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Behavioral adaptation to heat-related health risks in cities

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ABSTRACT

Heat-related mortality is of growing concern for cities faced with the combined effects of increasing heat-wave frequency and intensity and stronger urban heat islands (UHI). In cities around the world, high air temperatures have been found to have strong repercussions in terms of heat-related mortality for populations aged 65 years and older, especially nighttime temperatures.

In response, many measures have been proposed to counteract the effects of UHI such as cool roofs and materials or urban greening. While these approaches are promising and are rightfully explored, behavioral adaptation measures have not received as much attention. Given the importance of nighttime temperatures on heat-wave mortality and the importance of sleep quality for individuals to recover from intense daytime heat exposure, adapting sleeping habits to reduce sleep time exposure to intense heat may help reduce the health impacts of heat-waves.

In this paper, outdoor and indoor temperature measurements conducted over the summer of 2015 in the bedrooms of two apartments in Paris, France are analyzed. The potential for this kind of behavioral adaptation to reduce occupant exposure to high sleep time temperatures is quantified and discussed. The policy implications of our findings and their practicality are also mentioned.

1. Introduction

Climate change is expected to bring increases in the intensity and frequency of extreme weather events over the coming decades [1]. This is namely the case for heat-waves in many European cities including Paris, France [2]. This is a major concern given the severe health impacts of such events, especially for populations over 65 years of age, as witnessed during the 2003 heat-wave [3]. Recent work has demonstrated the negative role played by the urban heat island (UHI) effect during heat-waves, amplifying temperatures further and thus making cities even more vulnerable to extreme heat [4].

To address the impacts of heat-waves, extensive research has been conducted to develop countermeasures to UHI and to promote urban cooling. Such tactics typically involve the use of so-called cool materials and coatings on urban surfaces [5–9], or the use of vegetation in streets, parks and on building envelopes [10–12]. Implemented at sufficiently large scales, it is hoped that these solutions can reduce exposure to extreme heat.

While these solutions are promising and are rightfully explored, many are costly and slow to implement at large scales in existing cities and cannot be relied on to address short- to medium-term concerns. In addition, UHI countermeasures are only rarely assessed for their improvement of indoor conditions [13], although that is where people spend the vast majority of their time [14].

To date, few efforts have focused on the potential for behavioral adaptation to reduce the risks associated with heat-waves and UHI. Behavioral adaptation is an interesting prospect as it is often a simple, immediate and cost-effective way of addressing certain issues. A prime example is the impact of reducing the indoor setpoint temperature in winter on building energy consumption. Indeed, heating energy consumption can be immediately reduced by 7% for every 1 °C-reduction in setpoint temperature without the need for any retrofitting.

This article sets out with a similar perspective for heat-waves, thus aiming to identify simple modifications of occupant behavior that might reduce the health impacts of heat-waves. Considering that the population most affected by heat-waves is that of persons 65 years of age and older and that night time temperatures affect heat-wave mortality the most due to their impact on sleep quality [15–18], we propose modifying occupant sleeping habits. By delaying the sleep period by one or two hours, we hope to reduce exposure of inhabitants to high indoor temperatures during their

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Nomenclature

HEI	Heat exposure index [°C.h]
MRT	Mean radiant temperature [°C]
UHI	Urban heat island
UTCI	Universal thermal climate index [°C]

sleep. The upcoming analyses will be based on indoor temperature measurements conducted inside the bedrooms of two apartments with internal or external thermal insulation over the summer of 2015 in Paris, France. The potential for the proposed modifications in sleeping habits to limit exposure to indoor heat and consequently heat-wave mortality and health impacts will be discussed.

2. Materials and methods

2.1. Heat exposure index (HEI)

As mentioned in the introduction, we focus on the sleep-time exposure of persons 65 years and older to high indoor temperatures. This choice is justified by the higher impact of minimum temperatures, reached at night, on heat-wave mortality compared to maximum temperatures, reached during the day. This higher impact has been interpreted as being the consequence of high night time heat on sleep quality, crucial to the proper recovery from daytime exposure to intense heat [13], [15–18]. Indeed, sleep quality and body temperature regulation are closely linked [19].

As a result of this choice, we must first determine the time period during which most of our target population is sleeping. While precise and relevant activity schedules may exist, we choose to simply assume an 8-h night spanning from 11 pm to 7 am. Although this may be a crude estimation, it will allow us to reasonably estimate and discuss the impact of behavioral change on sleep-time exposure to intense heat.

