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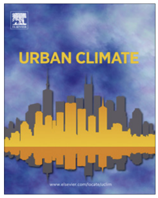

Mean radiant temperature – A predictor of heat related mortality

Sofia Thorsson [a,*], Joacim Rocklöv [b], Janina Konarska [a], Fredrik Lindberg [a], Björn Holmer [a], Bénédicte Dousset [c], David Rayner [a]

[a] *Department of Earth Sciences, University of Gothenburg, Gothenburg, Sweden*
[b] *Department of Public Health and Clinical Medicine, Epidemiology and Global Health, Umeå University, Umeå, Sweden*
[c] *Hawaii Institute of Geophysics and Planetology, University of Hawaii, Honolulu, HI, USA*

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ABSTRACT

Health studies have repeatedly used air temperature (T_a), sometimes adjusted for humidity, when analyzing the impact of weather on mortality. The aim of this study is to highlight the importance of mean radiant temperature (T_{mrt}) and its impact on heat related mortality. T_{mrt} is an essential meteorological parameter that influences the thermal comfort (heat load) of humans. It is useful when assessing the impact of weather, especially heat, on people's health. T_{mrt} is directly influenced by urban geometry and surface material, which also makes it a good measure to identify urban hot spots. The performance of models using T_a and T_{mrt} for daily mortality is compared for Stockholm County, Sweden. It is demonstrated that T_{mrt} models fit heat related mortality better than T_a models, which implies that health studies should consider using T_{mrt} rather than T_a. The use of T_{mrt} models allows us to determine more accurate thresholds for increased risks of heat related mortality, and thus to better identify adverse weather conditions and heat prone urban geometries. Such information is needed to implement heat-warning systems and mitigate harmful effects of heat stress.

* Corresponding author. Tel.: +46 31 7864733.
E-mail address: sofia.thorsson@gvc.gu.se (S. Thorsson).

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1. Introduction

Intense heat waves cause severe and devastating mortality and morbidity, especially in urban areas, due to local climate conditions (Jendritzky and Grätz, 1999; Pascal et al., 2006; Fouillet et al., 2003; Dousset et al., 2011; Gabriel and Endlicher, 2011). The elderly are most affected by risk factors related to health conditions or social environment, such as pre-existing diseases or social isolation (Kovats and Hajat, 2008). For example, the 2003 heat wave in Europe caused an estimated 15,000 excess deaths in France, of which 70% were in the age range of 75–94, with the largest part in Paris (Pirard et al., 2005; Le Tertre et al., 2006). It is predicted that cities will experience an increase in year-to-year variability of summer temperatures over the next century as a result of anthropogenic climate change, leading to a significant augmentation in the occurrence, intensity and duration of heat waves, particularly at mid-latitudes (Schär et al., 2004; Meehl and Tebaldi, 2004). The potential effects of climate change, together with the ageing of the population and on-going urbanization are expected to exacerbate the threats posed by heat stress in the future (McMichael et al., 2006; Oudin Åström et al., 2013). As a result, it is important to improve our understanding of the impact of weather on health and identify adaptation measures for societies to better cope with heat stress.

Heat exposure can generate heat stress as the human body attempts to retain normal temperature through sweating, often resulting in electrolyte imbalance, dehydration, and sometimes in heat stroke (Parsons, 2003). A decrease in temperature at night-time, which corresponds to lower physiological stress, allows for recovery. However, long episodes of heat exposure that exacerbate pre-existing cardiovascular and respiratory diseases, contribute to heat exhaustion, possibly leading to death, especially among the elderly (Kovats and Hajat, 2008). The time lag between exposure, stress, and death may range anywhere from a few hours to a few days (Kovats and Hajat, 2008; Rocklöv and Forsberg, 2008; Baccini et al., 2008). Temperature related mortality has increased considerably compared to "normal mortality levels" even on days that are not considered "heat waves" (Hajat, 2006; Rocklöv et al., 2011; Anderson and Bell, 2011). A few studies have differentiated the effects of heat intensity from those of heat wave duration and demonstrated contrasting impacts on population groups (Rocklöv et al., 2012; Barnett et al., 2012). Besides the elderly and people living in social isolation, individuals afflicted by pre-existing diseases or taking specific drugs or medications that affect perception or regulation of heat in the body are especially vulnerable to heat stress (Kovats and Hajat, 2008; Åström et al., 2011; Bouchama et al., 2007; Hajat et al., 2010).

One of the most important meteorological parameters governing the human energy balance and thermal comfort (heat load) is the mean radiant temperature, T_{mrt} (Mayer and Höppe, 1987; Ali-Toudert and Mayer, 2007). The T_{mrt} is defined as the 'uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body equals the radiant heat transfer in the actual non-uniform enclosure' (ASHRAE, 2001). The radiant (short-wave and long-wave) heat exchange between a person and their surroundings can be monitored or modelled. The most accurate way to monitor T_{mrt} is by measurements of short-wave and long-wave radiation flux densities from the three-dimensional surroundings of humans (east, west, north and south, upward and downward) and the calculation of angular factors (i.e. proportion of radiation received by the human body in each direction) (Höppe, 1992; Thorsson et al., 2007). If the radiation flux densities and angular factors are known, the T_{mrt} (°C) can be calculated using the Stefan–Boltzmann law:

$$T_{mrt} = \sqrt[4]{(S_{str}/(\varepsilon_p \sigma))} - 273.15 \tag{1}$$

with

$$S_{str} = \alpha_k \sum_{i=1}^{6} K_i F_i + \alpha_l \sum_{i=1}^{6} L_i F_i \tag{2}$$

where: S_{str} (Wm^{-2}) is the total radiant flux density absorbed by body; K_i and L_i are, respectively the short-wave and long-wave radiation fluxes densities in the six directions (i = 6); F_i is the angular factor (i = 6); α_k and α_l are, respectively the absorption coefficients for short-wave and long-wave radiation; ε_p is the emissivity of the human body and σ is the Stefan–Boltzmann constant.

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