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Heat adaptation measures in private households: an application and adaptation of the protective action decision model

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Extreme heatwaves will occur more frequently and with higher intensity in future. Their consequences for human health can be fatal if adaptation measures will not be taken. This study analyses factors related to heat adaptation measures in private households in Germany. During the summer months of 2019, indoor temperatures were measured in over 500 private households in the City of Augsburg, Germany, accompanied by a survey to find out about heat perception and adaptation measures. Hypotheses deducted from the Protective Action Decision Model were tested using one-way ANOVAs, regression analysis and in the end a multiple hierarchical regression model. The results of the hypotheses tested imply an influence of knowledge and heat risk perception of heat adaptation behaviour and an influence of age on heat risk perception. The results of the regression model show an influence of the efficacy-related attribute, of age, indoor temperature, subjective heat stress and health implications to heat adaptation behaviour. In the end, this study proposes adjustments to the PADM according to the results of the hierarchical regression analysis.

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Introduction

The probability of hazardous heatwaves caused by climate change is rising steadily (IPCC, 2019). By 2100, the exposure to extremely high temperatures is expected to be four to eight times higher than in the 2010s (Wang et al., 2020). Additionally to the rising temperatures, the latest revision of the World Urbanization Prospects by the United Nations suggests that by 2050 almost 70% of the world's population will live in urban areas (United Nations, Department of Economic and Social Affairs, Population Division, 2019) which results in urban heat islands with a very slow heat release overnight (Manoli et al., 2019). This is an extreme challenge for cities and communities as research has shown the association between human mortality and heatwaves and how the growing risk for human life seems inescapable in future (Mora et al., 2017).

At the same time, studies imply that heat wave and health impact research is necessary, especially in regions that are not experienced extreme temperatures during the summer months (Campbell et al., 2018). According to the 2020 report of The Lancet Countdown on health and climate change (Watts et al., 2020), heat has caused a 50% increase in global heat-related deaths among people over 65 years from 2000 to 2018. In the summer of 2018, there were over 20,000 cases of death caused by heatwaves in Germany alone according to model calculation. Additionally, the rising frequency and intensity of heatwaves are causing a rising probability of new infectious diseases (Watts et al., 2020). Therefore, in the literature, there are calls for taking more adaptation measures and developing strategies for protecting people from high-temperature exposure, especially during nighttime (Zhao, 2018; Alcoforado et al., 2015).

Studies aiming to explain heat adaptation behaviour found that risk perception has an influence (Esplin et al., 2019; Kim et al., 2014; Wolf et al., 2010), as well as being female or of older age (Esplin et al., 2019; Khare et al., 2015; Kim et al., 2014; Semenza et al., 2008). Other factors are income and education (Esplin et al., 2019; Khare et al., 2015; Semenza et al., 2008) as well as the social network around individuals (Klinenberg, 2015). However, protective behaviour against heatwaves is a complex construct. Climate change adaptation in general aims to reduce risks for vulnerable groups and increase their resilience to climate change consequences (Smit and Pilifosova, 2001). Wolf et al. (2010) examine the consequences of adaptation behaviour in preventing morbidity and mortality caused by heatwaves. In 2018, a study found that in German households the probability of adaptation behaviour rises by 2.3% for every degree celsius the mean temperature during summer is rising (Kussel, 2018).

Still, adaptation behaviour in private households in Germany is relatively low and often heat is not seen as a health risk. Especially the older generation shows lower perception of heat as a risk (Beckmann and Hiete, 2020) as well as lower subjective heat stress (SHS) (Beckmann et al., 2021) despite being part of a vulnerable group. Kussel (2018) found that the elderly also show lower probability to adapt. Therefore, policy should mainly aim to communicate among such vulnerable groups (Kussel, 2018). However, data on taken adaptation measures in private households, as well as on indoor temperatures is rather scarce. Even though knowing about influencing factors of adaptation behaviour—not only amongst vulnerable groups—leads to a better intervention against climate change consequences (White-Newsome et al., 2011).

