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OPINION

Perception of heat stress in cities and measures for health protection

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The topic of urban heat has become a global issue and is an increasingly widely recognised research priority given its well-identified impacts upon urban areas and the health of their inhabitants [1, 2]. In response to these impacts, many practical and policy actions have already been undertaken at different levels and scales [3, 4]. Indeed, the negative effects on urban infrastructure and human health and wellbeing (including increases in morbidity and mortality rates and altered labour patterns) have not only initiated political action, but have created significant socioeconomic pressures in cities, stimulating responses in civil society [2–4]. These societal movements have been catalysed and propagated by a departure from focusing solely on mitigation, and the acceptance that there is a growing need for concrete regional and local action for climate change adaptation within urban fabrics [2, 5, 6]. A clear example of this shift in paradigm that has been maturing since the turn of the century can be found in the creation of Heat Action Plans (HAPs) that epitomise the development of cross-sector heat management efforts, especially in cities [2, 5]. A key part of these evolving frameworks is deciphering which actions and measures can be best applied in specific contexts, and through which methods [2]. As a consequence, looking forwards into an era that will be further jeopardised by such growing threats to urban wellbeing and safety, there are numerous issues that require urgent discussion, research, and optimisation. Here we reflect further on key priorities.

Heat as experienced by the human body is not equal to air temperature [7]. For the effective quantification of heat [8], and more specifically its holistic impact upon the human biometeorological system, a range of thermal indices have been developed [7, 9]. Thermal indices are based on empirical and statistical approaches that incorporate the principles of human thermo-physiology [7, 10]. Close to 200 indices have thus far been developed by the international community in its efforts to quantify the effects of heat and cold [2–4]. More attention has been paid to urban heat rather than cold because of the challenges brough about by the Urban Heat Island (UHI) effect, a consequence of the continuous densification of urban centres, and interactions with climate change [6, 10]. These indices, many of them in the form of a temperature equivalent, have been used in the last two-to-three decades within numerous geographic contexts, climatic typologies, and morphological contexts around the world [2, 11].

Thermal indices differ in the range of climatic input, and the weighting accorded to each in the quest to capture the complexity of biometeorological environments such as those found in cities [12]. Dry heat can be managed more easily by the human body than heat that occurs in combination with high atmospheric moisture levels. In addition, other atmospheric factors, such as pollutants from anthropogenic or biological sources, can also play an important role.

These can include high ozone levels, pollen, pyrogenic particles and other pollutants [13]. Synergistic and antagonistic interactions between such factors shape the ultimate impacts on public health, and we must therefore prioritise research that further elucidates these interactions [2, 14]. In addition, thermo-physiological responses can also be considered within thermal indices, and are mostly focused on activity patterns, clothing and behaviour [7, 11]. There are challenges in capturing the full diversity of human behaviours, which may be influenced by cultural, financial, religious and other considerations. There are also factors associated with age groups, health status, dietary habits, and gender differences [13]. There are many research questions to be addressed around how these factors affect the perception and experience of urban heat, and how they can be incorporated into assessment methodologies and tactics. It is arguably here where the physiological approach must, to some extent, be combined with psychological dimensions of thermal comfort whilst retaining the principles of human biometeorology as a common 'grounding mechanism' [2, 13].

When it comes to heat quantification, thresholds are frequently utilised. One threshold that is commonly used to identify periods of excessive heat is based on the maximum daytime air temperature (frequently that of $Ta >= 30^{\circ}C$). Nevertheless, and as mentioned above, heat as experienced by the human body cannot be described by a single parameter, or by isolated factors. Even if one factor remains constant, others will change through different periods of the day or seasons of the year, altering the overall impact on the human body. Temporal periodicity also plays an integral role in the relationship between heat and the human biometeorological system. In other words, exposure to heat can be both progressive and cumulative; physiological (or psychological) impacts on humans do not only take place instantaneously. The human body requires time to recover from heat stress, and chronic exposure to heat stress may result in very different impacts from those associated with acute exposure. These effects have been seen clearly in large-scale, long-lasting heatwave events such as those of 1995 in Chicago and in 2003 in Europe.

To a certain extent, under the right conditions, humans can to adapt to a new situation through changes in behavioural patterns and practices. There is also some biological scope for thermo-physiological adaptation to altered temperature regimes, but opportunities for such adaptation to extreme heat are more complex and more limited than for cold. There is thus less possibility of 'escape' from extreme heat without appropriate behavioural and technological interventions, which must take into account both instantaneous and cumulative exposure. A topic that is still maturing within the literature and which needs further research is the significance of transitions between indoor and outdoor environments. This includes how indoor-outdoor movements are able (or not able) to facilitate the recovery of the human biometeorological system after heat exposure. Furthermore, investigation of these recovery patterns extends to nocturnal sleep patterns and associated health impacts.

Continuing this line of reasoning, we must develop thresholds that include thermo-physiological assessments/responses, and appropriate adjustments for different seasons. Such efforts must be grounded upon solid scientific foundations based on extensive and long-term data (with multiple temporal and spatial resolutions for different suitable purposes) and statistical techniques, and informed by relevant health data [15]. This could significantly increase the potential for the application of thresholds and indicators in decision-making contexts. Recently developed early warning systems have been informed by the statistical relationships between meteorological, biometeorological and epidemiological data [15]. Making these connections is of paramount importance, because it channels the findings of basic scientific research into applications that can protect specific vulnerable groups, especially in urban areas. These interdisciplinary interactions are required to not only understand heat, but also to communicate it effectively to practitioners, decision-makers, and to the public. Ultimately,

they can also support and encourage those who are responsible for physically shaping cities to respond to growing heat risk factors through informed bioclimatic design rationales [2].

Efforts to adapt to climate change and minimise its already unravelling impacts in the form of exacerbated heatwaves are ultimately based upon human interest. Adaptation can take place both in the short and long term. In the short term, there needs to be a focus on the impacts of extreme heat on sections of urban populations based on health status [13]. Adaptation during acute extreme heat events is driven primarily by behaviour, and specific actions and advisories should be inflected by our understanding of the risks for specific groups within society. Long term adaptation can be achieved by measures based on the modification of the built environment and up-to-code indoor conditions [5]. There is a particular need for further studies on how urban mobility interacts with heat exposure and heat-related behaviours, particularly across the indoor-outdoor interface [12]. To build on the existing evidence base, additional approaches and interdisciplinary cooperation between disciplines and sectors are required, which are not only comprehensive, but flexible and adjustable in quantification and application.

Beyond the accumulation of technical evidence and development of interventions, clear communication of urban heat risks and adaptation measures is imperative [2–4]. It is the last but perhaps most important link in the chain that delivers successful management of urban heat and its public health impacts. The healthcare sector- and others that are heavily impacted by urban heat (tourism, horticulture, civil protection)- should be directly involved in decision-making processes and development of HAPs. Urban heat can be seen as a systemic hazard, with effects not only on the health outcomes of individuals, but on the operations and resilience of health systems themselves. Responding to a hazard of this kind requires the implementation of wide-ranging changes, from the reimagining of urban infrastructure and energy systems to management of daily occupational health [12]. The best interventions will be feasible, rapidly implementable, efficient, and ideally inexpensive. Given the growing impact of urban heat on the welfare, safety and prosperity of our warming cities, this is an area of research that needs to be prioritised and tackled with a solutions-oriented mindset. The urgency of the situation is such that we must ensure that scientific endeavour is aimed squarely at delivering evidence-based approaches to maintaining health standards and systemic resilience in our present and future cities.

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