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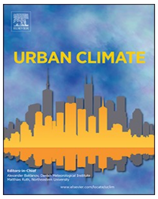

Cold-related mortality in three European metropolitan areas: Athens, Lisbon and London. Implications for health promotion

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ABSTRACT

The aim of this study is to estimate the mortality burden attributable to low temperature in Athens, Lisbon and London from 2002 to 2011 and to discuss related inequalities in socioeconomic conditions. We address a lack of quantitative estimates of cold-related mortality, particularly for the cities of Lisbon and Athens. To estimate the mortality burden attributable to low temperature, time-series regression analyses were carried out on daily mortality with respect to daily mean temperature for the three metropolitan areas to estimate the relative risk associated with a decrease in temperature. The number of cold-related deaths was estimated using the population Attributable Fraction. Lisbon presents higher relative risk (RR) than London and Athens; the RR for Athens is lower than for London. The coldrelated death rate is higher in Lisbon (53.2 deaths per 100,000 inhabitants) than in Athens (32.6) and London (37.6). The spatial heterogeneity between the three metropolitan areas in the risk estimates and cold-related mortality may result from the significant disparities in the built environment. Adequate public health planning and preventive measures in the built environment may help reduce cold-related deaths and decrease vulnerability to cold in European cities.

1. Introduction

The effect of cold weather is currently an important public health concern, considered responsible for a significant mortality and morbidity burden (Analitis et al., 2008; Gasparrini et al., 2015). Studies assessing the effect of climate change on temperature-related mortality indicate that the effects of cold on health are projected to decrease while the heat effects are increasing (Gasparrini et al., 2017; Vardoulakis et al., 2014). Nonetheless, in some locations the number of cold related deaths is still expected to remain significantly high and even higher than heat related deaths (Gasparrini et al., 2017).

The relationship between temperature and mortality has previously been described as having a non-linear shape, with increasing numbers of deaths associated with high and low temperatures. Despite the general relationship being common to several locations worldwide, the magnitude of the increase and the shape of the temperature-mortality curve can vary significantly depending on local conditions and the extent of population vulnerability (Analitis et al., 2008; Curriero et al., 2002; De' Donato et al., 2015; Gasparrini

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et al., 2015; Vardoulakis et al., 2014).

In Europe, most temperature related deaths are associated with cold rather than heat (Braga et al., 2002; Hajat et al., 2014; Rau, 2004) and, despite the climate change trend, the mortality attributable to low temperatures is likely to remain higher than the one related to heat (Vardoulakis et al., 2014). Moreover, most of the temperature-related mortality burden has been attributed to relatively cold but not extreme cold temperatures (Gasparrini et al., 2015).

Studies comparing European countries (Fowler et al., 2015; Healy, 2003) or cities (Analitis et al., 2008) report that the vulnerability to cold tends to be higher in regions where the winters are milder. Significant spatial disparities in cold-related mortality are not only found when looking across cities, regions and countries, but also among specific population groups (Conlon et al., 2011).

The heterogeneity in the spatial pattern of vulnerability to cold is a reflection of the complex combination of built environment and physiological, social and cultural adaptations to the effects of adverse temperatures (Hales et al., 2012). Features of the place where people live (e.g. housing quality, urban design) as well as socioeconomic characteristics (e.g. education, income) (Almendra et al., 2017; Anderson and Bell, 2012; Healy, 2003; Marí-Dell'Olmo et al., 2018; O'Neill et al., 2003) may be important modifying factors of the relationship between temperature and mortality, thus representing significant explanatory factors for the geographical disparities concerning vulnerability to cold. Other environmental, epidemiological (e.g. air pollution, influenza and other viral epidemics) and individual (e.g. behaviours, adaptation ability) factors with important geographical disparities may also contribute to the spatial variations found in cold-related mortality (Analitis et al., 2008; Conlon et al., 2011; Vestergaard et al., 2017).

