatures and energy usage, Energy Build. 39 (2007) 783–791, doi:10.1016/j.enbuild.2007.02.012.

[181] J. Wingfield, M. Bell, D. Miles-Shenton, T. South, B. Lowe, Evaluating the impact of an enhanced energy performance standard on load-bearing masonry domestic construction, Department for Communities and Local Government, London, 2012.

[182] A. Mavrogianni, M. Davies, P. Wilkinson, A. Pathan, London housing and climate change: impact on comfort and health — preliminary results of a summer overheating study, Open House Int. 35 (2010) 49–59.

[183] S.K. Firth, A.J. Wright, 2008. Investigating the thermal characteristics of English dwellings: summer temperatures. pp. 27–29.

[184] A. Beizaee, K.J. Lomas, S.K. Firth, National survey of summertime temperatures and overheating risk in English homes, Build. Environ. 65 (2013) 1–17, doi:10.1016/j.buildenv.2013.03.011.

[185] K.J. Lomas, T. Kane, Summertime temperatures and thermal comfort in UK homes, Build. Res. Inf. 41 (2013) 259–280, doi:10.1080/09613218.2013.757886.

[186] Y.G. Yohanis, J.D. Mondol, Annual variations of temperature in a sample of UK dwellings, Appl. Energy 87 (2010) 681–690.

[187] A. Sakka, M. Santamouris, I. Livada, F. Nicol, M. Wilson, On the thermal performance of low income housing during heat waves, Energy Build 49 (2012) 69–77.

[188] R. Basu, J.M. Samet, Relation between elevated ambient temperature and mortality: a review of the epidemiologic evidence, Epidemiol. Rev. 24 (2002) 190–202.

[189] B. Anderson, M. Bell, Heat waves in the United States: mortality risk during heat waves and effect modification by heat wave characteristics in 43 U.S. Communities, Environ. Health Perspect. 119 (2) (2011) 210–218.

[190] R.S. Kovats, S. Hajat, P. Wilkinson, Contrasting patterns of mortality and hospital admissions during hot weather and heat waves in Greater London, UK, Occup. Environ.Med. 61 (2004) 893–898.

[191] A. Gasparrini, B. Armstrong, S. Kovats, P. Wilkinson, The effect of high temperatures on cause-specific mortality in England and Wales, Occup.Environ. Med. 69 (2012) 56–61.

[192] H. Johnson, R. Kovats, The impact of the 2003 heat wave on mortality and hospital admissions in England, Health Stat. Quart. 25 (2005) 6–11.

[193] M. Stafoggia, F. Forastiere, D. Agostini, Vulnerability to heat-related mortality: a multicity, population-based, case-crossover analysis, Epidemiology 17 (2006) 315–323.

[194] L. Page, S. Hajat, R.S. Kovats, L. Howard, Temperature-related deaths in people with psychosis, dementia and substance misuse, Br. J. Psychiatry (2012).

[195] W.T.L. Chow, W.-C. Chuang, P. Gober, Vulnerability to extreme heat in metropolitan phoenix: spatial, temporal, and demographic dimensions, Prof. Geogr. 64 (2) (2012) 286–302.

[196] A. Fouillet, G. Rey, V. Wagner, K. Laaidi, P. Empereur-Bissonnet, A. Le Tertre, et al., Has the impact of heat waves on mortality changed in France since the European heat wave of summer 2003? A study of the 2006 heat wave, Int. J. Epidemiol. 37 (2008) 309–317.

[197] S.L. Harlan, A. Brazel, G.D. Jenerette, S. Jones, L. Larsen, L. Prashad, W.L. Stefanov, In the shade of affluence: the inequitable distribution of the urban heat island, Res. Soc. Probl. Public Policy 15 (2008) 173–202.

[198] Moghadamnia, et al., Ambient temperature and cardiovascular mortality: a systematic review and meta-analysis, PeerJ 5 (2017) e3574, doi:10.7717/peerj.3574.

[199] C.E. Reid, M.S. O'Neill, C.J. Gronlund, S.J. Brines, A.V. Diez-Roux, D.G. Brown, J.D. Schwartz, Mapping community determinants of heat vulnerability, Environ. Health Perspect. 117 (2009) 1730–1736.

