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Factors of subjective heat stress of urban citizens in contexts of everyday life

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Abstract

Heat waves and the consequent heat stress of urban populations have a growing relevance in urban risk management and strategies of urban adaptation to climate change. In this context, social science studies on subjective heat stress of urban citizens are a new emerging field. To contribute to the understanding of subjective heat stress and its major determinants in a daily life perspective, we conducted a questionnaire survey with 323 respondents in Karlsruhe, Germany, after a heat wave in July and August 2013. Statistical data analysis showed that heat stress is an issue permeating everyday activities. It was found that the subjective heat stress at home is lower than at work and in general. Subjective heat stress in general, at home, and at work was determined by the health impairments experienced during the heat and the feeling of being helplessly exposed to the heat. For heat stress at home, additionally characteristics of the residential building and the built environment played a role. Although the rate of implemented coping measures was rather high, coping measures showed no uniform effect for the subjective heat stress. The results furthermore show that coping with heat is performed within the scopes of action in daily life. We conclude that in terms of urban adaptation strategies, further research is needed to understand how various processes of daily social (work) life enable or limit individual coping and adaptation capacities and that communication strategies are important for building capacities to better cope with future heat waves.

1 Introduction

Heat waves and the social impacts emerging from heat stress of urban populations have become a growing concern in managing natural hazards impacts on society. The 2003 heat wave in Europe with an estimated total of up to 70 000 additional deaths in 16 affected countries (Robine et al., 2008) and the 2010 heat wave in Moskow, Russia with approximately 20 000 excess deaths (Revich and Shaposhnikov, 2012) dramatically

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show the magnitude of the impacts of such extreme events on human health. In the context of the increased likelihood of longer, more frequent and more intense heat waves in Europe, which has been recently concluded by the IPCC again (IPCC, 2013), prevention of the health consequences of heat stress of urban citizens is an emerging environmental challenge (WHO and WMO, 2012). In terms of economic impacts of heat, Dunne et al. (2013) recently assessed that with rising temperatures and humidity due to climate change, lost-labor capacity in peak months of heat stress may double by 2050 compared to that in the historical period even with climate mitigation measures (both in RCP 4.5 and RCP 8.5). Due to the urban heat island effect (Oke, 1973), in particular urban citizens are likely to be exposed to heat and to suffer heat wave impacts more often in the future (Beniston et al., 2007; Revi et al., 2014; Patz et al., 2005). Reducing impacts of heat stress thus is among the top issues of urban climate change adaptation strategies in Europe (EEA, 2012; Revi et al., 2014).

Heat stress is a problem individuals experience in their daily lives in a built environment and to which they respond and adapt in their everyday-life settings. To develop effective strategies that help reduce impacts of heat stress, it is thus necessary to understand how individuals subjectively experience heat stress in everyday life and what factors influence and determine it. So far, only a few studies have investigated the social dimensions of subjective heat stress (Großmann et al., 2012; Pfaffenbach and Siuda, 2010) and have shown that social demographic characteristics, health impairments, coping behavior during the heat, and factors in the urban built environment are associated with higher or lower heat stress. At the same time, however, it is not yet clear to which extent these factors statistically determine subjective heat stress and help explain the variance observed.

To close this gap in the current understanding of the subjective heat stress of urban citizens, we present the results of a questionnaire survey on subjective heat stress conducted in Karlsruhe, Germany, immediately after a heat wave in 2013. We first outline the research background and the aim of our study in Sect. 2 and then briefly describe the study concept, operationalization, data collection, and analysis in Sect. 3.

In Sects. 4 and 5 we present and discuss the results. We finally summarize our conclusions in Sect. 6.

2 Research background related to factors for heat stress and aims of the study

Heat health impacts, heat stress, and factors that contribute to heat stress have been investigated extensively in temperature-related mortality studies and in biometeorological studies on human thermal discomfort. More recently, social science perspectives have emerged that focus on vulnerability to heat waves, behavior during heat waves, and on subjective heat stress.

2.1 Heat stress in temperature-related approaches

Epidemiological studies investigating temperature-related mortality have revealed a widespread pattern of factors that are associated with increased mortality risks during heat events. Mortality was higher among the elderly, among those with pre-existing health problems or those confined to bed (Conti et al., 2007; Foulliet et al., 2006; Vandentorren et al., 2006). Furthermore, it was higher among individuals living alone (Foulliet et al., 2006), in some cases among women (Borell et al., 2006; D'Ippoliti et al., 2010), or in census tracts with a high percentage of manual workers (Xu et al., 2013). Vandentorren et al. (2006) demonstrated additionally the positive effects of heat-protective behavior e.g., of cooling the body or going outside during cooler times of the day. Regarding factors of the urban built environment, increased mortality rates were observed in large cities with high temperatures also during the night (Conti et al., 2005; Grize et al., 2006; Laaidi et al., 2012; Vandentorren et al., 2004), in areas with little surrounding green (Xu et al., 2013) and in dense urban structures (Gabriel and Endlicher; 2011). Furthermore, housing conditions such as living in a building with low insulation standard or having the bedroom in the attic floor were associated with a higher mortality risk (Vandentorren et al., 2004, 2006; Xu et al., 2013). Similarly, Harlan et al. (2006) found the combination of dense urban settlement structures and low socio-economic status to be a factor for vulnerability to heat stress in their investigation on urban neighborhood microclimates using the outdoor human comfort index HTCI.

To measure human heat stress before its consequences become visible in the form of increased morbidity and mortality, biometeorological studies have used indices of thermal discomfort such as the above-mentioned HTCI. They combine meteorological parameters (temperature, humidity, wind velocity, radiation fluxes, and others) with energy balance and thermoregulation models of the human body (Laschewski and Jendritzky, 2002; Blazejczyk et al., 2012; Jendritzky et al., 2012). Since individuals spend most of their time indoors and can be exposed to and affected by high temperatures at home or at work, it is necessary to consider also indoor temperatures to understand potential factors for individual heat stress. Several studies explored the outdoor-indoor temperature relationship for different building types and, in some cases, combined meteorological parameters with surveys on heat perception or the adaptive behavior during heat waves in relation to the indoor temperature (Franck et al., 2013; Semenza et al., 2008; White-Newsome et al., 2012). White-Newsome et al. (2012) observed in their study in Detroit, USA, that outdoor temperatures, solar radiation, and dew point temperature predicted only 38 % of the variability of indoor temperatures; their results at the same time underpin the small-scale variability of indoor temperatures depending on sensitivities of building materials to outdoor temperature and heat gain and its surroundings. Studies for German cities additionally show that indoor temperatures in the analyzed buildings increased with increasing floor level (Franck et al., 2013; Langner et al., 2014). Comparing temperature measurements with survey results on subjective heat perception during a heat wave in Leipzig, Germany, Franck et al. (2013) found that the evening temperatures measured in the sleeping room dominated the heat perception, whereas other parameters, such as urban structure type and green space showed no clear relation to heat perception. In their in-depth-study of 29 homes of elderly persons in Detroit, USA, White-Newsome et al. (2011) showed that adaptive behavior was significantly associated with increasing indoor temperatures, and that residents in high-rise buildings and impervious areas showed a higher rate of adaptive behavior.