Although hypothermia may be considered the main direct cause of death attributable to exposure to cold, mortality from this cause is residual, and most cold-related mortality is associated with diseases of the circulatory and respiratory system (Rau, 2004). In addition, low temperature has been considered an important risk factor for several other diseases, such as diabetes (Li et al., 2014) or external causes (Orru and Åström, 2017) suggesting the existence of multiple biological pathways on which cold affects human health (Analitis et al., 2008).

Comparisons of the health impacts of cold in different regions with different socioeconomic, environmental and climatic conditions can contribute to the identification of risk factors to be addressed in the planning of suitable public health interventions (Marí-Dell'Olmo et al., 2018; Vardoulakis et al., 2014). Thus, the aim of this paper is to estimate the mortality burden attributable to low temperature and to discuss socioeconomic conditions and environmental inequalities between the three metropolitan areas. For this reason, we have selected Athens, Lisbon and London metropolitan areas, with contrasting climatic, socioeconomic and built environment characteristics in Southern, Western and Northern Europe.

Moreover, this study addresses the lack of quantitative estimates of cold-related mortality, particularly for Lisbon and Athens, where the mortality burden of cold has not been previously estimated.

2. Data and methods

2.1. Study areas

The climate of the Lisbon and Athens metropolitan areas is classified as Hot-summer Mediterranean climate according to the Koppen classification, characterized by warm and dry summers and mild and wet winters. The London metropolitan area has a Temperate Oceanic climate, with mild summers and cold winters (Rubel and Kottek, 2010).

Comparing the three metropolitan areas, London has a larger population (population in 2011: Athens-3.1 million; Lisbon-2.8 million; London-8.2 million). In the three metropolitan areas, higher population density is found in the central municipalities and tends to decrease as the distance from the city centre increases (Fig. 1); Athens has the highest population density with 7, 669 inhabitants per square km (Table 1). Similarly, the more central municipalities also have a higher ageing index (the ratio between population aged 65 and above to the population aged between 0 and 14 years old, multiplied by 100); Athens and Lisbon have, on average, an ageing index of 1.3 and 1.2, respectively, while London is near 0.6. Education levels are highest in Athens and lowest in Lisbon, with, on average, 75.0% and 40,3% of inhabitants aged 25–64 with upper secondary or tertiary education attainment, respectively; London's average rate is 55.5%. The percentage of households with central heating is higher in London, where near 97% of households have central heating, 89% in Athens, while in Lisbon that value is lower than 10% and in no municipality does the value reach 20%.