[200] H.C. Ho, A. Knudby, B.B. Walker, S.B. Henderson, Delineation of spatial variability in the temperature–mortality relationship on extremely hot days in greater Vancouver, Canada, Environ. Health Perspect. 125 (2017) 66–75, doi:10.1289/EHP224.

[201] K. Laaidi, A. Zeghnoun, B. Dousset, P. Bretin, S. Vandentorren, E. Giraudet, P. Beaudeau, The Impact of Heat Islands on Mortality in Paris during the August 2003 Heat Wave, Environ. Health Perspect. 120 (2) (February 2012).

[202] D.M. Hondula, M. Georgescu, R.C. Balling Jr., Challenges associated with projecting urbanization-induced heat-related mortality, Sci. Total Environ. 490 (2014) 538–544.

[203] K.M.A. Gabriel, W.R. Endlicher, Urban and rural mortality rates during heat waves in Berlin and Brandenburg, Germany, Environ. Pollution 159 (2011) 2044–2050.
[204] D.M. Hondula, A.G. Barnett, Heat-related morbidity in Brisbane, Australia:spatial variation and area-level predictors, Environ Health Perspect 122 (2014) 831–836, doi:10.1289/ehp.1307496.
[205] D. Bélanger, B. Abdous, P. Valois, P. Gosselin, A. Elhadji, Laouan Sidi: A multilevel analysis to explain self reported adverse health effects and adaptation to urban heat: a cross-sectional survey in the deprived areas of 9 Canadian cities, Public Health 16 (2016) 144.
[206] W.B. Goggins, E.Y.Y. Chan, E. Ng, C. Ren, L. Chen, Effect Modification of the Association between Short-term Meteorological Factors and Mortality by Urban Heat Islands in Hong Kong, PLoS ONE 7 (6) (2012) e38551.
[207] J.-Y. Son, K.J. Lane, J.-T. Lee, M.L. Bell, Urban vegetation and heat-related mortality in Seoul, Korea, Environ Res. 151 (2016) 728–733.
[208] K. Burkart, F. Meier, A. Schneider, S. Breitner, P. Canario, M.J. Alcoforado, D. Scherer, W. Endlicher, Modification of heat-related mortality in an elderly urban population by vegetation (urban green) and proximity to water (urban blue): evidence from Lisbon, Portugal, Environ. Health Perspect. 124 (2016) 927–934, doi:10.1289/ehp.1409529.
[209] A. Milojevic, B.G. Armstrong, A. Gasparrini, S.I. Bohnenstengel, B. Barratt, P. Wilkinson, Methods to estimate acclimatization to urban heat island effects on heat- and cold-related mortality, Environ. Health Perspect. 124 (2016) 1016–1022, doi:10.1289/ehp.1510109.
[210] S.L. Harlan, J.H. Declet-Barreto, W.L. Stefanov, D.B. Petitti, Neighborhood Effects on Heat Deaths: Social and Environmental Predictors of Vulnerability in Maricopa County, Arizona, Environ. Health Perspect. 121 (2013) 197–204, doi:10.1289/ehp.1104625.
[211] J. Madrigano, M.A. Mittleman, A. Baccarelli, R. Goldberg, S. Melly, S. von Klot, J. Schwartz, Temperature, myocardial infarction, and mortality effect modification by individual- and area-level characteristics, Epidemiology 24 (3) (May 2013).
[212] C.J. Gronlund, V.J. Berrocal, J.L. White-Newsome, K.C. Conlon, M.S. O'Neill, Vulnerability to extreme heat by socio-demographic characteristics and area green space among the elderly in Michigan, 1990–2007, Environ. Res. 136 (2015) 449–461.
[213] J.K. Rosenthal, P.L. Kinney, K.B. Metzger, Intra-urban vulnerability to heat-related mortality in NewYork City, 1997–2006, Health Place 30 (2014) 45–60.
[214] S. Vandentorren, P. Bretin, A. Zeghnoun, L. Mandereau-Bruno, A. Croisier, C. Cochet, J. Riberon, I. Siberan, B. Declercq, M. Ledrans, Heat wave in france: risk factors for death of elderly people living at home, Eur. J. Public Health 16 (6) (August 2003) 583–591.
[215] G.D. Jenerette, S.L. Harlan, A. Buyantuev, W.L. Stefanov, J. Declet-Barreto, B.L. Ruddell, S.W. Myint, S. Kaplan, X. Li, Micro-scale urban surface temperatures are related to land-cover features and residential heat related health impacts in Phoenix, AZ USA, Landscape Ecol. 31 (2016) 745–760.
[216] J. Tan, Y. Zheng, X. Tang, C. Guo, L. Li, G. Song, X. Zhen, D. Yuan, J. Adam, Kalkstein & Furong Li & Heng Chen: The urban heat island and its impact on heat waves and human health in Shanghai, Int. J. Biometeorol. 54 (2010) 75–80.
