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Blanca Fernandez Milan[1,2,*], Felix Creutzig[1,2]

Abstract

Global warming increases the frequency, intensity and duration of heat waves, particularly endangering urban populations. However, the health risks of heat waves are distributed unequally between people because of intrinsic person-specific characteristics and extrinsic factors. The confluence of forecasted urbanisation and projected heat wave increase necessitates the identification of strategies that both lower the overall health impact and narrow the gap in risk distribution within urban populations. Here, we review the literature on vulnerability to heat, highlighting the factors that affect such distribution. As a key lesson we find that the literature strands on public health, risk reduction and urban planning all contribute to the identification of alleviation options for urban heat wave health impacts, but that they are rarely jointly evaluated. On the basis of the literature review, we suggest a common framework. We also evaluate response measures in addressing total and distributed risks. We find that person- specific risk is effectively addressed by public health and risk reduction intervention, while intra-urban variations of extrinsic factors can be efficiently tackled with urban planning, both in scale and scope.

Keywords: urban heat island, health riks, equity, heath exposure.

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1. Introduction

Projected changes in heat waves and ongoing urbanisation provide the setting for a dramatic increase in heat-related morbidity and mortality in urban settings. Recent forecasts suggest that a robust, several-fold increase in the frequency, intensity and duration of observed global heat waves and warm spells will occur irrespective of the emission scenario (Perkins, Alexander, and Nairn 2012; Coumou and Robinson 2013; Dong et al. 2015). At the same time, more than two thirds of the population will live in cities by the 2050´s (UN 2014). Heat-related risk develops into one of the main climate-change related hazards in cities (Karen C Seto and Shepherd 2009). Two dynamics converge: the global increase in average temperature and the urban heat island (UHI), i.e. the temperature gradient between higher density human built environments and the non-built-up environment around the city (Karen C Seto and Shepherd 2009). Hence, the added heat stress in cities will be even higher than the sum of the background urban heat island effect and the heat wave effect (Li and Bou-Zeid 2013). A population faces particular risk situations during urban heat waves (UHW), which are elongated periods of excessive heat when urban temperature crosses a certain threshold, or peak events when urban temperature crosses a relative threshold (e.g. two standard deviations of yearly average urban temperature) (Harlan et al. 2006; Reid et al. 2009; Tian et al. 2013). Evidence points towards increasing health risks, especially in cities where the UHI intensifies extreme heat events (Dong et al. 2015; Luber and McGeehin 2008; Smargiassi et al. 2009), which will require economic and social resources, particularly in the areas most directly affected. It is therefore urgent that researchers and practitioners take appropriate measures in responding to this threat (IPCC 2014; Dong et al. 2015). Total health risks will increase with both increased vulnerability and the expected increase in hazard severity. These risks will develop differently for different world regions. Looking at future trends in urban population and number of heat waves, while the risk for North America, Europe and, to some extent, South America will increase due to changes in the hazard itself (number of heat wave days), Asia and Africa also show a significant increase in vulnerable population (urban population growth). On the other hand, individual susceptibility will increase vulnerability, especially in developed countries due to factors such as ageing population and cardiovascular diseases (UN 2012; Dong et al. 2015; UN 2014; Kovats and Hajat 2008) (Fig. 1).

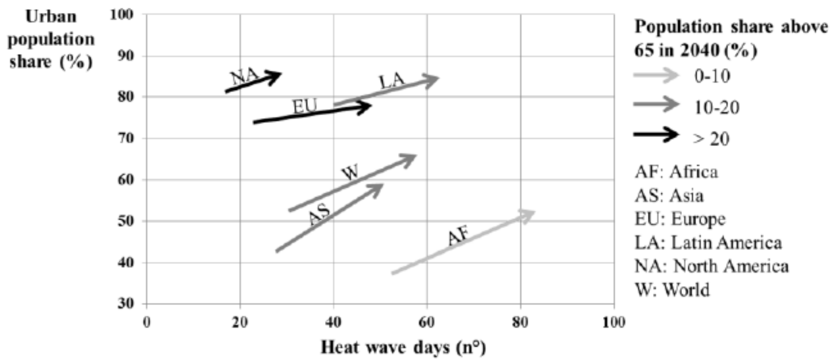

Figure 1 Future heat risk is likely to increase because of increases in hazard severity, urban population and ageing population. The figure is based on the following data: urban population rates, population share above 65 and number of annual heat wave days for the main five world regions in 2010 and 2040. The starting point of the arrow is based on 2010 values and the end on those projected for 2040. The colour coding of the arrow represents the population share above 65 in 2040. Data sources: UN (2014), UN (2012) and Dong et al. (2015).