Several theoretical frameworks were applied in previous studies about heat or climate change adaptation behaviour such as the Theory of Planned Behaviour (TPB) (Valois et al., 2020), the Health Belief Model (HBM) (Akompab et al., 2013), the Value Belief Norm (VBN) (Zhang et al., 2020) or the Protection Motivation Theory (PMT) (Murtagh et al., 2019). This study applies the Protective Action Decision Model (PADM), a theoretical framework that so far has not been applied in heat risk and heat adaptation literature, to shed light on people's heat adaptation behaviour. The availability of indoor bedroom temperatures of private households in this study requires a theoretical model that includes external stimuli or the exposure to a certain hazard (in this case heat) in the evaluation of influences on adaptation behaviour. The PADM includes this factor. The authors are not aware of a study that applies the PADM to heat adaptation behaviour. The results show which factors influence the implementation of heat protection measures in private households and give guidance on to whom communication should be directed in the first line.

Background theory

This section introduces theories that have been applied to heat adaptation or climate change adaptation behaviour and point out the differences and advantages of applying the PADM.

A very commonly applied theory is the *TPB*. It has recently been applied to investigate climate change adaptation in agricultural production while being compared to the VBN (Zhang et al., 2020), for heat adaptation behaviour in the elderly population (Valois et al., 2020), political ideology and threat perception that affects climate adaptation decisions (Schwaller et al., 2020) and for the link between knowledge and climate change adaptation among German forest owners (Hengst-Ehrhart, 2019). The TPB is an extension of the Theory of Reasoned Action both co-developed by Icek Ajzen. According to the TPB, the factors of attitude and perceived behavioural control, together with a person's subjective norm, create the individual intention for a specific behaviour. Thus, a person's perceived behavioural control together with his or her intention leads to a specific behaviour (Ajzen, 1991). The TPB has proven to be adequate for climate change adaptation studies and pro-environmental behaviour studies, including extending it by factors like moral obligation (Bamberg and Möser, 2007; Chen, 2016) or socioeconomic and communication variables (Arunrat et al., 2017).

The *VBN* is another framework found in the literature. It has commonly been used to analyse pro-environmental behaviour in various settings (Chen, 2016; Wynveen et al., 2015; Kim and Shin, 2017; Çakır Yıldırım and Karaarslan Semiz, 2019); whereas applications for climate change adaptation are scarce. One of the studies has been mentioned in the paragraph before together with the TPB (Zhang et al., 2020). Another example is Yousefpour et al. (2019) who applied the VBN to climate change adaptation in Singapore focussing on the rise of sea level. Literature, however, shows that risk perception is an important factor for climate change adaptation behaviour (Kalkstein and Sheridan, 2007). This factor is not part of the initial VBN model.

The *HBM* is another framework that can be found in climate change adaptation literature. In 2011, Semenza et al. applied the HBM to analyse a survey of 771 people in the United States with respect to the motivation for adaptation and mitigation to climate change in general. Akompab et al. (2013) applied the HBM on predictors for risk perception and adaptive behaviour during heat waves in Australia. Another study investigating adaptation to and perception of heatwaves and applying the HBM is Rauf et al. (2017). The HBM explains the likelihood of taking preventive health action through the factors related to individual perceptions (perceived susceptibility and perceived severity) that lead to perceived threat and modifying factors (demographic variabilities, perceived threat and cues to action) (Rosenstock, 1974). The