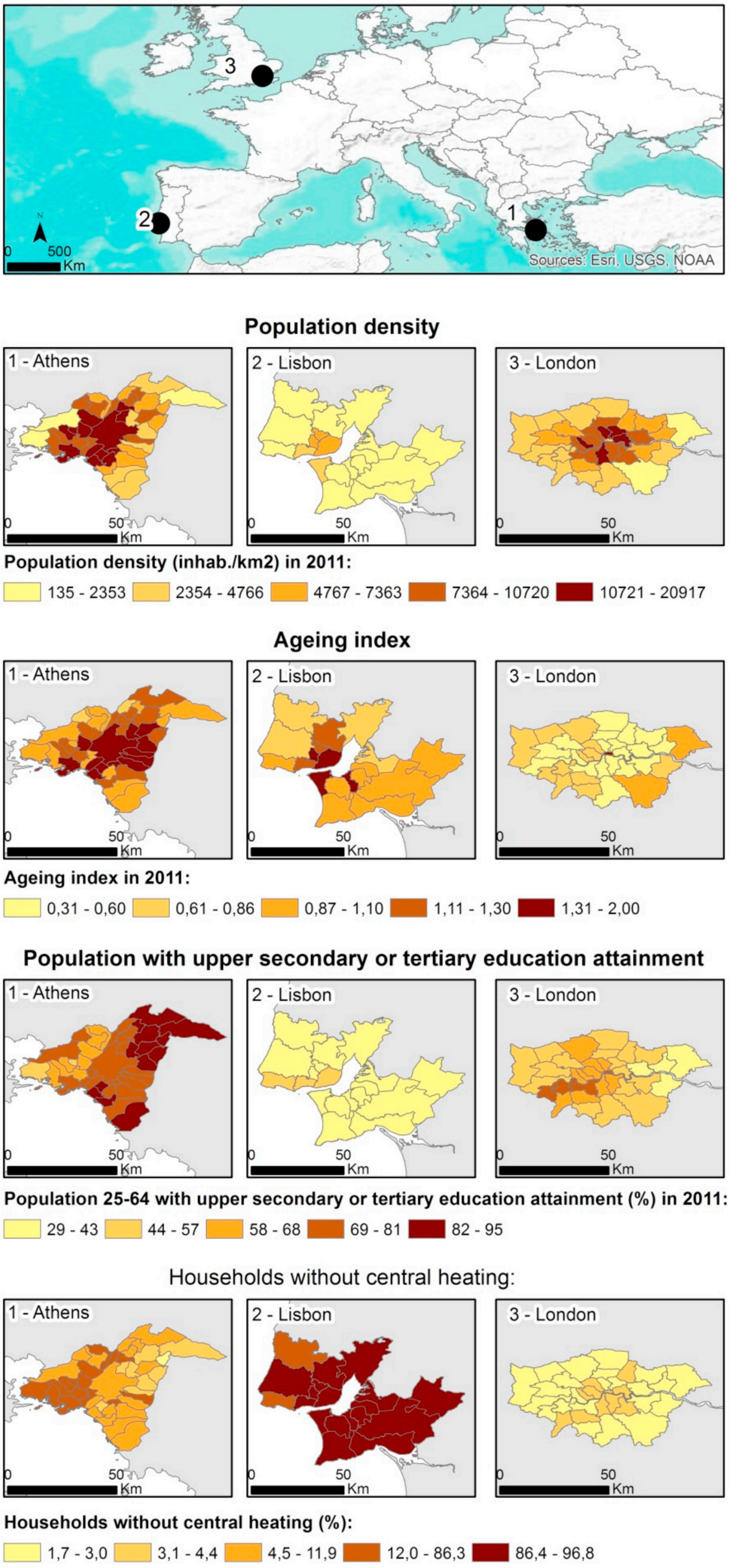
2.2. Mortality, meteorological and air quality data

To estimate the mortality burden attributable to low temperature, 10 years of daily data (2002 − 2011) was collected from the Athens, Lisbon and London metropolitan areas (Table 2). One meteorological station with good data coverage was selected from each metropolitan area to collect the daily mean temperature and relative humidity (Athens- Thision; Lisbon- Gago Coutinho Meteorological Station; London-Heathrow Station). Hourly concentrations of particulate matter with aerodynamic diameter $< 10\,\mu m$ (PM_{10}) were collected from urban background monitoring stations, with at least 75% data coverage, and averaged into daily values for each city.

Athens had the highest mean daily temperature (18.7 °C), and also the widest temperature range, with values ranging from −6.7 °C to 36.4 °C (first quartile of the mean temperature: 12.9 °C and third quartile: 25.2 °C) (Table 3). The lowest mean temperature was recorded in London (11.6 °C). Lisbon has the narrowest temperature range, where 50% of days have temperatures between 12.9 °C and 20.5 °C.

2.3. Health impact assessment

The estimation of cold-related deaths, between 2002 and 2011, was carried out in three stages: a) assessment of the relationship between daily mean temperature and daily mortality and identification of the temperature thresholds for health effects; b) estimation



(caption on next page)

Fig. 1. Location and characterization of the metropolitan areas.
Source: Eurohealthy data platform (available at https://eurohealthydata.uc.pt for authorised users).

Table 1
Characterization of the metropolitan areas.

Indicators (2011)	Athens	Lisbon	London
Population density (inhab/km^2)	7669	942	5145
Ageing index	1.3	1.2	0.6
Population with upper secondary or tertiary education attainment (%)	75.5	40.3	55.0
Households without central heating (%)	10.7	91.3	2.8

Source: National Statistical Service, Statistics Portugal, Office for National Statistics.