2.1.1. Indoor air temperature

Next, we must determine an appropriate exposure index. Ideally, a thermal model of the human body should be used to determine the thermal stress level of the studied individuals, combined with an exposure-health effect response curve. Although such information may be available, as a first approach we choose to focus on the duration of exposure to indoor air temperatures above 26 °C between 11 pm and 7 am local time.

We briefly discuss the selected threshold temperature. While health-relevant outdoor temperature thresholds can easily be chosen from the existing literature relating extreme heat to mortality or morbidity [20], very few studies have sought similar temperature thresholds for indoor environments [21–24]. Guidelines published by the World Health Organization indicate maximum indoor temperatures of 24 °C [25], though more recent work indicates thresholds of 26 °C or more depending on the room considered and their air movement (e.g. use of fans) [26]. For lack of better information, we choose a threshold of 26 °C.

Such an index makes sense firstly because sleep is typically an indoor activity. Furthermore, it is intuitive to proceed in such a fashion and the resulting index is very similar to the “cooling degree hours” (CDH) used for building cooling load quantification with a setpoint temperature of 26 °C, often found in the literature or in building energy regulations [27].

Although the resulting index is imperfect and imprecise from a thermal heat stress perspective, it can be readily modified to a more appropriate setpoint temperature or used with an equivalent temperature obtained from a more accurate or relevant thermal stress model.

Our Heat Exposure Index (HEI) is defined as follows, with $T_{setpoint} = 26°C$:

$$HEI = \int_{11pm}^{7am} \left(T_{indoors} - T_{setpoint}\right)_{T_{indoors} \geq T_{setpoint}} dt$$

In addition to the intensity of heat exposure – measured by HEI – it is also interesting to measure the length of time during which indoor temperatures exceed the setpoint temperature. Indeed, this indicator will help determine if the proposed scenarios mainly impact the frequency of exposure to high temperature or its intensity.

2.1.2. Occupant heat stress

Similarly, to better reflect exposure to heat stress, we also monitor the period of time during sleep spent above a certain Universal Thermal Climate Index (UTCI) equivalent temperature threshold. We chose UTCI because it is being increasingly adopted by the scientific community for evaluating thermal stress levels, ensuring comparability with existing and future studies [11,28,29]. However, the proposed method is not index-specific and alternative indices could have been used, such as Perceived Temperature (PT) or Physiological Equivalent Temperature (PET).

Regardless which index is used, thermal comfort estimation requires information on air temperature and humidity as well as the radiative environment and air movement. For air temperature and relative humidity, bedroom measurements are used. For wind speed and mean radiant temperature (MRT), which were not measured, we assume the minimal value (0.5 m/s) for 10-m wind speed and a MRT equal to air temperature.

The assumed wind speed value is that of the UTCI reference conditions and is the minimum value that can be computed with the fast-calculation developed by Bröde et al. [30]. MRT equal to air temperature is representative of a room where the walls and air are in or near thermal equilibrium. While air and wall temperatures are in reality constantly fluctuating, this assumption seems valid for nighttime. Given our assumptions, which set identical wind speed and MRT to those of the UTCI reference conditions, the only distinguishing variable between UTCI and air temperature is relative humidity.

It should also be noted that UTCI makes assumptions for clothing and metabolic activity, i.e. European clothing habits and the metabolic activity of a pedestrian walking at a speed of 4 km/h, i.e. 2.3 Met [31]. These assumptions merit a short discussion. In reality, it is unlikely that sleeping occupants are dressed the same way as when outdoors and their thermal insulation is also modified by the type of bedding they use [32]. Furthermore, the metabolic rate during sleep is 0.7 Met, i.e. more than three times lower than that assumed [33]. However, the relative wind speed would also be much lower than the assumed 1.4 m/s. These two errors tend to compensate for each other, though they may not cancel out. The error made for clo values is hard to quantify *a priori*. We now proceed to select an appropriate UTCI threshold with these shortcomings in mind.

Lemonsu et al. have used a similar approach to evaluate indoor thermal heat stress under different idealized heat-waves in Paris [28]. This analysis was conducted with a UTCI threshold of 32 °C, i.e. strong or greater heat stress. This threshold was used for simulated heat-waves with maximum temperatures of 34 °C–46 °C over 3–38 consecutive days. We select a threshold of 26 °C, i.e. a state of moderate or greater heat stress, as UTCI in the considered bedrooms does not exceed 32 °C over the study period.

To evaluate the effect of different sleeping habits, we now formulate our control and case scenarios.

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