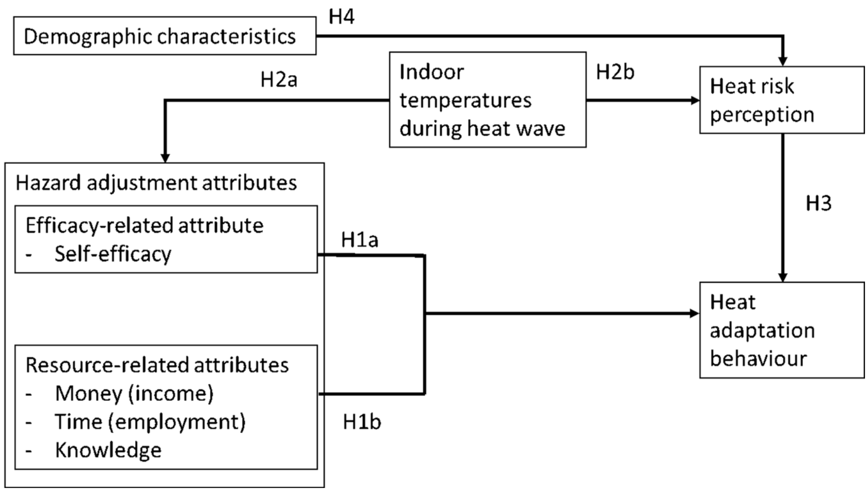

Fig. 1 The PADM applied to heat adaptation behaviour in this study referring to Terpstra and Lindell (2013). Figure shows flow of information in the PADM. Boxes show variables, arrows show deduced hypotheses.

HBM is widely used to explain health-related actions. However, the current study aims to include external stimuli (exposure in terms of indoor temperature).

The VBN is commonly used in literature predicting behaviour and the TPB, as well as the HBM, are established theoretical models when it comes to climate change adaptation. However, all three of them lack the inclusion of external influences, hence also the external stimuli. When it comes to heat risk adaptation behaviour, the external stimulus (high temperature) is a necessary factor that should be paid attention to.

Another framework worth noting, as it is often used to analyse climate change adaptation is the *PMT*. Recent research applied PMT to explain adaptation behaviour to extreme weather events (Budhathoki et al., 2020), the relation of climate change adaptation and gender (Goli et al., 2020) and the motivation to protect building stocks from climate-related overheating (Murtagh et al., 2019). The PMT combines a person's threat appraisal (that is the probability and severity of a threat) with one's coping appraisal (self-efficacy, response-efficacy and cost) to explain the intention of motivation to take protective action (Rogers, 1975). However, as other studies point out, knowledge is an important influencing factor for climate change adaptation behaviour (Birkmann and von Teichman, 2010). Therefore, in the current study it is necessary to include knowledge as a variable in the framework.

The *Protective Action Decision Model* initially was established to explain people's decision to take protective actions to hazards and risks (Lindell and Perry, 1992). In 2012, Lindell and Perry extended the model to explain long-term adjustment. They use variables explaining efficacy related ('hazard-related') and adjustment-related ('resource-related') attributes to explain adaptation behaviour (Lindell and Perry, 2012). In the model by Lindell and Perry, efficiency-related attributes (ERAs) include the efficacy for protecting people, property and other purposes. Adjustment-related attributes include the amount of money, time, knowledge and skills required. Based on these characteristics and the fact, that the PADM has been successfully applied to other natural hazards before, this study applies PADM to model heat adaptation behaviour. The depiction of the model for this study is shown in Fig. 1 in the section 'Hypotheses'.

Method

Research design. The research area in this study is the city of Augsburg, Germany. There are nearly 300,000 inhabitants living in Augsburg, Germany in an area of 147 km^2. For the period 1981–2010, the average temperature in July, the hottest month of the year, was 18.1 °C and the annual mean temperature was 8.5 °C (Deutscher Wetterdienst, 2019). During that climate period, there were only 6 days per year with maximum temperatures above 30 °C (Deutscher Wetterdienst, 2019). In this context, it is interesting and important to keep in mind that the number of hot days in recent summers has risen dramatically: 12 hot days in 2018, as well as in 2019; 11 hot days in 2017, eight hot days in 2016. During the survey period from July 1, 2019, to September 1, 2019, the highest temperature was 34.4 °C, measured on July 25 (Deutscher Wetterdienst, 2020). During the summer months of 2019, indoor temperatures were measured in private households and a questionnaire survey was carried out as part of the project 'Augsburg stays cool' (Projekt Augsburg bleibt cool, 2019). The overall objective of the project was to identify heat hotspots in the urban area, raise awareness of heat risks among citizens and develop heat adaptation measures for the city. In the survey, enquiries were raised regarding heat risk perception, knowledge and taken or planned adaptation measures, but also regarding sociodemographic details such as age, education, gender and personal information, such as chronic diseases or health-related problems during heatwaves. Data collection was conducted among participants who signed up to place a temperature data logger in their bedrooms to measure indoor temperatures during summer 2019. The research area was chosen by allocating the city into local climate zones (LCZs; Beck et al., 2018). A cross-section was drawn over the city to ensure the inclusion of as many LCZs as possible. Citizens living in the research area obtained an invite to contribute to the project and to receive the temperature data logger. According to the manufacturer, the distributed loggers (Elitech RC-5) have an accuracy of ±0.5 °C (Elitech, 2020). Accompanying the data logger, registered participants got access to the online survey; alternatively, they could choose a telephone interview. The survey was taken in German language and the results were translated into English for publication. Whenever possible, constructs were taken from studies in the German language to avoid possible shifts in meaning by translating them. Hereby, 431 datasets were collected containing both, the indoor temperature during summer and personal information through completed questionnaires. Even though the temperature was measured in bedrooms, the questionnaires likely were answered by one household member only, hence the registered participant.