Table 2
Data collected and sources.

Variable	Source		
	Athens	Lisbon	London
Deaths by all causes (n.°)	Hellenic Statistical Authority (EL. STAT)	Portuguese National Statistics Institute	Office for National Statistics
Average temperature (°C)	National Observatory of Athens	National Climatic Data Centre Online	National Climatic Data Centre Online
Relative humidity (%)	National Observatory of Athens	National Climatic Data Centre Online	National Climatic Data Centre Online
PM_{10} (μg/m^3)	Ministry of Environment & Energy	Portuguese Environment Agency	UK Department for Environment Food and Rural Affairs (DEFRA)

Table 3
Descriptive statistics of mortality, meteorological and air quality data.

Variable	Source								
	Athens			Lisbon			London		
	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
Daily deaths by all causes (n.°)	40	79.5	127	38	70.3	154	85	141.9	282
Mean daily temp (°C)	−6.7	18.7	36.4	3.9	16.8	32.3	−3.2	11.6	28.3
Mean daily relative humidity (%)	20.7	64.2	100.0	20.5	69.7	100.0	36.1	74.3	100.0
Mean daily PM_{10} concentrations (μg/m^3)	4.9	31.5	362.5	6.4	28.2	187.4	5.8	24.7	90.4

of the relative risks associated with a temperature decrease below the cold threshold; c) quantification of cold-related deaths.

To identify the temperature thresholds of the three metropolitan areas, individual quasi-Poison time series regression analysis was applied using the R statistical software with the DLNM and MGCV packages, as in previous studies (Antunes et al., 2017; Gasparrini et al., 2015).

The association between daily deaths and temperature was modelled by applying a distributed lag non-linear models: the lag-response curve was modelled with a natural cubic B-spline with an intercept and three internal knots placed at equally spaced values in the log scale. Based on previous studies, we considered a lag period of 28 days for cold effects on mortality (Bhaskaran et al., 2010; Vardoulakis et al., 2014); the exposure-response relationship was modelled with a quadratic B-spline with three internal knots placed at the 10th, 75th, and 90th percentiles. Potential confounders of the relationship between daily deaths and outdoor temperature, such as relative humidity, PM_{10}, day of the week and time, were considered in the model. Relative humidity and time were modelled through natural cubic splines with 3 and 60 (6 per year) degrees of freedom (df), respectively. PM_{10} concentration was modelled linearly. Day of the week was added to the model using six indicator terms. The models parameters were selected based on a sensitivity analysis where preference was given to the lower Generalized Cross Validation (GCV) values (summary statistic for Athens model: GCV = 1.221, Deviance explained = 41.8%; Lisbon model: GCV = 1.1305, Deviance explained = 57.9%; London model: GCV = 1.1233, Deviance explained = 66.2%) (see supplementary material).

Through the model previously presented, it was possible to assess the relationship between temperature and mortality (RR and CI) and, therefore, to identify the temperature below which mortality increases significantly, when compared to the median temperature for each metropolitan area (both RR and CI are higher than 1). These temperature values were considered as cold temperature thresholds for health effects.

On the second stage, linear threshold models were applied to estimate the relative risk associated with the temperature decrease below the cold threshold temperature. The same modelling options were applied as for the previous stage.

The number of cold-related deaths was estimated using the population Attributable Fraction (AF) (Steenland and Armstrong, 2006). The attributable fraction is as follows:

$$AF = \frac{RR^{\Delta T} - 1}{RR^{\Delta T}}$$

Where ΔT corresponds to the daily mean temperatures below the metropolitan area cold threshold, and RR is the relative risk of mortality derived from the linear threshold models.

3. Results

Between 2002 and 2011, there were around 290,000 deaths in Athens, 257,000 in Lisbon and 518,000 in London, resulting in an average daily death rate for the 10-year period of 2.5, 2.5 and 1.8 deaths per 100,000 inhabitants, respectively.

The assessment of the relationship between daily mean temperature and daily mortality allowed for the identification of cold thresholds of 17.0 °C in Athens; 16.5 °C in Lisbon; and 11.5 °C in London (Fig. 2).