These differences in risks are even more apparent within cities between distinct parts of urban populations. Specifically, an increasing number of studies show an unequal distribution of risks due to intrinsic person-specific characteristics and extrinsic factors within and across urban populations (Harlan and Ruddell 2011; Gronlund 2014; Uejio et al. 2011). Hence, response measures need to adjust to this stratification. Yet the range of responses to urban heat risk fail to systematically conceptualise approaches in a way that integrates knowledge across disciplines (Solecki, Leichenko, and O'Brien 2011; Jabareen 2013; Kovats and Hajat 2008; Kovats and Kristie 2006). Given the forecasts on urban population and heat waves, we need frameworks and tools that can compare and integrate findings across research fields (Harlan and Ruddell 2011; O'Neill et al. 2009; K.C. Seto et al. 2014). This paper merges the different strands of literature on combating urban heat risk. In order to do so, after presenting the methodology we review different literatures on the issue and suggest a framework for assessing implementation strategies, both individually and jointly. The paper concludes with a discussion of potential improvements to addressing forecasted risk factors.

2. Methodology

The objective of this paper is to critically review and compare current theoretical and practical approaches to heat-related risk reduction in cities. On this basis we attempt to answer the following research questions:

a. Which factors contribute to health impact and the existing differences in risk distribution from extreme heat events in cities (Section 3)?

b. Which interventions effectively reduce the different risk factors (Section 4)?

In order to address these questions we review the literature on urban heat risk, concentrating on peer-reviewed papers that have been published over the last five to ten years. We uncover health studies and research on disaster risk reduction, climate change, adaptability and resilience at the city level as well as reviews of current responses to heat, including public health and urban planning perspectives.

In the following paragraphs we introduce concepts from public policy and health literature and combine them with the body of literature on urban resilience in order to develop a framework for the evaluation of interventions. We will use this framework in section 4 to discuss the contributions and limitations of current intervention approaches and potential improvements for those to come.

Risk can be addressed at multiple levels: by avoiding and reducing exposure to hazards, lessening susceptibility and improving preparedness through response and recovery mechanisms (Wamsler, Brink, and Rivera 2013; Solecki, Leichenko, and O'Brien 2011; Jabareen 2013; Romero Lankao and Qin 2011). Each factor may be addressed either by different intervention strategies or a sum of them. In the literature on public policy analysis, and particularly that of public health intervention, effectiveness, efficiency and equity are commonly used evaluation criteria[3] (Tones and Tilford 2001; Andrews and Entwistle 2010; Davis et al. 2013; Haynes 1999). We adapt the definitions from the literature and include insights from urban resilience, adaptation and climate change risk reduction research (Solecki, Leichenko, and O'Brien 2011; Jabareen 2013; Wamsler, Brink, and Rivera 2013; Romero Lankao and Qin 2011) and specify the following criteria:

a. Effectiveness assesses the capability of the intervention to produce the desired effect under real life circumstances (does it work in practice?) (Haynes 1999). In the case of interventions aiming to reduce urban health impact from heat, this would be a measure of heat-related mortality and morbidity reduction taking into account the urban context. Public health studies often refer to the slope of the temperature-mortality/morbidity response (Kovats and Hajat 2008; Andrews and Entwistle 2010) (Fig. 2.a).

b. Efficiency refers to the ratio of output to the input; it measures the effect of an intervention in relation to the resources it consumes (is it worth it?) (Haynes 1999). Applied to our case, it is the lessened effect of urban heat on health in relation to the intervention costs. In climate change science, this is calculated by looking at the effects on government revenue and expenditure, paying particular attention to externalities: how much revenue and expenditure the government generates overall by implementing this policy (K.C. Seto et al. 2014; Harlan and

[3] In health care interventions the concept efficacy is also used. Efficacy refers to the extent to which an intervention does more good than harm under ideal circumstances (Haynes 1999). Given the urban complexities, we believe this term does not apply to the evaluation of health risk reduction in cities.