[217] D.P. Johnson, J.S. Wilson, G.C. Luber, Socioeconomic indicators of heat-related health risk supplemented with remotely sensed data, Int. J. Health Geograph. 8 (2009) 57, doi:10.1186/1476-072X-8-57.
[218] C.K. Uejio, O.V. Wilhelmi, J.S. Goldenc, D.M. Mills, S.P. Gulino, J.P. Samenow, Intra-urban societal vulnerability to extreme heat: The role of heat exposure and the built environment, socioeconomics, and neighborhood stability, Health Place 17 (2011) 498–507.
[219] H.C. Ho, A. Knudby, B.B. Walker, S.B. Henderson, Delineation of spatial variability in the temperature–mortality relationship on extremely hot days in greater Vancouver, Canada, Environ. Health Perspect. 125 (2017) 66–75, doi:10.1289/EHP224.
[220] P. Vaneckova, P.J. Beggs, C.R. Jacobson, Spatial analysis of heat-related mortality among the elderly between 1993 and 2004 in Sydney, Australia, Social Sci. Med. 70 (2010) 293–304.
[221] L.-C. Chien, Y. Guo, K. Zhang, Spatiotemporal analysis of heat and heat wave effects on elderly mortality in Texas, 2006–2011, Sci. Total Environ. 562 (2016) 845–851.
[222] T. Benmarhnia, W. Kihal-Talantikite, S. Martina, Ragettli, Séverine Deguen:Small-area spatiotemporal analysis of heatwave impacts on elderly mortality in Paris: A cluster analysis approach, Sci. Total Environ. 592 (2017) 288–294.
[223] I.G. Ellen, T. Mijanovich, K.N. Dillman, Neighborhood effects on health: exploring the links and assessing the evidence, J. Urban Aff. 23 (3–4) (2001) 391–408, doi:10.1111/0735-2166.00096.
[224] B.M. Jesdale, R. Morello-Frosch, L. Cushing, The racial/ethnicdistributionof heat risk-related land covering relation to residential segregation, Environ. Health Perspect. 121 (7) (2013) 811–817, doi:10.1289/ehp.1205919.
[225] C. Heaviside, S. Vardoulakis, X.-M. Cai, Attribution of mortality to the urban heat island during heatwaves in the West Midlands, UK, Environ. Health 15 (Suppl 1) (2016) 27.
[226] H.R. Sobral Dr, Heat island in São Paulo, Brazil: Effects on health, Critical Public Health 15 (2) (2005) 147–156, doi:10.1080/09581590500151756.
[227] S.A. Lowe, An energy and mortality impact assessment of the urban heat island in the US, Environ. Impact Assess. Rev. 56 (2016) 139–144.
[228] M. Richard, P. Frank: Effect of exposure to natural environment on health inequalities: an observational population study, www.thelancet.com Vol 372 November 8, 2008
[229] D. Hondula, R. Davis, The characteristics of places within seven u.s. cities where the mortality rate is highest during extreme heat events, ISEE Conference – August 26-30, 2012.
[230] B.A. Zanobetti, M.S. O'Neill, C.J. Gronlund, J.D. Schwartz, Susceptibility to Mortality in Weather Extremes: Effect Modification by Personal and Small Area Characteristics In a Multi-City Case-Only Analysis, Epidemiology 24 (6) (2013 November) 809–819, doi:10.1097/01.ede.0000434432.06765.91.
[231] M. Bc Ledrans, S. Vandentorren, P. Bretin, A. Croisier 2005. Étude des facteurs de risque de décès des personnes âgées résidant à domicile durant la vague de chaleur d'août 2003. Rapport de l'Institut national de Veille Sanitaire [in French]. http://fulltext.bdsp.ehesp.fr/Invs/Rapports/2005/rapport_canicule.pdf [accessed 1 March 2015].
[232] M. Santamouris, D. Kolokotsa, Urban Climate Mitigation Techniques, Earthscan Publishers, London, 2016.
[233] M. Santamouris, Using cool pavements as a mitigation strategy to fight urban heat island—A review of the actual developments, Renew. Sust. Energy Rev. 26 (October 2013) 224–240.
[234] F.C. Curriero, K.S. Heiner, J.M. Samet, S.L. Zeger, L. Strug, J.A. Patz, Temperature and mortality in 11 cities of the eastern United States, Am. J. Epidemiol. 155 (2002) 80–87.
[235] S. Hajat, T. Kosatky, Heat-related mortality: a review and exploration of heterogeneity, J. Epidemiol. Commun. Health 64 (9) (2010) 753–760.
[236] W.R. Keatinge, G.C. Donaldson, E. Cordioli, M. Martinelli, A.E. Kunst, J.P. Mackenbach, et al., Heat related mortality in warm and cold regions of Europe: observational study, BMJ 321 (2000) 670–673.