Table 4 shows the cold temperature threshold, RR in all-cause mortality per 1 °C decrease in daily mean temperature below the threshold, the cold-related deaths per 100,000 inhabitants and the percentage of all-cause mortality attributable to cold. In all metropolitan areas, there was a significant increased risk in mortality associated with cold exposure (RR $>$ 1). The mortality increase per 1 °C drop in temperature below the cold threshold was 1.6% (95% CI 1.0 to 2.2) in Athens, 3.0% (95% CI 2.1 to 3.9) in Lisbon and 2.6% (95% CI 2.2 to 3.0%) in London.

The mortality burden of cold, expressed here by the cold-related death rate, is higher in Lisbon (53.2 deaths per 100,000 inhab.), followed by London (37.6 deaths per 100,000 inhab.) and Athens (32.6 deaths per 100,000 inhab.). The cold-attributable mortality fraction was 5.7% (95% CI 4.2 to 7.2) in Lisbon, 5.6% (95% CI 4.7 to 6.4) in London and 3.6 (95% CI 2.2 to 4.9) in Athens.

4. Discussion

This study estimates the mortality burden attributable to low temperature in Athens, Lisbon and London from 2002 to 2011. The three metropolitan areas have different climates and present strong disparities in terms of population density, ageing index, education attainment and household central heating availability. The results indicate that London (11.5 °C) has the lowest temperature threshold while in Lisbon and Athens it is very similar, and around 5 degrees higher. Lisbon has higher relative risk than London and Athens (but with overlapping CIs), the RR for Athens is lower than for London. The cold-related death rate is highest in Lisbon.

The contrast in cold-related mortality between the metropolitan areas reinforces the findings from previous studies which compare the vulnerability to cold among cities from different climates, observing that people living in places with milder winters are more vulnerable to cold weather than those living in places with colder winters (Analitis et al., 2008; Eurowinter, 1997). These results highlight the impact of factors relating to local conditions in the place of residence, as this contrast may be a consequence of different socioeconomic conditions, behaviour and physiological acclimatization, which exacerbate exposure to cold and its consequences (Marí-Dell'Olmo et al., 2018; Medina-Ramón and Schwartz, 2007; Mitsakou et al., 2019; Rodopoulou et al., 2015).

Cold-related mortality is generally higher for older age groups (Hajat et al., 2014), as the elderly are more vulnerable than the general population to harmful weather conditions due to behavioural factors, biological and social vulnerability. According to Carter et al. (2016), in a study conducted in Finland, Norway and Sweden, with increasing age there is a progressive loss of psychological resilience and deterioration of health, adoption of less healthy lifestyles and a tendency towards loneliness and social isolation. Results from the Eurowinter (1997) show that in relatively warm countries, the elderly often fail to wear protective clothing and do not remain indoors, and so are exposed to cold weather conditions outdoors. In addition, Sheridan (2007), identified (in four North American Cities) that in elderly populations, knowledge of the activities recommended to be undertaken to help mitigate the effects of the heat, was limited, despite the diversity of information available; Tod et al. (2012) indicate that knowledge and awareness of safe temperatures, the health impact of cold as well as how to use heating efficiently were low across the elder population studied and that the values and beliefs of the individuals can interact with the contextual factors and barriers in such a way that they often end up being cold at home. Therefore, the ageing index gradient between London (0.6), Athens (1.3) and Lisbon (1.1) suggests disparities with respect to the biological dimension of the vulnerability to cold among the populations of the three metropolitan areas.

From the socioeconomic indicators presented here, Lisbon presents the lowest education levels (population with upper secondary or tertiary education), and has central heating in $<$ 10% in metropolitan households (according to Portuguese national statistics, 60% of households use mobile heating devices, such as electric heaters or gas heaters, as these are the most frequently available systems).

Less educated individuals have been reported as being more vulnerable to cold weather (O'Neill et al., 2003) as education level may be a predictor of low socioeconomic status and can influence the access to adequate housing conditions (e.g. central heating, thermal insulation) or the ability to keep the houses at a comfortable temperature (Marí-Dell'Olmo et al., 2018; Marmot Review Team, 2011).