Measures. A total of 431 datasets were obtained containing both, indoor temperature and personal information from the survey in the German language. Table 1 shows the base rate of the population and the data sample size. 250 (60.4%) of the participants are female and 164 (39.6%) are male. More details about social characteristics are shown in the section 'Descriptive statistics' below. The questionnaire contained 35 questions and was designed to investigate heat risk perception, personal heat stress, knowledge and adaptation behaviour.

PADM constructs. Following Lindell and Perry (2012), the PADM describes how adaptation decisions protecting from environmental hazards are usually taken. The constructs used in this study to investigate heat adaptation behaviour are described in the following section.

Heat adaptation behaviour. To find out about adaptive behaviour and the intention to adapt to heatwaves, participants were first asked to rate five adaptation measures for their private household according to the likeliness of taking these measures. The five possible adaptation measures were buying air conditioning, installing more inside blinds or outside shadings, installing more green or blue areas around the house or on the balcony, buying a fan, moving into a cooler house or city. Additionally to those optional adaptation measures, participants were asked which adaptation behaviour they already apply during a heatwave to ensure adequate sleeping quality. The statistics of heat adaptation behaviour is shown in Table 2. To conduct statistical hypothesis tests, the adaptation measures were summarized in an Adaptation Behaviour Score by dichotomizing all answers into 'is an option/is already taken' = 1 and 'is not an option/is not taken' = 0 and summarizing data into one score (mean $(M) = 6.15$, standard deviation $(\text{sd}) = 1.65$).

Table 1 Base rate of population and sample size (Source: Statistical Source from Augsburg, Germany, 2020).

Criteria	Total 2019	*n* in this study
Citizens	299.620	427
Female	151.301 (50.5%)	260 (60.9%)
Male	148.319 (49.5%)	167 (39.1%)
Under 18	45.661 (15.2%)	-
18–29	55.633 (18.6%)	97 (22.7%)
30–64	141.360 (47.2%)	263 (61.6%)
Above 65	56.966 (19%)	67 (15.7%)
People living alone	84.310 (28.1%)	152 (35.6%)

Risk perception. Risk perception is known to be an influencing factor for adaptive behaviour to environmental hazards. It is part of the PMT (Threat Appraisal) as well as the PADM. In this study, heat risk perception constructs were based on previous studies (Rauf et al., 2017; Akompab et al., 2012).

To find out about heat risk perception and its relation to the perception of other natural hazards, the items from Martens et al. (2014) were used. The items can be found in the database of the GESIS—Leibniz Institute for the Social Science—(Leibniz-Institut für Sozialwissenschaften, 2021) in the German language, as used in the questionnaire, and have already been tested and validated. Two of the eight statements were modified to ask about (a) heat risk perception for the individual and (b) for his/her environment. The items were rated on a 4-point Likert scale (1 = 'strongly disagree', 2 = 'disagree', 3 = 'agree', 4 = 'strongly agree') and later summarized to a Heat Risk Perception Score. An overview is given in Table 3.