[237] C. Iñiguez, F. Ballester, J. Ferrandiz, S. Pérez-Hoyos, M. Sáez, A. López, et al., Relation between temperature and mortality in thirteen Spanish cities, Int. J. Environ. Res. Public Health 7 (2010) 3196–3210.
[238] Q. Luo, S. Li, Y. Guo, X. Han, J.J.K. Jaakkola, A systematic review and meta–analysis of the association between daily mean temperature and mortality in China, Environ. Res. 173 (2019) 281–299.
[239] H. Green, J. Bailey, L. Schwarz, J. Vanos, K. Ebi, T. Benmarhnia, Impact of heat on mortality and morbidity in low and middle income countries: A review of the epidemiological evidence and considerations for future research, Environ. Res. 171 (2019) 80–91.
[240] M. Santamouris, Analyzing the heat island magnitude and characteristics in one hundred Asian and Australian cities and regions, Sci. Total Environ. 512–513 (2015) 582 –59.
[241] M. Santamouris, S. Haddad, F. Fiorito, L. Ding, D. Prasad, W. Ruzhu, P. Osmond, X. Zhai, Urban Heat Island and Overheating Characteristics in Sydney, Australia. An analysis of Multiyear measurements, Sustainability (2017).
[242] K. Knowlton, M. Rotkin-Ellman, G. King, G. Margolis, D. Smith, G. Solomon, R. Trent, P. English, The 2006 heat wave: impacts on hospitalizations and emergency department visits, Environ. Health Perspect. 117 (2009) 61–67.
[243] M. Li, B.A. Shaw, W. Zhang, E. Vásquez, S. Lin, Impact of Extremely Hot Days on Emergency Department Visits for Cardiovascular Disease among Older Adults in New York State, Int. J. Environ. Res. Public Health 16 (2019) 2119, doi:10.3390/ijerph16122119.
[244] D. Phung, Y. Guo, H.T.L. Nguyen, S. Rutherford, S. Baum, C. Chu, High temperature and risk of hospitalizations, and effect modifying potential of socio-economic conditions: A multi-province study in the tropical Mekong Delta Region, Environ. Int. 92–93 (2016) 77–86.
[245] S. Lin, M. Luo, R.J. Walker, X. Liu, S.A. Hwang, R. Chinery, Extreme high temperatures and hospital admissions for respiratory and cardiovascular diseases, Epidemiology 20 (2009) 738–746.
[246] K.L. Ebi, K.A. Exuzides, E. Lau, M. Kelsh, A. Barnston, Weather changes associated with hospitalizations for cardiovascular diseases and stroke in California, 1983–1998, Int. J. Biometeorol. 49 (2004) 48–58.
[247] J. Schwartz, J.M. Samet, J.A. Patz, Hospital admissions for heart disease: the effects of temperature and humidity, Epidemiology 15 (2004) 755–761.
[248] J. Dawson, C. Weir, F. Wright, C. Bryden, S. Aslanyan, K. Lees, et al., Associations between meteorological variables and acute stroke hospital admissions in the west of Scotland, Acta Neurol. Scand. 117 (2008) 85–89.
[249] M. Paola, A. Gabriele, D.S. Manuela, D. Daniela, M. Claudia, B. Michela, B. Annibale, H.R. Anderson, K. Klea, B. Ferran, B. Luigi, C. Ennio, F. Bertil, F. Francesco, G. G. Patrick, H. Ana, K. Ursula, M. Sylvia, P. Anna, S. Christian, S. Jordi, and A. Carlo Perucci: High Temperature and Hospitalizations for Cardiovascular and Respiratory Causes in12 European Cities, Am. J. Resp. Criti. Care Med. Vol 179 2009
[250] G. Mastrangelo, S. Hajat, E. Fadda, A. Buja, U. Fedeli, P. Spolaore, Contrasting patterns of hospital admissions and mortality during heat waves: are deaths from circulatory disease a real excess or an artifact? Med. Hypoth. 66 (2006) 1025–1028.
[251] C.J. Gronlund, A. Zanobetti, G.A. Wellenius, J.D. Schwartz, M.S. O'Neill, Vulnerability to renal, heat and respiratory hospitalizations during extreme heat among U.S. elderly, Climatic Change 136 (2016) 631–645.
[252] X. Ye, R. Wolff, W. Yu, P. Vaneckova, X. Pan, S. Tong, Ambient temperature and morbidity: a review of epidemiological evidence, Environ. Health Perspect. (2012) 19–28, doi:10.1289/ehp.1003198.
[253] K. Knowlton, M. Rotkin-Ellman, G. King, H.G. Margolis, D. Smith, G. Solomon, R. Trent, P. English, The 2006 California heat wave: impacts on hospitalizations and emergency department visits, Environ. Health Perspect. 117 (2009) 61–67 available via http://dx.doi.org/, doi:10.1289/ehp.11594.