The effects of housing conditions on cold-related mortality have been highlighted by several authors, stating that the inability to keep the house at a comfortable temperature increases one's vulnerability to cold (Dear and McMichael, 2011; Rudge and Gilchrist, 2007). The difficulty of keeping housing at comfortable temperatures can be influenced by the lack of a heating system (e.g. households without central heating), the thermal response of the building (e.g. existence of doubled glazed windows) or the behaviour of the household (e.g. use of heating devices) (Bøkenes et al., 2011; Vasconcelos et al., 2013).

The inability to keep one's house at an adequate temperature due to economic reasons is referred to as Fuel Poverty, and it can be

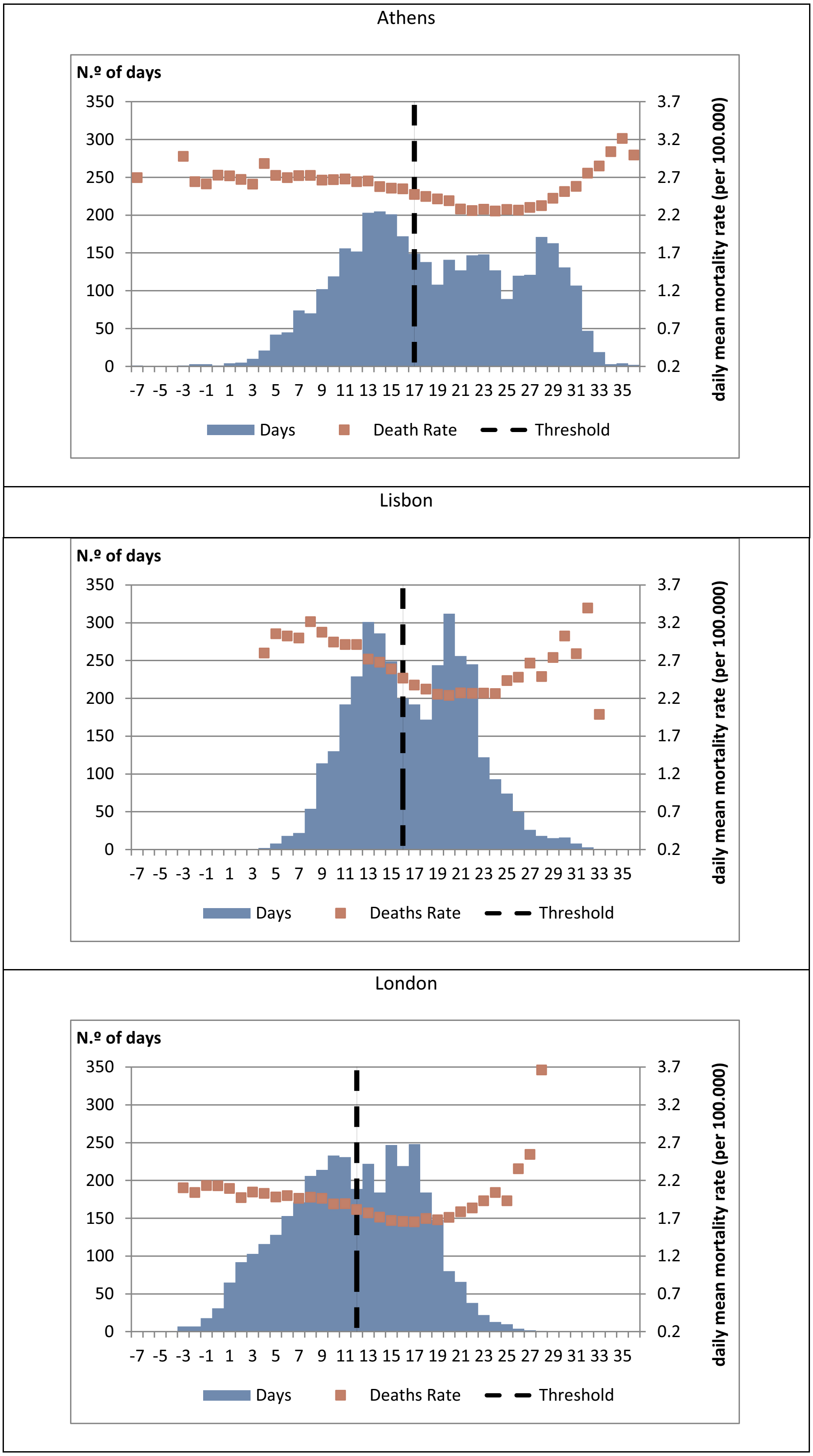


Fig. 2. Mean daily death rate, number of days by daily mean temperature and cold thresholds in Athens, Lisbon and London metropolitan areas.

Table 4
Estimated cold temperature threshold, RRs, cold related deaths and Fraction of all-cause mortality attributable to cold.

Metropolitan area	Cold temperature threshold (°C)	RR (CI)	Cold-related deaths rate (per 100,000 inhab.) (CI)	Fraction of all-cause mortality attributable to cold (%)
Athens	17.0	1.02 (1.01–1.02)	32.6 (20.2–44.6)	3.6 (2.2–4.9)
Lisbon	16.5	1.03 (1.02–1.04)	53.2 (38.9–67.0)	5.7 (4.2–7.2)
London	11.5	1.03 (1.02–1.03)	37.6 (31. 8–43.2)	5.6 (4.7–6.4)

related to excessive energy consumption in terms of household income or the need to self-ration to avoid high energy consumption costs (Boardman, 2013). Living in cold homes and experiencing fuel poverty has been linked to adverse effects on physical and mental health, as well as to negative impacts on social well-being (Anderson et al., 2012). Moreover, socioeconomic conditions such as social isolation, low income and stress are associated with fuel poverty and may also contribute to the aggravation of one's health status (Marmot Review Team, 2011).