Hazard adjustment attributes. The hazard adjustment attributes consist of the ERA and resource-related attributes (RRA). In this study, ERA is measured by the internal locus of control (LOC) of reinforcement. The construct plays an important role in

Table 3 Heat Risk Perception item and statistics.

Item	*n*	*M*	sd
'I think that heatwaves endanger my personal health'		2.42	1.06
Strongly disagree	95		
Disagree	154		
Agree	89		
Strongly agree	93		
'Heat waves threaten plants and animals'		3.28	0.84
Strongly disagree	7		
Disagree	87		
Agree	115		
Strongly agree	222		

M mean, sd standard deviation.
Cronbach's $\alpha = 0.66$.

Table 2 Overview of heat adaptation measures and behaviour.

	Is an option/is already taken		Is not an option/is not taken	
	n	%	*n*	%
Adaptation measure				
Buying air conditioning	122	28.3	309	71.7
More shadings (inside/outside)	340	78.9	91	21.1
More green/blue around the house	323	74.4	108	25.6
Buying fan	271	62.9	160	37.1
Moving into cooler house/city	196	45.5	235	54.5
Adaptation behaviour				
Using thin/no bedding	368	85.4	63	14.6
Using thin/no nightwear	359	83.3	72	16.7
Taking showers at night	73	16.9	358	83.1
Putting up wet cloths at open window	21	4.9	410	95.1
Keep window open during night time	353	81.9	78	19.1
Airing bedroom before sleeping	199	46.2	232	53.8
Sleeping at a cooler place	27	6.3	404	93.7

Reliability for this formative construct has been verified by testing the variance influence factor (VIF; <10) and the tolerance of each item (>0.1).

predicting and explaining an individual's behaviour and—in this case—the convincement and, therefore, the willingness to take adaptation measures. The internal LOC describes the extent to which participants think they control events happening in their lives and experience them as a consequence of their own behaviour. The external LOC is defined as the extent to which an individuum thinks everything happening in his or her life depends on destiny or fate or is under the control of others (Kovaleva et al., 2014; Levenson, 1973; Rotter, 1966). The statements used to find out about the LOC in the questionnaires are shown in Table 4. Responses were given on a 5-point Likert scale (1 = 'I totally agree'; 5 = 'I do not agree at all'). The two items were summarized to one score.

The RRAs were measured by asking participants about their available resources to adapt. Those are the available amount of financial resources (household income), the available amount of time (employment/unemployment) and knowledge about heatwaves.

Knowledge about heat risks was operationalised in ten statements about heatwave risks; these statements were partly adopted from Rauf et al. (2017) and partly completed by statements taken from the information in Bunz and Mücke (2017). Table 5 shows the 10 statements including the number of participants that answered the statements correctly. The choices of answers were 'true', 'false' or 'I don't know', leading to an overall knowledge score.

Risk area. As Esplin et al. (2019) pointed out, in order to protect citizens in certain urban areas, it is essential to pay attention to spatial variations as heat exposure may vary from area to area. In this case, indoor heat exposure varies from household to household and is measured by actual indoor temperature during the summer months. The distributed temperature data loggers recorded indoor temperature in bedrooms every 15 min during July and August 2019. For this study, the temperature during a 3 days heatwave in Augsburg, Germany from 24 to 26 July 2019 is used. The overall mean indoor temperature (day and night) during this heatwave was 27.14 °C, sd = 1.6. Table 6 summarizes the mean temperatures.

Other influencing factors. Additionally to the prior introduced factors that are included in the PADM and will be tested in hypotheses, there are further variables identified in the literature affecting heat or climate adaptation behaviour in the literature. One of those is the health symptoms a person experiences during extreme weather events (Esplin et al., 2019; Kim et al., 2014). In this study, a health implication score (HIS) will be included in later analyses, generated from seven questions about health implications experienced during heat waves. Answers were given according to the frequency of health implications occurring from 1 = 'never', 2 = 'sometimes', 3 = 'often'. The possible health implications included in the questionnaire were: drowsiness ($M = 2.1$, sd = 0.64), sleeping problems ($M = 2.1$, sd = 0.69), concentration problems ($M = 2$, sd = 0.67), vertigo ($M = 1.56$, sd = 0.65), headache ($M = 1.69$, sd = 0.66), nausea ($M = 1.19$, sd = 0.43), cardiovascular problems ($M = 1.44$, sd = 0.60).