[254] P. Michelozzi, D. D'Ippoliti, C. Marino, F. de'Denato, K. Katsouyanni, A. Analitis, A. Biggeri, M. Baccini, C.A. Perucci, B. Menne, Effect of high temperature and heat waves in European cities, Epidemiology 20 (2009) S263–S264.
[255] C. Gronlund, M. O'Neill, J. Schwartz, D. Brown, S. Brines, Heat waves, impervious surfaces, and hospital admissions among the elderly in U.S. cities, Epidemiol. 20 (2009) S145.
[256] C. Linares, J. Diaz, Impact of high temperatures on hospital admissions: comparative analysis with previous studies about mortality (Madrid), Eur. J. Public Health 18 (2008) 317–322.
[257] D. Phung, C. Chu, S. Rutherford, H.L.T. Nguyen, C.M. Do, C. Huang, Heatwave and risk of hospitalization: A multi-province study in Vietnam, Environ..Polluti. 220 (2017) 597–607.
[258] C.J. Gronlund, A. Zanobetti, J.D. Schwartz, G.A. Wellenius, M.S. O'Neill, Heat, heatwaves, and hospital admissions among the elderly in the United States, 1992–2006, Environ. Health Perspect. 122 (2014) 1187–1192, doi:10.1289/ehp.1206132.
[259] M. Oberlin, M. Tubery, V. Cances-Lauwers, M. Ecoiffier, D. Lauque, Heat-related illnesses during the 2003 heat wave in an emergency service, Emerg. Med J 27 (2010) 297–299.
[260] M. Nitschke, G.R. Tucker, P. Bi, Morbidity and mortality during heatwaves in metropolitan Adelaide, Med. J. Aust. 187 (2007) 662–665.
[261] A.L. Hansen, P. Bi, M. Nitschke, P. Ryan, D. Pisaniello, G. Tucker, The effect of heat waves on mental health in a temperate Australian city, Environ. Health Perspect. 116 (2008) 1369–1375.
[262] M.S. O'Neill, K.L. Ebi, Temperature extremes and health: impacts of climate variability and change in the United States, J. Occup. Environ. Med. 51 (2009) 13–25.
[263] K.L. Bassil, D.C. Cole, R. Moineddin, A.M. Craig, W.Y.W. Lou, B. Schwartz, E. Rea, Temporal and spatial variation of heat-related illness using 911 medical dispatch data$, Environ. Res. 109 (2009) 600–606.
[264] IPCC (Intergovernmental Panel on Climate Change), Climate change 2014: synthesis report, in: Core Writing Team, R.K. Pachauri, L.A. Meyer (Eds.), Contribution of Working Groups I, II and III to the Fifth Assessment Report of the IntergovernmentalPanel on Climate Change, Intergovernmental Panel on Climate Change, Geneva, 2014.
[265] M. Collins, R. Knutti, J. Arblaster, J.L. Dufresne, T. Fichefet, P. Friedlingstein, et al., Long-term Climate Change: Projections, Commitments and Irreversibility, in: T.F. Stocker, D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, P.M. Midgley (Eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel On Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2013, pp. 1029–1136.
[266] b IPCC, Annex I: Atlas of Global and Regional Climate Projections Supplementary Material RCP8.5, in: G.J. van Oldenborgh, M. Collins, J. Arblaster, J.H. Christensen, J. Marotzke, S.B. Power, M. Rummukainen, T. Zhou, T.F. Stocker, D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, P.M. Midgley (Eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel On Climate Change Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2013.
[267] J.A. Patz, H. Frumkin, T. Holloway, D.J. Vimont, A. Haines, Climate change:challenges and opportunities for global health, JAMA 312 (2014) 1565, doi:10.1001/jama.2014.13186.
[268] C. Huang, A.G. Barnett, X. Wang, P. Vaneckova, G. FitzGerald, S. Tong, Projecting future heat related mortality under climate change scenarios: A systematic review, Environ. Health Perspect. 119 (2011) 1681–1690 PMID: 21816703, doi:10.1289/ehp.1103456.