Ruddell 2011). Based on concepts from urban agglomeration economics (Fujita, Krugman, and Venables 2001; Simone Singh 2014), we include the following considerations, which are fundamental for future risk mitigation: forecasts on urban population size, the development of levels of susceptibility and hazard characteristics (frequency, intensity and duration). With regards to the first one, efficiency refers to the marginal intervention costs of an additional person that has to be covered in the intervention (economies of scale). Efficiency in addressing changes in susceptibility and hazard level is given by the marginal costs of including an additional level (greater scope). Susceptibility changes can be due to factors such as ageing population and cardiovascular diseases. Hazard severity may be given by changes in the frequency, intensity or duration (economies of scope). Fig. 2.b illustrates the different dimensions of efficiency that should be considered in the design of optimal public interventions for decreasing urban heat risk.

c. Equity: the extent to which the benefits of a policy and the costs are spread among those affected in such a way that no group or individual receives less than a minimum benefit level or more than a maximum cost level (Phelan et al. 2004; Tones and Tilford 2001; Kjellstrom, Mercado, et al. 2007). Typically, policymakers measure how fairly a service is distributed among various targeted groups by considering how much of a needed service the individuals in each recipient group receive. Because the needs and abilities of individuals and groups will differ, one could evaluate equity in two ways. Commutative justice is the equal provision of a good or service to each group or individual. Distributive justice considers that a fair amount should be provided according to the level of need (Childress 2013) (Fig. 2.c).

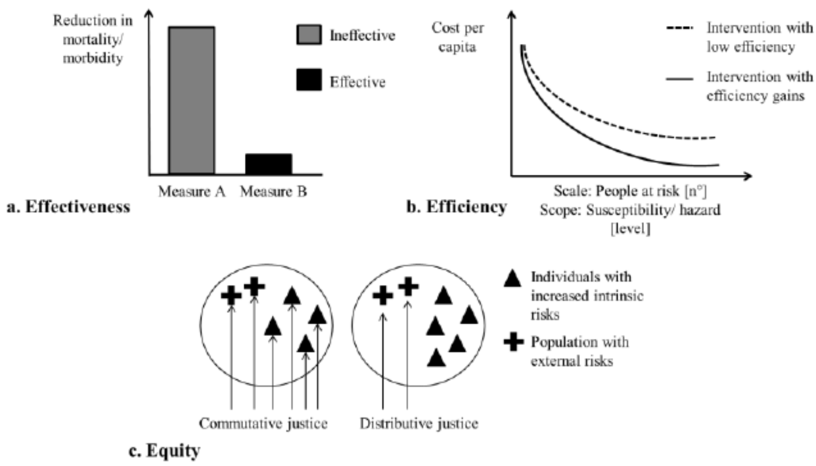

Figure 2 Evaluation criteria for urban heat risk reduction

3. UHW: Health risk factors

Risk from urban heat waves differs with so-called intrinsic and extrinsic factors. Intrinsic factors refer broadly to the physical condition of individuals (typically named susceptibility factors or sensitivity in public health literature), whereas extrinsic factors point to stratified levels of risk across socio-economic and spatial urban settings. We briefly review the literature on both sets of factors to clarify their importance.

3.1 Intrinsic factors

Among the susceptibility explanatory variables of risk unequal distribution, age is at the forefront (Baccini et al. 2008; Son et al. 2012; Sung et al. 2013; Yang et al. 2013; Zeng et al. 2014; Madrigano et al. 2013; Reid et al. 2009). Several studies suggest women are more heat sensitive than men due to gender-related physiological and thermoregulatory differences (Son et al. 2012; Yang et al. 2013; Druyan et al. 2012), but literature shows inconsistencies in this regard (Zanobetti et al. 2013; Robine, Michel, and Herrmann 2012). Alternatively, much of the excess mortality and morbidity is related to previous medical status. People with lower mobility and confinement to bed (Y. Zhang, Nitschke, and Bi 2013; Vandentorren et al. 2006), people suffering from cardiovascular diseases (Bouchama et al. 2007; Tian et al. 2013; Tran et al. 2013; Vandentorren et al. 2006; Klein Rosenthal, Kinney, and Metzger 2014; Hajat, O'Connor, and Kosatsky 2010) and those with pre-existing psychiatric and pulmonary illnesses and renal problems show higher susceptibility (Bouchama et al. 2007; Price, Perron, and King 2013; Zeng et al. 2014; Y. Zhang, Nitschke, and Bi 2013). Pregnant women may observe shorter lengths of pregnancy (Auger et al. 2014; Carolan-Olah and Frankowska 2014). Personality traits and behavioural characteristics may also influence susceptibility; those most commonly mentioned are isolation, high risk perception and low behaviour adjustment (Y. Zhang, Nitschke, and Bi 2013; Vandentorren et al. 2006; Baccini et al. 2008; Liu et al. 2013; Tran et al. 2013). Finally, drug consumption has also been said to influence physiological responses to heat (Sommet et al. 2012).