2.2 Factors of heat stress in social science perspective

Based on current theoretical frameworks and concepts of the natural hazards and climate change research community, a recently growing number of social-science studies have explored the social dimensions of heat stress. Some of them focused on the risk perception and the response to heat warnings of vulnerable groups such as the elderly (Abrahamson et al., 2009; Hansen et al., 2011; Sampson et al., 2013; Sheridan, 2007) and their social networks (Wolf et al., 2010). Others tried to understand the social dimensions of subjective heat stress and behavior during heat (Großmann et al., 2012) or the social production of heat wave impacts (Klinenberg, 2002). They employed qualitative or quantitative research designs and differ as well regarding the temporal relation to heat experience. In some studies, data collection took place during a heat wave (Großmann et al., 2012; Klinenberg, 2002; Sheridan, 2007), in others in the summer season without pronounced heat (Abrahamson et al., 2009; White-Newsome et al., 2011), in late spring (Pfaffenbach and Siuda, 2010), or during winter (Kalkstein and Sheridan, 2007).

Despite these methodical differences, the common explicit or implicit understanding underlying these research activities is that heat and heat stress are problems that unfold in the context of everyday social life and that a number of social characteristics interacting with health and urban spatial structures affect heat stress, adaptation and coping behavior and vulnerability to heat. In contrast to the previously mentioned biometeorological approach using thermal discomfort indices (Harlan et al., 2006; Langner et al., 2014), “heat stress” here refers to the subjective and individual experiencing of heat as stress and is measured with the statements expressed by individual study participants.

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Previous empirical studies on subjective heat stress among residents of the German cities Leipzig (Großmann et al., 2012), Aachen (Pfaffenbach and Siuda, 2010), and Nürnberg (Wittenberg et al., 2012) clearly indicated that heat stress in terms of everyday life is not solely an issue at home and in the residential environment, but also at work. As the most common expression of heat stress at work, the studies found a decreased ability to concentrate due to the heat (Großmann et al., 2012; Pfaffenbach and Siuda, 2010). Similarly, Sampson et al. (2013) pointed to the effect of the heat on the energy level and its effect to function also in daily activities. Other impairments and health-related problems reported by study participants in the context of heat included circulatory complaints, but also headaches, disturbed sleep, exhaustion, and respiratory diseases (Pfaffenbach and Siuda, 2010; Wittenberg et al., 2012). In terms of subjective heat stress, Pfaffenbach and Siuda (2010) found higher subjective heat stress rates among respondents with a chronic respiratory or cardiovascular disease. Furthermore, the studies mentioned found significant differences in subjective heat stress according to elements of the urban spatial structure (building type and inhabited level in the building, settlement density, and surrounding green) that correspond to the results of heat discomfort studies outlined above.

Regarding social demographic characters that make a difference for the intensity of subjective heat stress, results of previous studies diverged in particular for heat stress of elderly persons reporting higher (Pfaffenbach and Siuda, 2010) against lower (Großmann et al., 2012) subjective heat stress levels than the younger respondents. Studies on the vulnerability of elderly citizens to heat in the UK (Abrahamson et al., 2009; Wolf et al., 2010), the US (Sampson et al., 2013; Sheridan, 2007), and Australia (Hansen et al., 2011) suggested that elderly persons did not perceived themselves as vulnerable to heat just because of their chronological age. Moreover, as Großmann et al. (2012) found that retired respondents more often changed their daily routines during the heat than the younger and economically active ones, they raised the question as to whether and how the elderly might balance their higher physical

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vulnerability by a higher adaptive capacity through their freedom from the constraints of working life.

Studies in several countries showed that people employed various adaptive behavior during hot-weather periods (Abrahamson et al., 2009; Kalkstein and Sheridan, 2007; Sampson et al., 2013; Sheridan, 2007). The measures reported throughout the studies can be categorized into three types: changes in routines (for example drinking more fluids) and changes of daily routines themselves (for example shifting activities to other parts of the day, seeking cooler places). The third group is the use of available technical or structural measures to modify the indoor environment (ventilation, shading, fans, and primarily in the studies in the USA, air condition). The implementation rate of the various measures and strategies to cope with and adapt to the heat, however, was rather variable and ranged from a third of respondents (Pfaffenbach and Siuda, 2010), half of respondents (Kalkstein and Sheridan, 2007; Sheridan, 2007) to two thirds of respondents (Großmann et al., 2012). At the same time, also beliefs and attitudes turned out to be relevant in the context of heat-adaptive behavior. A few studies (Kalkstein and Sheridan, 2007; Wolf et al., 2010) referred to respondents' reasoning that hot weather is normal during summer and to respondents' narratives that behavior changes in summer are just "common sense" (Kalkstein and Sheridan, 2007). Wittenberg et al. (2012) observed that respondents perceived persistent heat as a problem one is helplessly exposed to, indicating only a moderate attitude that heat stress is a problem one can actively cope with.

The outlined results from previous surveys on subjective heat stress suggest that lots of socio-demographic, health, and behavioral factors and many factors related to the built environment help to explain the observed differences. As these results have been obtained in bivariate analyses and comparisons, the previous studies, however, limit conclusions across the factors' effects on subjective heat stress and conclusions on major or minor determinants for subjective heat stress. Additionally, it is not yet clear what proportion of observed variability in subjective heat stress they actually explain. Furthermore, as for some of the mentioned studies the data collection took place

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without preceding pronounced hot-weather periods, the actual weather conditions and the fact that respondents had to rely on their memories of heat experience might have influenced the responses (Abrahamson et al., 2009).

To identify the determinants of subjective heat stress of urban citizens and contribute to the further understanding of heat stress of urban citizens, we conducted a questionnaire survey directly after a heat wave in 2013 in Karlsruhe, Germany. The general aim of the study was to investigate individual heat as experienced in the context of everyday life and to identify determinants for subjective heat stress in an approach combining potential factors for subjective heat stress related to health, social characteristics, coping behavior, and the spatial structures in the built urban environment.

3 Methods

3.1 Concept of the study

Karlsruhe, a city with approximately 300 000 inhabitants, is located in the Rhine Valley in Southwest Germany. The Karlsruhe weather station of the German Weather Service (DWD) has been providing a very long time series of meteorological measurements since 1876, which allows analyzing climate trends. Since the station was located within the city area of Karlsruhe until 2008, the measured temperatures are representative of the urban climate (in 2008, the Karlsruhe weather station was moved to its present location "Rheinstetten", just south of Karlsruhe). These data have been revealing a positive trend in summer temperatures. The number of hot days with daily maximum temperatures $\geq 30\,^{\circ}\mathrm{C}$ increased from 6 days per year during the time period 1881 to 1910 to 16 days per year during the period 1971 to 2000. Also, the number of tropical nights (daily minimum temperatures $\geq 20\,^{\circ}\mathrm{C}$) increased from 0.5 in 1881 to 1910 per year to 1.2 in 1971 to 2000 (data source: German Weather Service). Until 5 July 2015, Karlsruhe held the temperature record for Germany of $40.2\,^{\circ}\mathrm{C}$ measured

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during the heat wave in August 2003.[1] As climate model simulations project a warming over Germany in the future (Wagner et al., 2013), the city of Karlsruhe is expected to experience more heat waves. In the city's strategy to adapt to climate change, preventing future heat wave impacts through public health measures, information and communication and various urban planning adaptations is of high priority (Stadt Karlsruhe, 2013). Karlsruhe thus provides a suitable setting for a study on subjective heat stress.

In the summer of 2013 when the survey was carried out, all summer months June, July, and August had a positive temperature anomaly compared to the climatological reference periods 1961 to 1990. From 17 to 19 June, three hot days and a maximum temperature of 34.4 °C and two tropical nights were measured. July was very warm, with a mean temperature of 22 °C, which means an anomaly of 2.9 K, and a maximum temperature of 38.1 °C. According to the heat wave definition by Tinz et al. (2008) describing a heat wave as a period of at least five consecutive hot days, a heat wave with 8 hot days in a row occurred from 16 to 23 July. In August, again four consecutive hot days were measured with a maximum temperature of 36.8 °C on 2 August (Mühr, 2014). As the new Rheinstetten DWD station is not located directly within an urban area, it can be assumed that the temperatures in parts of the city of Karlsruhe were higher due to the urban heat island effect. During both mentioned hot weather periods, the DWD had issued heat warnings for Karlsruhe with forecasted apparent temperatures of 34 to 36 °C and 38 °C corresponding to a strong, respectively a extreme thermal stress. The weather conditions were therefore appropriate for a survey on subjective heat stress.