[269] M. Gover, Mortality during periods of excessive temperature, Public Health Rep. 53 (27) (1938) 1122–1143.
[270] D. Mills, J. Schwartz, M. Lee, M. Sarofim, R. Jones, M. Lawson, Climate change impacts on extreme temperature mortality in select metropolitan areas in the United States, Cl.im Change 131 (2015) 83–95.
[271] S. Hajat, S. Vardoulakis, C. Heaviside, B. Eggen, Climate change effects on human health: projections of temperature-related mortality for the UK during the 2020s, 2050s and 2080s, J. Epidemiol. Commun. Health 68 (2014) 641–648 PMID: 24493740, doi:10.1136/jech-2013-202449.
[272] S.C. Sheridan, M.J. Allen, C.C. Lee, L.S. Kalkstein, Future heat vulnerability in California, Part II: projecting future heat-related mortality, Clim. Change 115 (2012) 311–326.
[273] J.D. Schwartz, M. Lee, P.L. Kinney, S. Yang, D. Mills, M.C. Sarofim, et al., Projections of temperature-attributable premature deaths in 209 U.S.cities using a cluster-based Poisson approach, Environ. Health 4 (2015) 85 PMID: 26537962, doi:10.1186/s12940-015-0071-2.
[274] E.P. Petkova, J.K. Vink, R.M. Horton, A. Gasparrini, D.A. Bader, J.D. Francis, P.L. Kinney, Towards more comprehensive projections of urban heat-related mortality: estimates for New York City under multiple population, adaptation, and climate scenarios, Environ. Health Perspect. 125 (1) (2017) 47–55 PMID.
[275] E.P. Petkova, R.M. Horton, D.A. Bader, P.L. Kinney, Projected heat-related mortal- ity in the U.S. urban northeast, Int. J. Environ. Res. Public Health 10 (12) (2013) 6734–6747 PMID:.
[276] R.D. Peng, J.F. Bobb, C. Tebaldi, L. McDaniel, M.L. Bell, F. Dominici, Toward a quantitative estimate of future heat wave mortality under global climate change, Health Perspect. 119 (5) (2011) 701–706.
[277] S. Hales, R.S. Kovats, S. Lloyd, D. Campbell-Lendrum, eds. 2014. Quantitative risk ate change on selected causes of death, 030 s and 2050s. Geneva, Switzerland: World Health Organization (WHO).
[278] G. Flato, J. Marotzke, B. Abiodun, P. Braconnot, S.C. Chou, W. Collins, et al., Evaluation of climate models, in: T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, P.M. Midgley (Eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel On Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2013.
[279] IPCC, Special Report on Emissions Scenarios, in: N. Nakicenovic, R. Swart (Eds.), Special Report on Emissions Scenarios, Cambridge University Press, Cambridge, UK, 2000.
[280] R.H. Moss, J.A. Edmonds, K.A. Hibbard, M.R. Manning, S.K. Rose, D.P. van Vuuren, et al., The next generation of scenarios for climate change research and assessment, Nature 463 (2010) 747–756 PMID: 20148028, doi:10.1038/nature08823.
[281] G.C. Donaldson, R.S. Kovats, W.R. Keatinge, A.J. McMicheal, Heat- and cold related mortality and morbidity and climate change, in: R.L. Maynard (Ed.), Health Effects of Climate Change in the UK, Department of Health, London, 2001, pp. 70–80.
[282] A.J. McMichael, R. Woodruff, P. Whetton, K. Hennessy, N. Nicholls, S. Hales, A. Woodward, T. Kjellstrom, in: Human Health and Climate Change in Oceania: Risk Assessment 2002, Department of Health and Ageing, Canberra, Commonwealth of Australia, 2003, p. 128.
[283] United Nations, World Population to 2300, Department of Economic and Social Affairs Population Division, New York, 2004.
[284] United Nations, Department of Economic and Social Affairs, Population Division (2017). World Population Ageing 2017 - Highlights (ST/ESA/SER.A/397).