In line with previous studies, the results presented here show that the harmful effects of cold on mortality can be identified at relatively mild temperatures, which can be experienced outside the typical definition of the Northern Hemisphere winter (December to February). Moreover, in previous studies, it was observed that the mortality related to the effect of extreme temperature was substantially less than the mortality attributable to milder but non-optimum weather (Gasparrini et al., 2015) and extreme cold days are responsible for only a small fraction of the cold-related mortality burden (Arbuthnott et al., 2018), as these events are also less frequent.

Although the direct comparison with previous studies is limited by different methodological techniques, the results presented here are still comparable to a certain extent. The assessment of the vulnerability to cold through the estimation of temperature thresholds, the RR associated to cold or the measurement of the mortality burden attributable to low temperatures in London has been assessed by several authors. Vardoulakis et al. (2014) and Hajat et al. (2014) estimated the RR associated with a 1-degree decrease to be around 2% and associated with 60.5 and 77.3 cold-related deaths per 100,000 inhabitants, respectively. The difference of the estimates between these results and the figures presented in this study may be related to different approaches addressing the cold temperature thresholds (in this study the threshold was almost two degrees lower: 11.5 °C), and the different periods under analysis.

Previous studies have addressed the influence of extreme cold on mortality (Antunes et al., 2017), but temperature thresholds, the quantification of the mortality increase for each degree and the cold-related mortality are estimated here for the first time, as far as the authors are aware. According to Antunes et al. (2017), in Lisbon, mortality by all causes increased significantly with low temperatures (3.84% per 1 °C drop), identifying cold as an important public health problem.

In 1997, the Eurowinter group estimated that between 1988 and 1992 the increase in all-cause mortality per 1 °C drop in temperature below 18 °C in Athens was 2.15% (Keatinge, 1997). No further studies assessing the mortality burden of cold in Athens have been conducted.