3.2 Extrinsic factors

Additional uneven distribution of risk among populations in suburban population groups can be explained through the interaction of social, economic, environmental and political characteristics. These characteristics influence heat exposure directly or individual susceptibility indirectly (Wamsler, Brink, and Rivera 2013; Gronlund 2014; Uejio et al. 2011; Reid et al. 2009).

On a macro scale, regional climates and geography modify heat wave hazards among cities in terms of intensity, frequency and duration (Baccini et al. 2008; Michelozzi et al. 2005; Bobb et al. 2014). At the city and neighbourhood levels, socio-economic factors of risk include deprivation, economic or income levels and isolated minorities, particularly in inner cities (Depietri, Welle, and Renaud 2013; Hattis, Ogneva-Himmelberger, and Ratick 2012; Y. Zhang, Nitschke, and Bi 2013; Klein Rosenthal, Kinney, and Metzger 2014; Kovats and Hajat 2008; Uejio et al. 2011; Madrigano et al. 2013; Bobb et al. 2014). Education level also influences risk; it is a sign of technological strength and an individual's resilience due to higher awareness and better knowledge of hazard prevention (Johnson, Wilson, and Luber 2009; Reid et al. 2009). Different working and living conditions change the risk too (Tran et al. 2013; Xu et al. 2013; Fleischer et al. 2013; Gubernot, Anderson, and Hunting 2014). Living under the roof or on the upper floor and in old structures was a risk factor during the 2003 heatwave in France and during the warm seasons of 1999-2000 in Barcelona (Spain) (Vandentorren et al. 2006; Xu et al. 2013).

The awareness of the role of environmental factors (also known as urban climate) and their interaction with the urban fabric in explaining different levels of risk within cities is explored by an increasing body of research on urban structures and their link to public health. The landscape of the urban periphery shapes the decreases in temperature as the airflow enters the leeward rural area (Hu et al. 2012; Smargiassi et al. 2009), and ecosystem conservation contributes to this effect (Depietri, Welle, and Renaud 2013). At the neighbourhood level, physical factors and processes (radiation, elevation, wind and land use) interact with urban structures (housing orientation, construction materials, ventilation and other heat protection measures) (Wolf and McGregor 2013; Stone 2012; Coseo and Larsen 2014; Harlan and Ruddell 2011) and create differences in surface temperatures of up to 10 °C between districts (Klok et al. 2012). Transport networks, industrial activities and corridors, air quality (Breitner et al. 2014; Harlan et al. 2013; Laaidi et al. 2012), built-up densities and sealed surfaces (Tomlinson et al. 2011) are some examples of the urban fabric that shape heat hazard severity (Aubrecht and Özceylan 2013; Depietri, Welle, and Renaud 2013; Fischer and Schär 2010; Gabriel and Endlicher 2011; Giannaros and Melas 2012; Merbitz et al. 2012; Reid et al. 2009; Wolf and McGregor 2013; Klein Rosenthal, Kinney, and Metzger 2014). Open spaces, tree canopy and water bodies have been shown to reduce risk in the areas surrounding them to a certain extent (Xu et al. 2013; Dugord et al. 2014), depending on the morphology of urban structures nearby (Armson, Stringer, and Ennos 2012; Feyisa, Dons, and Meilby 2014; Coseo and Larsen 2014). At a lower spatial level, street design and building materials also change risk levels through the radiation exchange between buildings, the air circulation and the anthropogenic heat released (Stone 2012; Coseo and Larsen 2014; Mills et al. 2010). All this taken together, the urban fabric represents a great influence firstly on the nature of UHW and urban heat risks (Smargiassi et al. 2009; Coseo and Larsen 2014; Memon, Leung, and Chunho 2008) and secondly on the performance of interventions (Wamsler, Brink, and Rivera 2013).