[285] B. Ostro, J. Barrera-GoÂmez, J. Ballester, X. Basagaña, J. Sunyer, The impact of future summer temperature on public health in Barcelona and Catalonia, Spain, Int. J. Biometeorol. 56 (2012) 1135–1144 PMID: 22370738, doi:10.1007/s00484-012-0529-7.
[286] M. Omio, S. Hajat, S. Vardoulakis, C. Heaviside, B. Eggen, Climate change effects on human health: projections of temperature-related mortality for the UK during the 2020s, 2050s and 2080s, J. Epidemiol. Commun. Health 68 (2014) 641–648 PMID: 24493740, doi:10.1136/jech-2013-202449.
[287] V.R. Barros, C.B. Field, D.J. Dokken, M.D. MastrandrealPCC, Contribution of working group II to the fifth assessment report of the Intergovernmental panel on climate change, Cambridge University Press C, UK, 2014 Edited by.
[288] M. Boeckmann, I. Rohn, Is planned adaptation to heat reducing heat-related mortality and illness? A systematic review, BMC Public Health 14 (2014) 1112 PMID: 25349109, doi:10.1186/1471-2458-14-1112.
[289] D.M. Hondula, R.C. Balling, J.K. Vanos, M. Georgescu, Rising temperatures, human health, and the role of adaptation, Curr. Clim. Change Rep. 1 (3) (2015) 144–154, doi:10.1007/s40641-015-0016-4.
[290] K. Arbuthnott, S. Hajat, C. Heaviside, S. Vardoulakis, Changes in population susceptibility to heat and cold over time: assessing adaptation to climate change, Environ. Health 15 (Suppl 1) (2016) 33.
[291] E.P. Petkova, A. Gasparrini, P.L. Kinney, Heat and mortality in New York City since the beginning of the 20th century, Epidemiology 25 (4) (2014) 554–560.
[292] J.F. Bobb, R.D. Peng, M.L. Bell, F. Dominici, Heat-related mortality and adaptation to heat in the United States, Environ. Health Perspect. 122 (8) (2014) 811–816.
[293] Y. Honda, M. Ono, M. Kabuto, Do we adapt to a new climate as the globe warms? Epidemiology 17 (6) (2006) S204, doi:10.1097/00001648-200611001-00519.
[294] N. Todd, A.-J. Valleron, Space–time covariation of mortality with temperature: a systematic study of deaths in France, 1968–2009, Environ. Health Perspect. 123 (7) (2015) 659–664 PMID: 25803836, doi:10.1289/ehp.1307771.
[295] D.O. Åström, A. Tornevi, K.L. Ebi, J. Rocklöv, B. Forsberg, Evolution of minimum mortality temperature in Stockholm, Sweden, 1901-2009, Environ. Health Perspect. 124 (6) (2016) 740–744 PMID: 26566270, doi:10.1289/ehp.1509692.
[296] K.E. Smoyer, A comparative analysis of heat waves and associated mortality in St. Louis, Missouri–1980 and 1995, Int. J. Biometeorol. 42 (1) (1998) 44–50.
[297] C. Heaviside, H. Tsangari, A. Paschalidou, S. Vardoulakis, P. Kassomenos, K.E. Georgiou, et al., Heat-related mortality in Cyprus for current and future climate scenarios, Sci. Tot. Env. 569- 570 (2016) 627–633.
[298] P. Watkiss, A. Hunt, Projection of economic impacts of climate change in sectors of Europe based on bottom up analysis: human health, Clim. Change 112 (2012) 101–126.
[299] B. Ostro, S. Rauch, S. Green, Quantifying the health impacts of future changes in temperature in California, Environ. Res. 111 (2011) 1258–1264 PMID:, 21975126, doi:10.1016/j.envres.2011.08.013.
[300] L.S. Kalkstein, K.E. Smoyer, The impact of climate-change on human health: Some international implications, Experientia 49 (1993) 969–979 PMID: 8253171.
[301] L. Kalkstein, J. Greene, An evaluation of climate/mortality relationships in large U.S. cities and the possible impacts of a climate change, Environ. Health Perspect. 105 (1997) 84–93 PMID: 9074886.
[302] S.L. Martin, S. Cakmak, C.A. Hebbern, M.L. Avramescu, N. Tremblay, Climate change and future temperature-related mortality in 15 Canadian cities, Int. J. Biometeorol. 56 (4) (2012) 605–619.