In the concept of the study, subjective heat stress in everyday life experience was operationalized as subjective heat stress *in general*, *at home,* and *at work* as dependent variables and put in the context of subjective heat stress during twelve further typical daily activities. To identify the main determinant of heat stress, a wide

[1]On 5 July 2015, a new official German temperature record of 40.3 °C was measured at the DWD weather station "Kitzingen".

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range of factors associated with heat stress reported in previous research was considered. They included health (subjective health status, health symptoms, and impairments from the heat), negative coping attitude (agreement to the statement that one is helplessly subjected to the heat), coping behavior, elements of the urban built environment, and a number of social demographic characteristics. Characteristics of the type of work (sitting, standing, mentally or physically challenging, work clothes), and work place (outdoors, indoors, air conditioned, individual office, home office) were also included.

The coping measures referred to actions that can be performed immediately with the "here and now" capacities (Birkmann et al., 2013, p. 193). They were derived from public information material on behavior during heat and from previous research, in particular from the studies by Großmann et al. (2012) and Abrahamson et al. (2009). On the one hand, they covered measures targeted to the physical well-being during the heat that can be easily integrated in daily activities (such as drinking plenty of fluids) or that require changing daily activities to a certain extent (such as seeking cooler places, allowing breaks or slowing down, shifting work or activities). On the other hand, the coping measures comprised a set of structural and technical means of modifying the indoor environment (air and shade rooms, air conditioning, fans).

The elements of the urban built environment covered housing conditions and the spatial structures of the urban built environment tested in other previous studies in German cities (Großmann et al., 2012; Pfaffenbach and Siuda, 2010; Wittenberg et al., 2012). They included the residential district, a list of building characteristics (type of building, level used, use of multiple levels, building elements such as shutters or air conditioning, outdoor recreational elements such as balcony or garden, thermal insulation) and distance to the next public garden. The concept of the study was translated into a questionnaire that combined standardized questions with Likert scales, ordinally and categorically coded answers, and open-ended questions.

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3.2 Data collection and sample

The survey took place from 9 August until 25 September 2013 after the heat wave in July and the hot-weather period in August with heat warnings by the DWD. Data were collected with an online version of the questionnaire that was available on the web page of the South German Climate Office at KIT and that was advertised in the local and social media. Parallel to the online survey, the senior citizens' office of the City of Karlsruhe sent a paper-pencil version of the questionnaire to groups of senior citizens.

In total, 323 respondents living in Karlsruhe participated in the survey, 249 of them online and 74 using the paper-pencil questionnaire. 159 of the respondents were female, 158 male. The age of the respondents ranged from 17 to 94 years. Compared to the Karlsruhe population, the sample was somewhat younger (population mean age 47.6 years vs. sample mean 43.6 years), and the proportion of respondents with an academic degree higher (25.0 % in the population vs. 47.3 % in the sample). The respondents represented almost all districts of Karlsruhe (see Fig. 1a) and different housing conditions. Corresponding to the high education level, most of the economically active respondents worked in mentally challenging jobs (89.4 %), mainly sitting (85.8 %) indoors (95.3 %). Only 6.3 % carried out physically demanding jobs and 3.6 % worked outside. In sum, data collection resulted in a sample suitable to explore relevant potential determinants of subjective heat stress in general and at home. However, the possibility of analyzing subjective heat stress at work is limited because of too little response spread in the characteristics of work type and work place and because of the fact that the resulting subgroup sizes are unsuitable for statistical comparisons.

3.3 Data analysis

Data were analyzed using the program IBM SPSS version 21. First, a descriptive univariate analysis was carried out to explore respondents' heat stress in different contexts of daily life, health impairments experienced during heat, their coping attitude,

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and what measures they used to cope with the heat. In order to understand what makes a difference for low or high heat stress in general, at home and at work, in the next step bivariate correlations and significant differences were tested with variables representing health, socio-demographic characters, coping measures, and elements of the spatial built environment. As the three dependent variables of the study, heat stress in general, at home, and at work, and also a number of other variables were either not normal distributed or coded on an ordinal level, Spearman's rank correlation coefficients and non-parametric statistical tests were applied.

Finally, three multiple regressions for heat stress in general, heat stress at home, and heat stress at work were performed to identify their main statistic determinants. Into the regression model those variables referring to health, beliefs, coping measures, social demographic variables, and the built environment were entered as independent variables that yielded significant results in bivariate analysis and that were plausible given the empirical evidence gained in other studies.

The analysis of subjective heat stress at work considered only the economically active respondents (54.5 %) and the students/trainees (21.7 %). Students were included based on the assumption that in the perspective of everyday life experience, the students' and trainees' time and performance requirements in the course of the day correspond to requirements of working life independently of earning an income with their work.

A number of variables first required transformation to test them against subjective heat stress. For health impairments, for each respondent, a score was calculated summarizing the frequency of health impairments reported in relation to the total number of heat impairments with valid answers offered in the questionnaire given that eight of the nine health impairments contained valid answers (311 of the 323 respondents). Two scores counted the number of available structural elements of residential buildings: the heat protection score covered window shutters, roller shutters or sun-blinds mounted outside the windows, and air conditioning. The score for outdoor recreational elements comprised having a balcony or patio, a backyard that can be

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used for leisure, and a garden. A third score summarized the number of six thermal insulation elements known by the respondents: (1) insulation of the attic or (2) the exterior wall, (3) insulated glazing, (4) green façade, (5) having thick walls typical of buildings before 1920–1930, and (6) energetic refurbishment in the last 10 years.

Regarding the residential district of the respondents, the 27 city districts of Karlsruhe were classified into four categories (see Fig. 1b). These categories corresponded to settlement density and heat loading as modeled in studies for Karlsruhe based on an urban climate model (Nachbarschaftsverband Karlsruhe [Karlsruhe Neighborhood Association], 2013) and on a combined approach using weather stations and remote sensing data to estimate the urban heat island effect for Karlsruhe (Bach et al., 2013). In the presented study, the two districts in the city center represent the districts with the highest settlement density and highest heat loading. The adjacent four urban districts (south, southwest, east, and west of the city center) represent the category with dense urban settlement at high heat loading. Eleven districts with urban and suburban characteristics form the third category corresponding to a moderate heat loading, and ten suburban districts that either are located out of town or close to adjacent forests correspond to the category with the lowest heat loading.

4 Results

4.1 Subjective heat stress, health impairments, and coping with the heat

The responses in the boxplots in Fig. 2 show that referring to the median of 7 and 6 on a scale from 1 to 9, the majority of the 323 respondents experienced heat *in general*, *at home*, and *at work* to a rather high extent as stressful. At the same time, the boxplots indicate a high individual variability for all of the three heat stress variables. Wilcoxon signed-rank tests, however, showed that the subjective heat stress at home was significantly lower than the overall general subjective heat stress ($z = -4.036$, $p = 0.000$) and the heat stress at work ($z = -2.529$, $p = 0.011$).