Finally, urban governance may also change risks and risk distribution among populations; this refers to how response and recovery mechanisms in place interact with all the previously described factors (Romero-Lankao and Dodman 2011; Wamsler, Brink, and Rivera 2013; Balbus and Malina 2009). For example, people living in cities with infrequent extremely hot weather are more at risk because of deficient response and recovery mechanisms (Anderson and Bell 2009; Baccini et al. 2008; Henderson, Wan, and Kosatsky 2013; Kovats and Kristie 2006; Medina-Ramón and Schwartz 2007; Reid et al. 2009). The burden of risk also increases for populations living in tropical cities of middle and low-income countries due to water scarcity issues (Vörösmarty et al. 2005; IPCC 2014).

4. Evaluation of responses to heatwaves

Research on strategies for coping with urban heat waves has grown considerably in the last decade, but interdisciplinary differences limit the overall understanding of how cities can respond to this ever increasing climate hazard. Health literature explores how and why particular populations are more at risk than others – intrinsic factors; climate change, risk reduction and urban planning research addresses extrinsic factors (Solecki, Leichenko, and O'Brien 2011; Pascal et al. 2012; Kinney et al. 2008; O'Neill et al. 2009). Disciplines have succeeded in evaluating the effectiveness of the isolated measures to a certain extent, but the gap between approaches hinders the discussion on the overall performance, which includes on the one hand scale efficiencies and on the other equity considerations (Romero Lankao and Qin 2011; Kovats and Hajat 2008; Kinney et al. 2008; O'Neill et al. 2009). Dichotomies between adaptation and mitigation literatures, and between health care and urban planning intervention approaches, hamper the emergence of inclusive approaches (Biesbroek, Swart, and van der Knaap 2009; Laukkonen et al. 2009; Romero-Lankao and Dodman 2011; Jabareen 2013; Hajat, O'Connor, and Kosatsky 2010; Sandink 2013; Soebarto and Bennetts 2014). We here highlight the main intervention approaches in the public health and urban planning literature, discuss how each of them can address some risk factors, and conclude that both approaches should be jointly planned to maximize synergies for public health outcomes. We focus on how they address distributive and commutative justice, meaning whether they prioritise their interventions in favour of individuals with increased intrinsic risks, or they cover the general population and their external risks.

4.1 Public Health interventions are effective and address intrinsic risk factors

Public health interventions have been proven effective. The collaboration between meteorological agencies and the public health sector has become practice worldwide, developing in the so-called Heat Health Warning Systems (HHWS) (Pascal et al. 2012). Australian and North American cities were the pioneers (Hajat et al. 2010; Price, Perron, and King 2013). Since the heat wave of 2003 the systems have spread all over Europe (Hajat et al. 2010; Kovats and Kristie 2006; K. Zhang et al. 2012). HHWS include interventions aimed at providing cool environments, enhancing public awareness through education plans and risk communication, and measures to produce behavioural change (Luber and McGeehin 2008). They focus on intrinsic factors (i.e. the elderly and medical statuses), which makes them highly efficient in reducing susceptibilities at the individual level (Daanen and Herweijer 2014; Ebi et al. 2004).