[303] T.B. Isaksen, M. Yost, E. Hom, R. Fenske, Projected health impacts of heat events inWashington State associated with climate change, Rev. Environ. Health 29 (1-2) (2014) 119–123.
[304] E.P. Petkova, D.A. Bader, G.B. Anderson, R.M. Horton, K. Knowlton, P.L. Kinney, Heat-related mortality in a warming climate: projections for 12 US cities, Int J Environ. Res. Public Health 11 (11) (2014) 11371–11383.
[305] T. Li, R.M. Horton, P.L. Kinney, Projections of seasonal patterns in temperature-related deaths for Manhattan, New York, Nat. Clim. Chang. 3 (8) (2013) 717–721.
[306] M.M.T.E. Huynen, P. Martens, Climate Change Effects on Heat- and Cold-Related Mortality in the Netherlands: A Scenario-Based Integrated Environmental Health Impact Assessment, Int. J. Environ. Res. Public Health 12 (2015) 13295–13320, doi:10.3390/ijerph121013295.
[307] B. Stone Jr, J. Vargo, P. Liu, D. Habeeb, A. DeLucia, M. Trail, et al., Avoided heat-related mortality through climate adaptation strategies in three US cities, PLoS One 9 (6) (2014) e100852.
[308] M. El-Fadel, S. Ghanimeh, Climate change and temperature rise in the Greater Beirt Area: implications on heat-related premature mortality, Reg. Environ. Chang. 13 (5) (2013) 1059–1067.
[309] S.N. Gosling, D.M. Hondula, A. Bunker, D. Ibarreta, J. Liu, X. Zhang, R. Sauerborn, Adaptation to climate change: a comparative analysis of modeling methods for heat-related mortality, Environ. Health Perspect. (2017) 087008-1.
[310] United Nations 2014. World Urbanization Prospects: The 2014 Revision, Highlights. United Nations Department of Economic and Social Affairs, Population Division (ST/ESA/SER.A/352).
[311] K. Jenkins, J. Hall, V. Glenis, C. Kilsby, M. McCarthy, C. Goodess, et al. 2014. Probabilistic spatial risk assessment of heat impacts and adaptations for London. Clim. Change 124:105–117.