Figure 3 displays how respondents experienced heat as stress in twelve typical situations and activities in daily life. More than half of the respondents reported "strong" or "very strong" heat stress in public transport (54 %), in the city center (53 %), and almost half of them at home while sleeping at night (46 %), and at work (41 %). The intensity of experiencing heat as stress was somewhat lower during leisure activities, while being on one's way, doing the housework or being at home during daytime. The lowest percentages of heat experienced as stress were reported for being outside in gardens, parks or pools/lakes, while doing shopping, and while being in the car, which in the two latter cases can be explained by the fact that most cars and shops or shopping centers are equipped with air conditioning. The responses shown in Fig. 3 also reveal that due to individual daily routines and life styles, the activities or situations to experience heat did not apply equally to all respondents.

The majority of respondents reported either a very good (29.4 %) or good (43.3 %) subjective health status. Respondents aged 65 years and older significantly more often expressed an impaired or strongly impaired state of health than the younger ones, χ^2 (24, $n = 319$) = 128.66, $p = 0.000$. The health impairments during the heat that respondents most often reported were excessive sweating, feeling tired, sleep disturbances, and concentration problems (see Fig. 4). Only for a small proportion of the sample, circulatory problems, headaches, feeling sick, and the worsening of existing diseases were frequent health problems. Respondents with a lower, impaired or strongly impaired, subjective health status significantly more often reported worsening of existing diseases ($\chi^2 = 111.34$, $p = 0.000$), circulatory problems ($\chi^2 = 66.66$, $p = 0.000$), headaches ($\chi^2 = 26.96$, $p = 0.008$), and feeling sick ($\chi^2 = 25.11$, $p = 0.014$). Elderly persons above 65 years significantly more often reported worsening of existing diseases ($\chi^2 = 35.5960$, $p = 0.000$) and having circulatory problems ($\chi^2 = 25.49$, $p = 0.013$), but less often concentration problems ($\chi^2 = 43.80$, $p = 0.000$; Chi-square tests with twelve degrees of freedom in each case, $n = 305$ to 314). The mean of 2.40 on the health impairments score (SD = 0.60, score range 1 to 4) indicates that

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the number and frequency of health symptoms suffered during the heat resulted on average in a modest health impairment rate.

Whereas the agreement among the respondents to the negative coping attitude, i.e. their being subjected to the heat without being able to do anything against it, was rather high (mean = 3.36, SD = 1.10 on a scale from 1 to 5), the majority of them implemented measures to cope with the heat. As can be seen in Fig. 5, almost all participants employed basic behavioral measures that focused on physical well-being during the heat and could be integrated into the daily routine without changing it substantially, such as drinking plenty of fluids, wearing light clothes, eating lighter meals. Among the other behavioral measures that imply more or less substantial changes or alternations in daily routines and thus may require certain flexibility, avoiding the direct sun, cooling the body, and avoiding exertion or exercise were implemented most by the respondents. To a lesser extent, the respondents sought cooler places, allowed themselves breaks and slowed down or shifted work or activities to other (cooler) times of the day. At the same time, approximately up to a third of all respondents would have employed the three latter measures if they had had the possibility to do so. Out of the structural and technical measures to keep the indoor temperature at a tolerable level, almost all respondents used ventilation and shading of their rooms. Fans and in particular air-conditioning (9.8 %) were used less frequently. However, with 43.6 %, a reasonable percentage of respondents would have switched on the air conditioning if they had had the possibility to do so.

Female respondents more frequently changed over to lighter meals ($\chi^2 = 7.37$, $p = 0.007$) and lighter clothing ($\chi^2 = 3.89$, $p = 0.049$) and more often avoided exertion or exercise ($\chi^2 = 4.77$, $p = 0.029$). Male respondents more often used air conditioning ($\chi^2 = 6.32$, $p = 0.012$; d$f = 1$ in each case, $N = 301$ to 316). Regarding age, in particular the respondents aged 65 years and older shifted their activities more often to other times of the day ($\chi^2 = 41.605$, $p = 0.000$) or allowed breaks and slowing down ($\chi^2 = 55.88$, $p = 0.000$). They also more often sought cooler places to evade the heat

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($\chi^2 = 26.89$, $p = 0.000$), and more often avoided direct sun and exertion ($\chi^2 = 11.75$, $p = 0.019$, $\chi^2 = 31.83$, $p = 0.000$ respectively; df = 4 in each case, $n = 307$ to 318).

4.2 What makes a difference for subjective heat stress?

The correlation coefficients (Spearman's rho) listed in Table 1 show that subjective heat stress *in general* correlated rather high with the health impairment score, the agreement to the statement "one is helplessly subjected to the heat", and only weakly correlated with the subjective health status, which in turn was weakly correlated with the heat impairment score. For subjective heat stress *at home* and *at work*, the respective correlation coefficients are somewhat lower, and there is no significant correlation with the subjective health status.

Regarding social demographic and economic characters, the respondents mainly differed in their experiencing heat as stress *at home*, and to a lesser extent, respectively not at all for subjective heat stress *in general* and *at work*. Table 2 lists the test results for subjective heat stress at home. The female respondents reported less subjective heat stress at home than the male ones. The younger respondents in the sample (up to 24 years) represented the group with the highest subjective heat stress levels at home. Against this, the respondents aged 65 years and older reported the lowest levels of subjective heat stress. Respondents who lived with their partner with or without children reported lower subjective heat stress at home than single parents, respondents living alone or living in shared flats. Students and trainees reported significant higher stress levels than employed respondents (full- and part-time) and the retired respondents. Similar to heat stress *at home*, the retired also reported lower subjective heat stress *in general* than the rest of the sample (χ^2 (4, $n = 319$) = 11.293, $p = 0.046$; Kruskal–Wallis Test).

Only five out of the twelve measures listed in the questionnaire showed significant differences in subjective heat stress (Table 3). Seeking cooler places, allowing oneself to rest, and using the air conditioning were more often associated with lower subjective heat stress *at work*. Against this, the other significant differences point in the opposite direction: avoiding the sun was more often associated with higher heat stress levels for all three contexts of heat stress, using the air condition with higher stress levels in general and at home, and using the fan with higher heat stress levels at home.

The respondents differ significantly in their subjective heat stress at home for almost all elements of the residential building and the surrounding urban environment included in the questionnaire, but not for subjective heat stress in general or at work. The test results for subjective heat stress at home are listed in Table 4. They show that regarding the heat loading of the district the respondents live in, the higher the heat loading, the higher on average (median) also the subjective heat stress level at home. The respondents living in a one- or two-family home and the respondents who have the possibility to use multiple floors in their home reported lower subjective heat stress levels than those living in multiple-unit dwellings or in apartment towers. The group of respondents living in apartments in the upper levels and in particular in attics expressed higher subjective heat stress at home than respondents living in apartments in the ground level. Based on the median values listed in Table 4, however, a steadily increasing row of subjective heat stress with increasing level in the building was not observed.

Regarding the scores for the number of heat-protective elements, the number of possibilities to sit outside, and the number of known insulation elements, the test results listed in Table 4 show that having none or a low number of elements in each case is associated with higher levels of subjective heat stress experienced at home. The respondents having no heat- protective element (neither shutters nor blinds mounted outside to shade the window, nor air conditioning) disproportionately often lived in apartments in the attic (χ^2 $(12, n = 308) = 25.50$, $p = 0.012$). Only for the walking distance to the next public green, no significant difference in the level of subjective heat stress at home could be observed.

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4.3 Determinants of subjective heat stress

Table 5 lists the results of the multiple regression analyses to identify which of the variables making a difference at the bivariate level are the main statistic determinants for subjective heat stress in general, heat stress at home, and heat stress at work on a multivariate level of analysis. With resulting determination coefficients R^2_{corr} of 0.567 for heat stress in general, 0.458 for heat stress at home, and 0.379 for heat stress at work, the regression models yielded moderate, yet satisfactory results in terms of the variance explained.