Furthermore, Kussel (2018) states that adaptation behaviour is a response to heat stress experienced. While heat stress can be determined by various factors, in this study, SHS will be included, meaning the perceived degree of stress caused by a heatwave at home. This was included in the questionnaire by asking about the SHS level at home (by day and night) on a 5-point Likert scale. Alternatively, the participants could answer 'I don't know' if they were not able to judge the level of SHS, for example, because they rarely experienced this situation. An overview of SHS is given in

Table 4 Efficacy-related attributes items and statistics.

Item	*n*	*M*	sd
'I am in control of my own life'		4.48	0.71
Totally agree	255		
Agree	138		
Partly	31		
Disagree	6		
Totally disagree	1		
'If I make an effort, I will succeed'		4.28	0.77
Totally agree	192		
Agree	182		
Partly	46		
Disagree	9		
Totally disagree	2		

Cronbach's $\alpha = 0.6$.
M mean, *sd* standard deviation.

Table 6 Overview of mean indoor temperatures as recorded by temperature data loggers 24 to 26 July 2019.

M Temperature	*n*	%
Below 24 °C	8	1.9
24–25 °C	26	6
25–26 °C	67	15.5
26–27 °C	103	23.9
27–28 °C	106	24.6
Above 28 °C	118	27.4

M mean.

Table 5 Statements included in knowledge about heat risks construct.

Item no.	Statement	*n* right	%
1	Older and very young people are particularly vulnerable during a heat wave.	412	95.6
2	Excessive sweating during a heat wave may be a sign of heat stress.	244	56.6
3	People with a cardiac disease are in danger of becoming sick during a heat wave.	355	82.4
4	Heat-related diseases can lead to death.	362	84.0
5	There is no such evidence for heat waves to cause respiratory diseases.	101	23.4
6	Diabetes is an example for a heat-related disease.	295	68.4
7	Heat waves foster the development of harmful bacteria in water and food.	392	91.0
8	Heat waves can be a factor for depression and anxiety.	108	25.1
9	Due to the building's shade, heat waves are less common in cities than in rural areas.	368	85.4
10	Heat stress during night time is worse than heat stress during daytime.	183	42.5

Cronbach's $\alpha = 0.45$.
Note that for dichotomous items the actual terminology for the reliability indicator is Kuder–Richardson-20 (KR20).

Table 7 Subjective heat stress item and statistics.

Item: How do you rate your personal heat stress perception in the following situation...	n	M	sd
... at home during the day		2.71	1.11
Very high	31		
High	57		
Neutral	139		
Low	121		
Very low	57		
No answer	26		
... at home during the night		3.2	1.16
Very high	64		
High	105		
Neutral	148		
Low	72		
Very low	38		
No answer	6		

M mean, sd standard deviation.
Cronbach's $\alpha = 0.71$.

Table 7. This variable will be included in the hierarchical regression model in the analysis section.

In his study, Kussel (2018) states that an increase of mean indoor temperature by one degree celsius during summer is related to a 2.3% higher probability of adaptation while White-Newsome et al. (2012) found that indoor temperature is significantly related to adaptive behaviour. Even though the indoor temperature will be included in the hypotheses that will be introduced in the next section, according to the PADM, indoor temperatures are supposed to have an indirect influence via heat risk perception. To examine their direct influences, indoor temperatures (INT) will be included in the later analysis as a direct influence as well.

Hypotheses. In this study the PADM is being applied to heat adaptation behaviour among citizens of the city of Augsburg, Germany. Heat adaptation behaviour is essential for (vulnerable) people during the summer months to protect themselves against health impairments during severe heat waves. The research model is shown in Fig. 1.