Although the population is continually adapting to heat (Bobb et al. 2014), the efficiency of HHWS has not yet been proven for future scenarios, where increasing heat-wave frequency, severity and duration is coupled with a rapidly growing at-risk population (Daanen and Herweijer 2014; Kenney, Craighead, and Alexander 2014; Koppe et al. 2009; Krau 2013; Patidar et al. 2014; Wu et al. 2014; Hajat, O'Connor, and Kosatsky 2010; IPCC and Ebi 2012; Bobb et al. 2014). These measures generally disregard the heterogeneous distribution of extrinsic factors such as hazard and exposure levels within urban populations (Sampson et al. 2013; Sandink 2013; Uejio et al. 2011; Smargiassi et al. 2009). For example, with regards to advice on heat avoidance, a typical measure is the use of air conditioning (Department of Health 2013; Koppe et al. 2009; Kovats and Kristie 2006; Barnett 2007; Sheridan, Kalkstein, and Kalkstein 2008). Air conditioning is extremely effective in reducing risks among vulnerable people facing continuous specific individual risks – enabling so-called distributive justice (Barnett 2007). However, its overall performance is questionable in the long term (Sheridan, Kalkstein, and Kalkstein 2008). First, disruptions to electricity supply during heat waves may hinder its effective performance (Sailor 2014). Second, the measure uses narrow perspective on equity. On the one hand, not only does it not include risk avoidance or reduction considerations, measures like air ventilation also further contributes to UHI, thus affecting those not addressed through the intervention (Tremeac et al. 2012; Memon, Leung, and Chunho 2008; Reid et al. 2009; Gronlund 2014; Bobb et al. 2014). On the other hand, access to air conditioning is highly stratified depending on poverty levels and racial and ethnic compositions (Klein Rosenthal, Kinney, and Metzger 2014; Sheridan 2007). Even if accessible, resorting to an air conditioner may not be the most preferred strategy for low-income groups due to the costs involved (Soebarto and Bennetts 2014; Sheridan 2007). Similarly hydration advice may not reach those most at risk; water availability and affordability does not distribute equally among population (Ruijs, Zimmermann, and van den Berg 2008). This is particularly true in regions where heat waves are accompanied by drought periods and water is scarce, thus being drought-sensitive (Vautard et al. 2013; Gershunov et al. 2013; Vörösmarty et al. 2005; Kjellstrom, Friel, et al. 2007; IPCC 2014).

Generally, public health interventions address those with higher intrinsic risks under a distributive justice perspective (i.e. prioritising the assistance of individuals at higher risk), but lack adequate measures to also intervene with commutative justice considerations (Romero Lankao and Qin 2011; Kovats and Hajat 2008). In addition, preventable causes of death show substantially larger socioeconomic inequalities because socioeconomic resources become more relevant for minimising risks (Phelan et al. 2004). Mechanisms allowing individuals and households to cope with the constant hazards encountered show high efficiencies at the individual level, yet it is difficult to up-scale these actions to the city level (Romero Lankao and Qin 2011). They forget key extrinsic aspects, and consequently measures do not necessarily reach the most at-risk populations (Soebarto and Bennetts 2014; Sampson et al. 2013). Although these public health measures play a key role in reducing individual susceptibility, they should not be overestimated by public authorities (Boumans et al. 2014; Hagerman 2007; Harlan and Ruddell 2011; Harlan et al. 2013; Harlan et al. 2006; Heaton et al. 2014; Kovats and Kristie 2006; Wolf and McGregor 2013).

4.2 Urban planning interventions become increasingly relevant but are rarely deployed

Urban heat has a strong interaction with built structures, ultimately shaping the frequency, intensity and duration of heat waves and further shaping exposure levels. Information on location specific thermal radiative power helps define the impact of urban structures at the community level (Wang and Akbari 2014). Spatial models of health–environment interactions include these figures, using information layers related to topography profiles, building densities, vegetation bodies, transport networks, night temperatures and socio-demographic data in order to build risk maps (Boumans et al. 2014; Laaidi et al. 2012; Merbitz et al. 2012; Xu et al. 2013; Johnson et al. 2012; Krüger et al. 2013). These exercises assist policy makers to identify spatial attributes from the built and natural environments that interfere with heat waves and the ensuing health effects.

Well-known strategies include the increase of albedo though the modification of urban building materials and colours and optimising the urban canopy layer (Sailor 2014; Ohashi et al. 2007). These alternatives are of particular importance from a cost-efficiency perspective at the household level; they are particularly recommended in housing for middle and low-income occupants, which also makes them vey inclusive from an equity point of view (Santamouris 2014; Susca and Creutzig 2013; Soebarto and Bennetts 2014; Claus and Rousseau 2012). In general, strategies that move away from electricity requirements perform better from a commutative justice perspective; effectiveness is not reduced when loss of power or electric system failures occur (Koppe et al. 2009; Sailor 2014).