As can be seen from the standardized beta coefficients in Table 5, first, not all of the variables that yielded significant differences in bivariate analyses turned out to have a significant effect also in the multiple regressions. Second, while health impairments and the feeling of being helpless had a significant positive (increasing) effect for heat in general, at home, and at work, the other determinants varied for heat stress in general, at home, and at work, and they varied in the direction of their effect. A number of characteristics of the residence significantly influenced the subjective heat stress at home only. Both the heat loading of the district and the level used in the building had an effect, whereby living in districts with higher heat loading or living on a higher level in a building increased subjective heat stress at home. The possibility to use more than one level at home, a higher number of available heat protection elements, a higher number of possibilities to sit outside, and a higher number of known insulation elements showed a decreasing effect on heat stress at home.

Among the measures, seeking cooler places and using air condition had a significant negative, thus decreasing, effect on subjective heat stress at work. Against this and as already observed on the bivariate analysis level, avoiding the sun had a weak positive, thus increasing effect for the subjective heat stress in general, and using a fan had a positive effect for heat stress at home. The tested demographic variables, age and male gender, did not show significant effects in the models, as was the case for the subjective health status.

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5 Discussion

The presented results of the Karlsruhe questionnaire survey show that the 323 respondents differ in their individual experience of subjective heat stress and that the subjective heat stress experienced in the preceding hot weather period, on average, was rather high. In addition to inter-individual variances, the responses clearly show that individual subjective heat stress varies for different contexts, places, and situations in daily life. At the same time, they illustrate that subjective heat stress is ubiquitous in daily life, at home during day or at night while sleeping, at work, and during other typical daily activities such as being on one's way or during household activities. As shown in the multiple regression analysis, the health impairments from the heat and the feeling of being helplessly exposed to the heat explain the inter-individual variance in subjective heat stress experienced *in general*, *at home*, and *at work* to a satisfactory extent. In addition, characteristics of the residential building and its surroundings determine the level of subjective heat stress experienced at home, and coping measures tantamount to a cooler environment (seeking cooler places, air conditioning) determine subjective heat stress at work. Age did not turn out to be a determinant for subjective heat stress. The coping measures showed no uniform effect for the subjective heat stress in the multiple regressions. At the same time, however, the implementation rate of coping behavior among the respondents was remarkably high.

Like other German social-science studies on heat stress, the results of our study underpin that subjective heat stress is an issue not solely at home or at work but throughout everyday life. Similar to the explorative survey conducted during a hot-weather period in Leipzig in 2010 (Großmann et al., 2012), the average heat stress experienced by the Karlsruhe respondents was rather high, in particular compared to the studies by Pfaffenbach and Siuda (2010) in Aachen and by Wittenberg et al. (2012) in Nürnberg. As Pfaffenbach and Siuda (2010) carried out their study in late spring 2010 and Wittenberg et al. (2012) in summer 2011 without particular hot temperatures, the

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higher average value of subjective heat stress in the Karlsruhe survey can be explained by the immediate heat experienced prior to the survey.

The respondents in Karlsruhe applied more measures to adjust to heat than found in other studies in Germany and the US (Pfaffenbach and Siuda, 2010; Sampson et al., 2013; Sheridan, 2007). Yet, they showed no substantial qualitative difference in their general coping behavior. The observed coping behavior rather confirms the pattern also found in other studies (Großmann et al., 2012; Sheridan, 2007; Sheridan and Kalkstein, 2007) that simple behavior measures and available measures to keep the indoor temperature at a tolerable level were used more often than measures that change daily routines. Against their well-pronounced and actually implemented coping behavior, the Karlsruhe respondents agreed to a rather high extent to the negative coping attitude statement that heat is something one is helplessly exposed to, and about in a same range as observed by Wittenberg et al. (2012) in Nürnberg. Moreover, this certain range of a fatalistic attitude towards heat turned out to be one of the two major determinants of subjective heat stress at home, in general, and at work.

The health impairments suffered during the heat emerged as the second major determinant for subjective heat stress *in general*, *at home*, and *at work*. Even though respondents with a lower subjective general health status reported to be suffering more often from health impairments, the subjective health status did not contribute to the explanation of subjective heat stress. As mortality and hospital admission studies clearly showed that people with pre-existing diseases were at higher risk during heat waves (Conti et al., 2007; D'Ippoliti et al., 2010; Foulliet et al., 2006; Scherber et al., 2014; Vandentorren et al., 2006), this result needs further explanation. Based on the everyday-life approach of the study, the health symptoms experienced during heat listed in the questionnaire did not follow the terminology of the International Statistical Classification of Diseases (ICD) as used in mortality studies. The presented results thus rather indicate how frequent, yet less serious impairments such as sweating, feeling tired, sleep disorders, concentration problems, headaches, and feeling sick determine subjective heat stress in everyday life. Additionally, the health impairments

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score entered into the regression was calculated using the type and frequency of impairments as reported by respondents and is thus dominated by health symptoms that may not represent the beginning of a lethal chain during heat. In this respect, the results of the study are not contradictive to the evidence from mortality status. They rather underline how even less serious health impairments significantly contribute to subjective heat stress of healthy citizens with a predominantly good or very good subjective health status and therefore complement the evidence from mortality studies.

The elements of the residence and the urban environment tested in the survey turned out to be determinants for subjective heat stress at home only. The elements making a difference for subjective heat stress confirm results of previous surveys in German cities by Großmann et al. (2012) and Pfaffenbach and Siuda (2010). Moreover, they are in line with results obtained in temperature-related indoor and outdoor heat discomfort studies regarding the location of the level within the building (Langner et al., 2014; White-Newsome et al., 2012). The decreasing effect of available elements of heat protection, outdoor recreation, and thermal insulation in the residential buildings on the subjective heat stress at home clearly illustrates at the same time that such structural measures are felt by building dwellers during hot weather periods.

In the context of available heat protection in residential buildings, the most prominent structural or technical measure among the Karlsruhe respondents to modify indoor temperatures was to air and shade their rooms. Air condition in residential buildings is not widespread in Germany as in the US, however the fairly large proportion of 45 % of the respondents who would have switched on air condition if they had the possibility to do so indicate that air condition in residential buildings was an issue for the respondents during hot weather periods in Germany as well. More important in the German context of structural urban adaptation to heat is to mention however that not all respondents lived in buildings equipped with shutters they can use to shade their windows.

Against the expectation from the overwhelming findings of mortality studies and against the findings by Pfaffenbach and Siuda (2010), in the Karlsruhe study age did not turn out as a significant determinant for higher subjective heat stress. Rather on the

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contrary, elderly respondents reported lower heat stress at home and in general than younger respondents. Großmann et al. (2012) observed similarly surprising lower heat stress levels of elderly persons and attributed this to the effect that they were able to apply more measures that change daily routines due to freedom from work constraints and consequently higher coping capacities. While a higher implementation rate of such measures by elderly persons was also found among the Karlsruhe respondents, there are more aspects in the data to explain the lower subjective heat stress of the elderly. First, as the elderly more often lived in districts with a lower heat loading and in single family homes which were also associated with lower subjective heat stress levels, the finding of lower subjective heat stress of the elderly can be attributed to a socio-spatial effect in the sample. In their spatial analysis of heat-related hospital admissions due to respiratory diseases during the summer months in the city of Berlin, Scherber et al. (2014) similarly observed that the elderly (> 64 year-olds) more often lived in areas with lower population density outside the city center and therefore in districts with lower heat loadings. Second, the elderly in the sample were either involved in the survey through the distribution of the questionnaire among the network of senior groups of the senior citizens' office of the city of Karlsruhe or they filled in the online questionnaire. They therefore represent elderly persons who are active, take part in social activities or are in reach of social services, and not the frail, bedridden elderly persons who are most vulnerable to heat. This is, admittedly, a general problem of questionnaire studies (Bassil and Cole, 2010; Klinenberg, 2002).