The impacts of cold weather are predictable and can be minimized (Hajat et al., 2016) with the implementation of well-designed plans or public health measures. The plans implemented to reduce the vulnerability to cold weather or to minimize the effects of cold in each city can also be considered as a significant factor potentially modifying vulnerability to cold weather (Conlon et al., 2011; Hajat et al., 2016; Monteiro et al., 2013).

The first Portuguese Contingency Seasonal Health Plan – Winter Module was implemented in 2015, and therefore did not influence the results presented in this study. It aims to minimize the negative effects of extreme cold and respiratory infections. The plan is active from November to March and in periods of extreme cold, and it includes a set of actions involving health professionals, civil protection departments and local communities (Direção-Geral da Saúde, 2017). From the 2015 edition of the plan (Direção-Geral da Saúde, 2015) to the one from 2017 (Direção-Geral da Saúde, 2017) an increasing awareness of the health consequences of cold weather throughout winter and the need for preventive measures is present. Despite this, the latest version of the plan still does not include a prevention phase throughout the year. Even though there is a significant health impact associated with extreme cold (Antunes et al., 2017; Monteiro et al., 2013), the results of this study show that in Lisbon cold-related deaths already occur at much milder temperatures (the threshold is near 16 °C) even outside the winter season, and this highlights the importance of preparedness measures throughout the year (e.g. identification of vulnerable groups, risk communication, housing interventions) to improve the ability to keep a comfortable thermal environment and to reduce the risks to health from cold weather.

The Cold Weather Plan for England was introduced in 2011; it aims to prevent the major avoidable effects on health during periods of cold weather by raising public awareness and enabling appropriate responses (Public Health England, 2017). The plan includes five different levels of action, from year-round planning for cold weather, winter and severe cold weather action to a major national emergency. Each alert level triggers a series of appropriate actions from the national level (e.g. NHS England, Public Health England, Met Office) through social care organizations and professionals, communities and individuals. According to Hajat et al. (2016) when assessing the development of Public Health England's Cold Weather Plan, the all-year planning for cold weather (level 0: year round planning) and the winter preparedness phase (level 1: winter preparedness and action) are crucial components in combination with the alerts. Greece, for its part, does not have a specific national plan to tackle the effects of cold on health.

5. Limitations of this work

Temperature–mortality relationships depend to some extent on the statistical methods applied to derive them, such as the lag structures used and controlling variables. Despite the importance of seasonal influenza to explain the relationship between temperature and health, the results of this study are not adjusted by this factor due to the unavailability of comparable influenza data among the three metropolitan areas. Although adjustment for PM10 was carried out, other air pollutants with significant influence on temperature-related mortality were not addressed due to data availability limitations; nonetheless, in previous work, Hajat et al. (2014) report that controlling for daily particulate matter $\leq 10\,\mu$m (PM10) and ozone (O3) in the London region did not change the estimated RR for cold. Although the impacts of sudden changes in temperature and weather conditions on mortality have been identified in previous studies (Kalkstein and Davis, 1989; Robinson, 2001), these were not addressed in this study.

This research compares the mortality burden attributable to low temperature in three metropolitan areas, the socioeconomic characterisation of the cities did not address cost of living disparities and its impacts (e.g. house price-to-income ratio or consumer price levels –to-income ratios) or other individual characteristics (e.g. behaviours). It is likely that education level and income are major factors determining housing quality and heating use in homes, and that there are differences in the cost of living between the cities studied.

6. Conclusions

This study assessed cold-related mortality in Athens, Lisbon and London over a 10-year period from 2002 to 2011. The results highlight the mortality burden attributable to cold as an important public health concern across these three cities to varying degrees. The cold-related mortality burden per population size was higher in Lisbon than in London and Athens over the study period; the spatial heterogeneity in risk estimates and cold-related mortality between the three metropolitan areas may have resulted from disparities in physiological, behavioural and built environment factors. The low prevalence of central heating in Lisbon is likely to have contributed to the higher cold mortality risk in this city compared to Athens and London. Adequate public health planning, communication and preventive measures in the built environment may reduce cold-related deaths and decrease vulnerability to cold in European cities.

Declaration of Competing Interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.uclim.2019.100532.

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