At the street and neighbourhood level, one could also reduce exposure times through shadowing and enhancing urban connectivity (Wilhelmi and Hayden 2010; Armson, Stringer, and Ennos 2012). Other structural strategies aim to optimise long-wave radiation loses, favouring air circulation and avoiding waste heat related activities. To this end, changes in street configuration, wall surfaces and roofs are suggested (Memon, Leung, and Liu 2010; Allegrini, Dorer, and Carmeliet 2012; Susca and Creuztig 2013). For example, avoiding street canyons may reduce air conditioning demands by half (Allegrini, Dorer, and Carmeliet 2012). Air flow optimisation through non-blocked street intersections, wind corridors and usage of porous construction materials also has a prominent mitigation effect, especially for locations with low wind speed (Hu et al. 2012; Memon, Leung, and Liu 2010; Allegrini, Dorer, and Carmeliet 2012; Saneinejad et al. 2012). City-wide albedo increase also mitigates peak temperatures up to 1 °C, especially for locations with high population density (Akbari and Matthews 2012; Susca and Creuztig 2013; Santamouris 2014; Santamouris 2013; Mackey, Lee, and Smith 2012). The cooling effect of water bodies can be up to 2 °C, which may be propagated through the avoidance of physical barriers and dark materials (such as brick or tarmac) and the increase of vegetation cover nearby (Hathway and Sharples 2012; Chun and Guldmann 2014).

Recent case studies of Seoul and Berlin, lead by the department of landscape planning at the Technical University of Berlin suggest specific urban planning strategies to mitigate urban heat island effects and urban heat waves (Eum et al. 2013; Dugord et al. 2014). With detailed spatial information, urban planning can focus on those districts with highest heat-wave related mortality (Schuster, Burkart, and Lakes 2014).

All these measures perform very well for commutative justice; the effects are in principle equally distributed among the whole population because they help to decrease the overall UHI effect. Research tells us that most of these strategies reduce overall anthropogenic heat intensity, thus providing benefits to all (Shashua-Bar, Pearlmutter, and Erell 2009; Memon, Leung, and Chunho 2008; Jr 2005). Furthermore, measures of urban planning increase in effectiveness with scale, including that of higher levels of risk and vulnerabilities (Memon, Leung, and Chunho 2008). The efficiency of reducing risk through measures addressing extrinsic factors increases with the number of the population at risk and the severity of the hazard (Shashua-Bar, Pearlmutter, and Erell 2009). Weaknesses of urban planning come mainly from the fact that effectiveness at the individual level to cope with susceptibilities is rather low compared to public health measures, which lowers the equity outcomes of urban planning with regards to distributive justice. Unequal distributions of access to cooling and green spaces based on income, ethno-racial characteristics, age, gender, (dis)ability and other axes of difference may reduce the positive outcomes, but this can still be addressed directly with alternative planning strategies (Dai 2011; McConnachie and Shackleton 2010; Shawn M Landry 2009; Sister, Wolch, and Wilson 2010; Wolch, Byrne, and Newell 2014; Sampson et al. 2013; Klein Rosenthal, Kinney, and Metzger 2014; Friel et al. 2011; Kjellstrom, Friel, et al. 2007). However, urban planning interventions to reduce risk from heat waves have rarely been implemented, despite their ability to address extrinsic risk factors beyond the reach of public health measures.

4.3 Achievements, challenges and the way forward

While public health measures focus on individual susceptibilities and levels of exposure, urban planning succeeds in lessening UHW hazard severity as well as intra-city exposures. Public health responses perform very effectively under a distributive-justice approach, yet it is difficult to up-scale intervention actions to the city level from a cost-efficiency perspective. This fact makes prioritisation a design criteria, and health care interventions do not directly address options aimed at the total population and tend to be based on mainly short term interventions (Krau 2013; O'Neill et al. 2009; Kinney et al. 2008; Kravchenko et al. 2013). They cannot alter urban climates (Harlan and Ruddell 2011; Koppe et al. 2009). Yet these shortfalls may be offset with planning strategies acting at an upper spatial level (i.e. street, neighbourhood) that include more people with relatively low costs (Eum et al. 2013; Dugord et al. 2014). At the same time, the relative ineffectiveness of urban planning in addressing individual susceptibilities makes it inevitable and necessary to intervene through public health actions.