Furthermore, studies have shown that the elderly's perception of their own vulnerability to heat due to age often does not correspond to their higher health risk during heat (Abrahamson et al., 2009; Wolf et al., 2010). In physiological terms, ageing is associated with intrinsic changes in the thermoregulation and with impaired homeostasis with the result that elderly persons may not be aware of getting ill from high temperatures; additionally, the use of drugs may interfere with the thermoregulation of the body (Basu and Samet, 2002; Koppe et al., 2004). In this regard, the result of lower subjective heat stress felt and reported by the elderly in the

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sample is no contradiction. In addition to the socio-spatial and the self-selection effects in the sample, the lower subjective heat stress of elderly as found in the Karlsruhe study therefore could be attributed to a combination of changes in the effects of thermoregulation of the body and active coping behavior with changing daily routines more often than economically active persons.

Despite the variety and high implementation rate of measures to cope actively with the heat, no clear and uniform effect of the coping behavior on subjective heat stress was found. The results of our study suggest two reasons for this. First, the very high implementation rate of simple measures, such as drinking more fluids, resulted in very different sizes of subgroups, which implicitly limits the possibility of analyzing their effects. Thus, even if we were not able to observe significant differences in heat stress levels related to the measure of drinking more fluids or airing and shading the rooms, it cannot be concluded from the results of the study that this measures do not make a difference for subjective heat stress at all. Second, both on a bivariate and multivariate analysis level, the implementation of some measures, namely to avoid direct sun and use a fan, was associated with higher subjective heat stress at home. The chicken-and-egg question underlying this result i.e., the question whether the observed differences are an effect of the measure or whether implementing a measure is a result of high subjective heat stress and thus an indicator of higher heat stress, cannot be answered based on the presented study. These open questions, however, underline that further research on the effects of coping behavior on subjective heat stress is necessary to understand what type of and how adaptive measures help reduce heat stress. This is in particular the case as the results of the study also show that coping behavior during heat is performed within the daily (working) life which, in turn, poses constraints, limits, or opportunities – as can be seen in the case of the retired respondents – to implement certain measures.

The above has already indicated limitations of the study due to the composition and effects in the sample. As already mentioned in Sect. 3.3, the analysis of further variables for subjective heat stress at work e.g., type of work and work environment,

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was additionally limited and could not be included in the further investigation. Therefore, in particular the results on subjective heat stress at work have only limited statistical power and need further exploration and confirmation from other studies.

As mentioned before, Karlsruhe is located in the warmest region in Germany in the Upper Rhine Valley, and the residents of Karlsruhe already experience hot weather periods in the summer more often. This leads to the question whether Karlsruhe residents are better adapted to the heat than the residents of cities in regions of Germany with a cooler climate and whether their pronounced coping behavior during heat is already the result of a long-term learning and adaptation process. The Karlsruhe respondents, however, showed higher rates of coping behavior than respondents from cities in cooler regions in Germany but did not employ a different behavior pattern during heat than these. Furthermore, they did not differ from respondents in other studies (Wittenberg et al., 2012) regarding their negative coping attitude expressed by their rather high agreement to the statement that heat is something one is helplessly exposed to. Even if the pronounced actual coping behavior may suggest some type of incremental adaptation, the aim of the study was to investigate determinants of subjective heat stress experienced during a hot weather period. Options for adaptation to climate change that address change and transformation of the existing institutional and social arrangements (Birkmann et al., 2013; Kates et al., 2012; O'Brien, 2012) or institutional heat risk governance (Zaidi and Pelling, 2015) were not included in the questionnaire. The results of the survey thus cannot test or challenge the conclusion drawn by Ginski et al. (2012) i.e., the statement that residents accept the heat and adjust in the short term but do not see heat stress as a problem that can be targeted by preventive long-term adaptation measures in the building stock, in urban planning, and in the organization of working life.

Although the survey focused on subjective heat stress and coping behavior of the respondents in their everyday life, the results still suggest a number of recommendations for urban adaptation strategies to future heat waves beyond what has been already mentioned regarding buildings and urban structure. Given the results

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that health impairments from heat and the negative coping attitude are the ubiquitous factors of subjective heat stress, the results underline the need for prevention of health impairments. While hot temperatures and heat in summer are “normal” in common sense, it is important to challenge the belief that nothing can be done to cope better with the heat. Thus, in addition to heat warning systems, accompanying communication of measures to prevent heat stress and health impairments is important for learning and for building coping capacities towards future heat waves. Finally, as the coping with heat is performed by the respondents within the constraints and structures of daily life while they maintain the basic structure of daily routine, more research on the social processes and arrangements that limit or enable adaptation to heat is necessary.

6 Conclusions

After a hot weather period in July and August 2013, we conducted a survey on subjective heat stress experienced by urban citizens with 323 participants in the city of Karlsruhe, Germany. The results of the study confirm results of previous case studies on subjective heat stress in Germany carried out immediately after a heat wave. They furthermore extend the current understanding of the significant factors of subjective heat stress in the context of everyday life. While health impairments from the heat and the feeling of being helpless contributed with slightly different weight to explaining heat stress *in general*, *at home*, and *at work*, elements of the urban spatial environment and the residential building were factors of heat stress at home only. The coping measures yielded non-uniform results regarding their effect for subjective heat stress. Given the variation of significant determinants of subjective heat stress in general, at home, and at work, it can be concluded that the individual subjective heat stress is context-dependent and that the determinants of subjective heat stress differ upon context regarding relevance and type.

The results presented rely on an expressed-preferences approach to measuring subjective heat stress and confirm and complement results of other social-science

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studies based on subjective ratings of heat stress. In general, they also agree with the main findings of heat stress factors obtained in studies based on measurements of meteorological parameters combined with morbidity and mortality data or with thermoregulation models. Investigating the subjective experiencing of heat stress in a survey with reference to the immediate experience of a heat wave prior to the survey yielded valid answers that allowed extending the current understanding of determinants of subjective heat stress in everyday life. The results, on the one hand, illustrate how structural measures for heat protection of buildings, energy-efficient refurbishment of buildings motivated by energy savings and climate mitigation, and urban spatial measures that focus on green and well-being in the city, help reducing subjective heat stress during hot-weather periods. To develop socially appropriate adaptations that help reducing impacts of heat stress, the results, on the other hand, show that responses to heat are performed within the scope of action in daily life. Therefore, further research is needed to understand how various processes of daily social (working) life enable or limit individual coping and adaptation capacities and how this may be fed into adaptation strategies.

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Table 1. Correlations (Spearman's rho) for subjective heat stress.

Spearman's rho (*n*)	(1)		(2)		(3)	
Subjective heat stress						
(1) ... in general	–					
(2) ... at home	0.500***	(313)	–			
(3) ... at work	0.570***	(254)	0.245***	(250)	–	
Health impairment (score)	0.637***	(308)	0.357***	(305)	0.456***	(253)
Subjective health status	0.134*	(318)	−0.066	(316)	0.009	(255)
Negative coping attitude	0.658***	(316)	0.466***	(313)	0.533***	(252)

Note. Heat stress in general, at home, and at work is measured on a scale from 1 (not at all) to 9 (very strong). The negative coping attitude was measured with the agreement to the statement "one is helplessly subjected to the heat" on a scale from 1 (no agreement at all) to 5 (strong agreement).
$^{*}p < 0.05$. $^{***}p < 0.001$.

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Table 2. Differences in subjective heat stress at home by sociodemographic variables.

Variable	Category	n	Median	Test statistics
Gender	female	156	5	$Z = 2.679^{**}$
	male	155	6	
Age groups	up to 24 years	72	7	$\chi^2 = 35.731^{***}$
	25–34 years	65	6	
	35–49 years	58	6	
	50–64 years	59	5	
	65 years and older	61	4	
Living conditions	with partner and children	44	4	$\chi^2 = 20.818^{***}$
	with partner	108	5	
	single parent	10	7	
	alone	86	6	
	flat share	62	7	
	assisted living communities	3	3	
Occupational status	not economically active	4	7	$\chi^2 = 41.987^{***}$
	student/trainee	77	7	
	retired	61	4	
	unemployed	1	7	
	part-time employed (< 70 %)	30	4	
	full-time employed (> 70 %)	143	6	

Heat stress measured on a scale from 1 (not at all) to 9 (very strong). Test statistics: Chi-square values obtained in Kruskal–Wallis tests for three and more independent samples, Z values obtained in Mann–Whitney U test for two independent samples.
$^{**}p < 0.01$, $^{***}p < 0.005$.

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Table 3. Differences in subjective heat stress by implemented measures.

Measure	Heat stress in general			Heat stress at home			Heat stress at work		
	n	*M*	*Z*	*n*	*M*	*Z*	*n*	*M*	*Z*
Avoid sun			-3.865^{***}			-2.082^{*}			2.274^{*}
not implemented	46	4		46	5		41	6	
implemented	272	7		269	6		214	7	
Seek cooler places			−1.845, ns			−1.910, ns			-4.494^{*}
not implemented	160	7		159	6		147	7	
implemented	150	6		149	5		107	6	
Slow down, allow oneself rest			−0.591, ns			−1.435, ns			2.042^{*}
not implemented	148	7		148	6		143	7	
implemented	170	7		167	5		112	6	
Air conditioning			-2.092^{*}			-2.773^{**}			-2.388^{*}
not implemented	274	6		272	6		225	7	
implemented	30	7		29	7		28	5	
Use of fan			−1.730, ns			-2.470^{*}			−1.556, ns
not implemented	169	7		168	5		129	7	
implemented	141	7		140	6		126	7	

Note. *M* = Median; *Z* values obtained in Mann–Whitney *U* test for two independent samples; ns = not significant. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.005$.

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Table 4. Subjective heat stress at home by structural building elements and urban environment.

Element	Category	*n*	Median	Test statistics
Heat loading of residential district	Category 1 (lowest)	44	4	$\chi^2 = 26.248^{***}$
	Category 2	130	5	
	Category 3	116	7	
	Category 4 (highest)	27	7	
House type	One or two-family home	50	4	$\chi^2 = 25.095^{***}$
	Multiple dwelling unit	239	6	
	Apartment tower	24	7	
Multiple levels	lives on one level	286	6	$Z = -4.689^{***}$
	lives on multiple levels	31	3	
Level*	Ground level	61	5	$\chi^2 = 28.603^{***}$
	Lower levels	54	6	
	Middle levels	48	4	
	Upper levels	57	7	
	Attic	66	8	
Heat-protective elements on building (score)	0 Element	28	8	$\chi^2 = 23.265^{***}$
	1 Element	185	6	
	2 Elements	84	5	
	3 Elements	6	4	
Possibilities at home to be outside (score)	0 Element	53	7	$\chi^2 = 35.571^{***}$
	1 Element	104	7	
	2 Elements	99	5	
	3 Elements	45	4	
Known insulation elements (score)	0 Element	78	7	$\chi^2 = 36.165^{***}$
	1 Element	67	6	
	2 Elements	49	6	
	3 Elements	46	6	
	4 Elements	31	4	
	5 Elements	27	5	
	6 Elements	19	4	
Walking distance to next public garden	1 to 5 min	164	6	$Z = -1.547$, ns
	> 5 min	130	6	

Note. Test statistics: Chi-square values obtained in Kruskal–Wallis tests for three and more independent samples, Z values obtained in Mann–Whitney U test for two independent samples.
* Without respondents living on multiple levels.
ns = not significant, $^{***}p < 0.005$.

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Table 5. Determinants of subjective heat stress (multiple regression).

Dependent variable	Subjective heat stress in general	Subjective heat stress at home	Subjective heat stress at work
Model summary	R^2 =0.769, R^2_{corr} = 0.568, F(16, 279)= 5.262, $p < 0.000$	R^2 = 0.699, R^2_{corr} = 0.459, F(16, 279)= 16.641, $p < 0.000$	R^2 = 0.651, R^2_{corr} = 0.383, F(16, 230)= 10.560, $p < 0.000$
Independent variables[a]	β	β	β
(Constant)	–	–	–
Health impairments from heat	0.408***	0.241***	0.295***
Health status	ns	ns	ns
Belief "feel helplessly subjected to heat"	0.412***	0.244***	0.354***
Avoid direct sun	0.128***	ns	ns
Seek cooler places	ns	ns	−0.151**
Allow oneself to rest	ns	ns	ns
Use air conditioning	ns	ns	−0.138*
Use a fan	ns	0.104*	ns
Heat loading category of residential district (1–4)	ns	0.122**	ns
Resides on more than one level	ns	−0.097*	ns
Level category	ns	0.155***	ns
Heat protection elements score	ns	−0.098*	ns
Possibilities sitting outside score	ns	−0.141***	ns
Thermal insulation elements score	ns	−0.135***	ns
Age (classes)	ns	ns	ns
gender (male)	ns	ns	ns

Note: [a]Regression method: enter. β = standardized regression coefficient. ns = not significant, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.005$.

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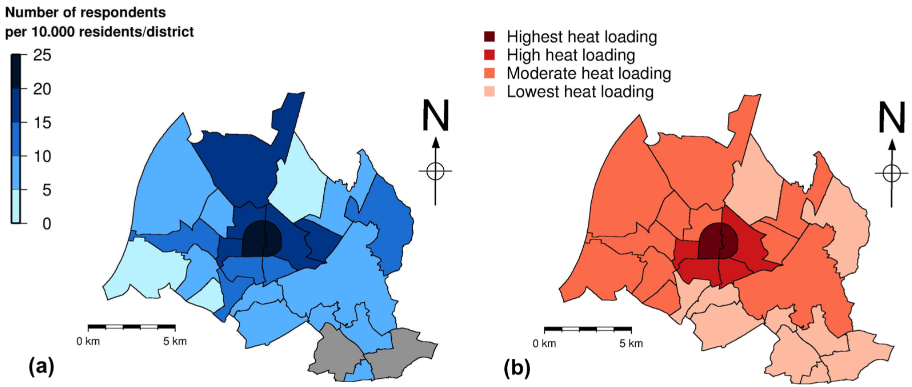

Figure 1. (a) Number of respondents in districts of Karlsruhe per 10 000 inhabitants/district. **(b)** Category of heat loading assigned to the 27 districts of Karlsruhe. Gray color in figure **(a)** indicates that there was no participation from this district in the study.