Currently, the majority of responses are based on susceptibility or individual exposure factors, but these do not reduce the population's exposure either on a larger scale or in the long term. Little has been done in regards to urban planning apart from isolated initiatives focussing on albedo modification (Santamouris 2013) and increase in vegetation cover (Armson, Stringer, and Ennos 2012; Feyisa, Dons, and Meilby 2014). Some are designed from a climate change mitigation perspective (greenhouse gas emissions reduction) rather than using an integrative mitigation-adaptation approach that also considers UHW (Harlan and Ruddell 2011; Biesbroek, Swart, and van der Knaap 2009; Laukkonen et al. 2009). In other words, urban planners' potential to address heat waves in the field remains largely untapped. Measures addressing urban microclimate interaction with social and environmental risks would assist in more effective long-term heat risk reduction strategies (Johnson et al. 2012; Wu et al. 2014). This is not counting the well-known co-benefits and synergies with other policy objectives that can be achieved through urban planning (i.e. enhanced entrainment of pollutant concentrations (Tong and Leung 2012; Harlan and Ruddell 2011). Growing awareness among scientists on the role of spatial planning in functioning as a switchboard for mitigation, adaptation and sustainable development objectives may assist practitioners in the future to implement changes in the traditional administrative structure that spatial planners are accustomed to (Biesbroek, Swart, and van der Knaap 2009). From a climate justice perspective it is extremely important that future interventions tackle commutative and distributive justice jointly (Soebarto and Bennetts 2014; Sampson et al. 2013; Hajat, O'Connor, and Kosatsky 2010; Klein Rosenthal, Kinney, and Metzger 2014).

The combination of actions addressing intrinsic and extrinsic factors at the same time could fill the gaps each approach has on its own. Fig. 3 below illustrates the potential contribution of each approach individually to motivate the idea that joint consideration, evaluation, design and implementation of the two currently existing approaches would better cover the spectrum of future risks related to urban heat waves. Strategies themselves could benefit from synergies through a multilevel governance context, including institutional arrangements, governance mechanisms and financial resources (Friel et al. 2011; Wolf and McGregor 2013; Pascal et al. 2012; IPCC 2012; K.C. Seto et al. 2014).

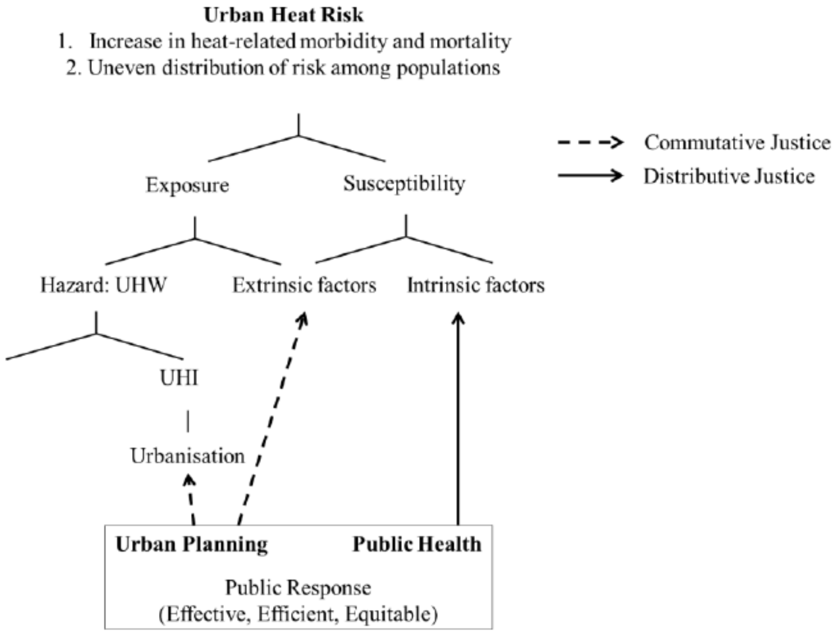

Figure 3 Person-specific risk is well addressed by public health interventions, while extrinsic factors can be tackled through urban planning considerations.

5. Conclusion

This review identifies intrinsic and extrinsic factors that contribute to stratified vulnerability to urban heat waves. We show that public health interventions are highly effective and can be used to address intrinsic risk factors. Urban planning measures show their efficiency on longer time scales but are rarely deployed. Crucially, urban planning measures would reduce exposure and through this help to mitigate extrinsic risk factors. We claim that this reduction of extrinsic risk factors becomes increasingly relevant due to the confluence of urbanisation and rising levels of urban heat hazards. We conclude that a coordinated effort between public health and urban planning departments would most effectively counter the threat of future heat waves worldwide, and specifically would help to address both individual susceptibility (intrinsic factors) and overall exposure (extrinsic factors).

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