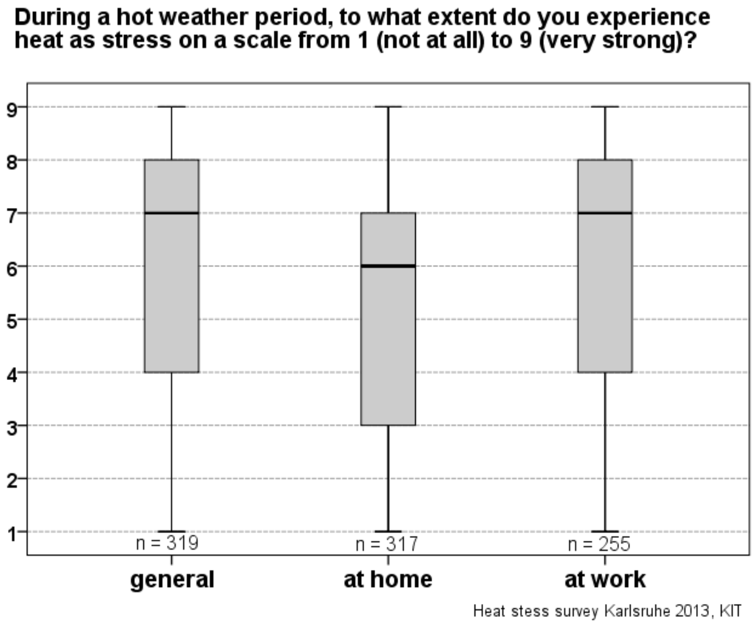

Figure 2. Boxplots for subjective heat stress experienced in general, at home, and at work. Only economically active respondents and students/trainees answered the question on heat stress at work.

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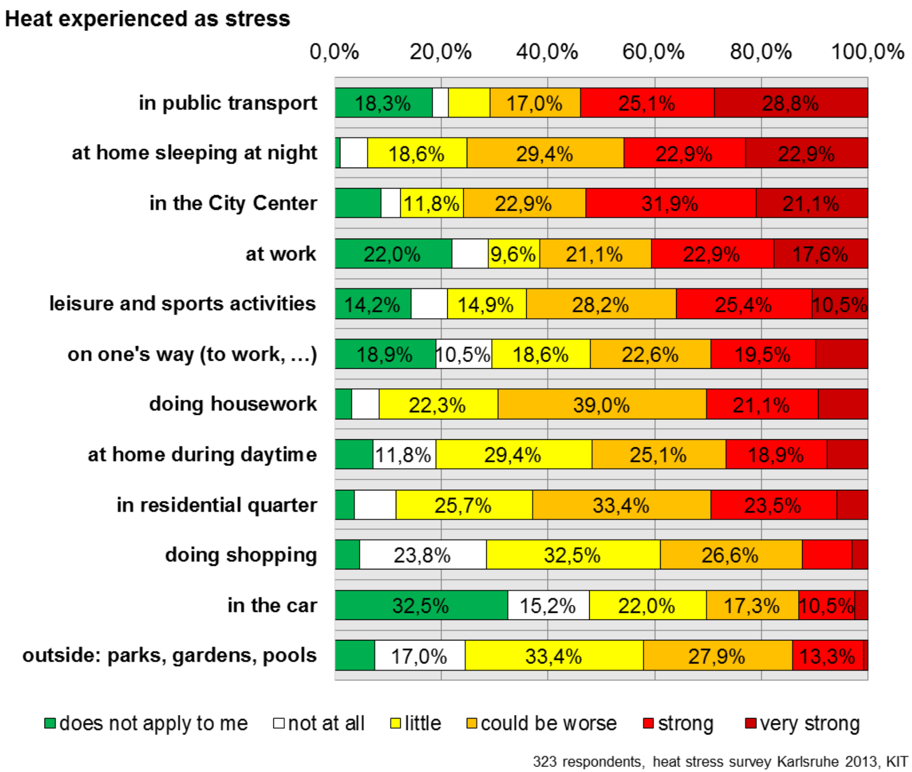

Figure 3. Subjective heat stress experienced by respondents in typical daily activities. Exact numbers for percentages below 10 % are not indicated in the figure.

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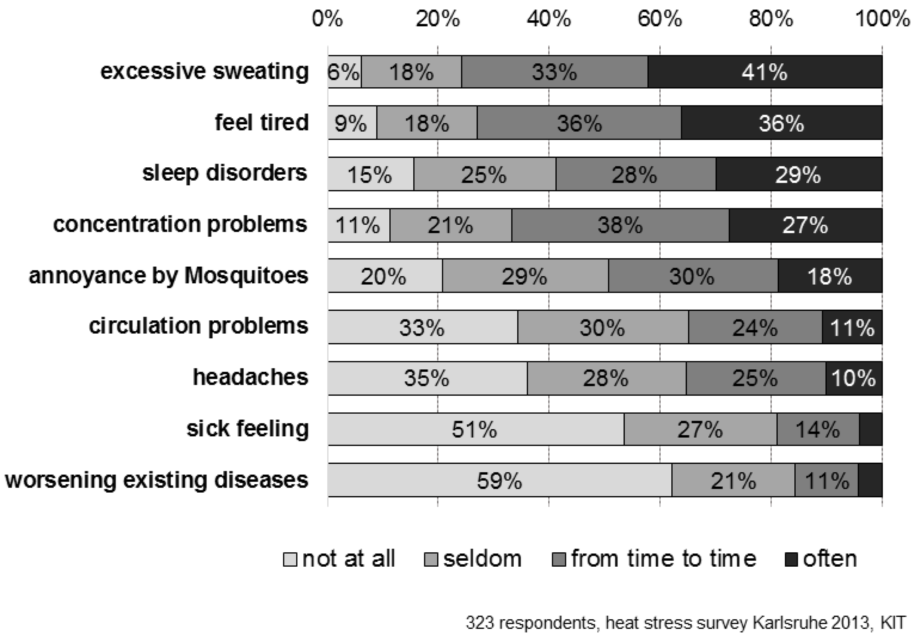

Figure 4. Type and frequency of health impairments from heat reported by respondents. Exact numbers for percentages below 5 % are not indicated in the figure.

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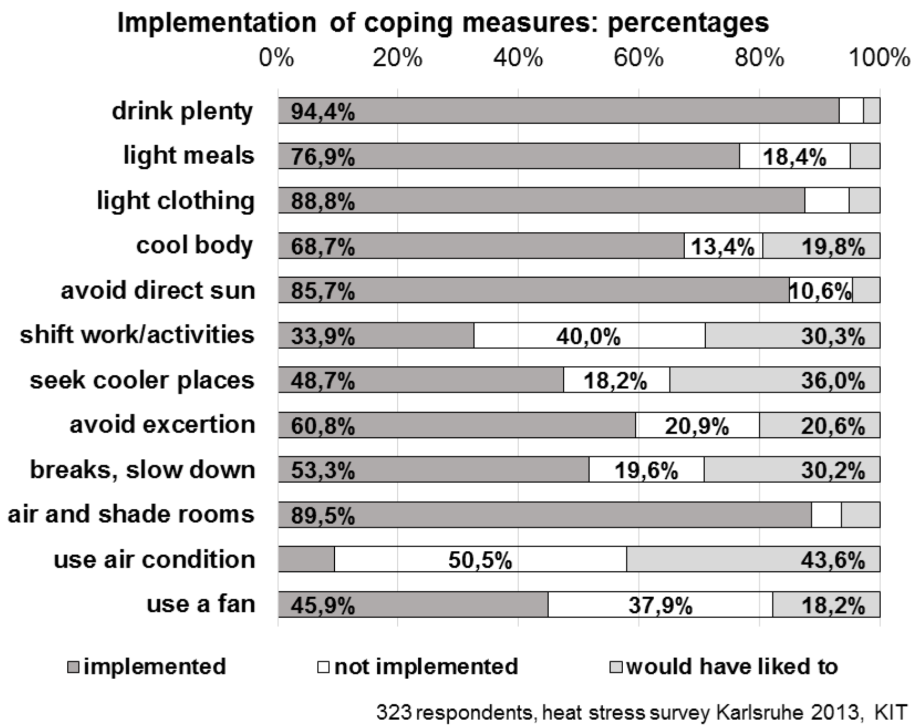

Figure 5. Implementation of coping measures: percentages of respondents. Exact numbers for percentages below 10 % are not indicated in the figure.

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