Next to efficacy-related and resource-related variables, the PADM assumes that adaptation behaviour depends on heat risk perception, whereas the perceived heat risk is related to the indoor temperatures during heat waves and the demographic characteristics of the participants. These two factors are thought to influence the hazard adjustment attributes as well.

Other studies using the PMT showed that threat and a coping appraisal are related to climate change adaptation behaviour (Goli et al., 2020). The PADM predicts efficacy-related and RRA influencing adaptation behaviour. The first hypotheses therefore are:

H1a: The efficacy-related attribute is positively related to heat adaptation behaviour.

H1b: The resource-related attributes are positively related to heat adaptation behaviour.

In their research, Lindell and Hwang (2008) showed that risk perception depends on the risk area a person lives in. Akerlof et al. (2015) found that being located in an area exposed to risk (of flooding) is related to higher risk perception. For heat as the risk in this paper, the risk area means the extent of exposure a person has to face, hence if the indoor temperature is high during a heat wave. Therefore, the following hypotheses are deducted:

H2a: The indoor temperature during a heat wave is related to the efficacy-related attribute and knowledge.

H2b: Indoor temperature during a heat wave is related to heat risk perception.

Esplin et al. (2019) found that risk perception influences self-reported protection behaviour. People that perceive heat as an actual risk are more likely to take adaptation measures that are meant to protect their health from consequences of heat exposure. In their study, Arbuckle et al. (2015) presented findings of farmers who are more willing to take adaptation measures when their perceived risk towards heat waves is higher. Other studies report similar results (Kim et al., 2014; Liu et al., 2013; Wolf et al., 2010). Therefore, the following hypothesis can be deducted:

H3: Heat risk perception is a significant predictor of heat adaptation behaviour.

Beckmann and Hiete (2020) found that young age is one of the predictors of heat risk perception, Akompab et al. (2013) additionally found that a higher income as well as being married were significant predictors of climate change risk perception. Other studies claim that females perceive higher climate change risks or are more likely to take adaptation measures (Esplin et al., 2019; Khare et al., 2015; Kim et al., 2014; Semenza et al., 2008). Therefore, the demographic characteristics included in this study are: age, living alone and gender and the hypothesis deducted is

H4: Demographic characteristics (age, gender, living alone) are significantly related to heat risk perception.

The items included in the questionnaire to test the hypotheses are listed in Table 8.

Analyses and results

To give an overview over participants in this study, descriptive statistics are presented in the following section. Afterwards, regression analyses were performed to test the previously introduced hypotheses.

Descriptive statistics. Table 9 shows descriptive statistics of the participants and their heat adaptation behaviour. 15.5% of the participants are 65 years old and older, 60.6% are female and 58.9% hold a university degree. Most of the participants reported a monthly household income of 1000–2000€ (21.6%) and of 2000–3000€ (20.6%). Of the 431 participants, 154 (35.7%) were living alone and 121 (28.1%) live in a house or apartment that they own themselves.

Table 10 shows Pearson correlation of all introduced variables. Regarding heat adaptation behaviour (HAB) there is a moderate correlation with age (negative), SHS and the HIS. Weak correlation can be found with knowledge, heat risk perception and living alone (negative) and the indoor temperature. These correlations will be analysed further in the following sections and the hierarchical regression model.

Results of hypotheses testing. The hypotheses were tested using different statistical tests. Effect sizes in this section are reported as *f* and interpreted following Cohen (1988). To test Hypothesis 1a ('The efficacy-related attribute is positively related to heat adaptation behaviour'), a one-way ANOVA was conducted. The ERA was measured on a 5-point Likert scale from 1 (totally disagree) to 5 (totally agree). Data is normally distributed for each group

Table 8 Overview of variables and constructs used for hypotheses testing.

Item	Variable	Data/questions	Categories	Hypothesis
Heat adaptation behaviour	HAB	Score of adaptation measures and behaviour, see Table 1	Score from 0 to 12	H1a, H1b, H3
Heat risk perception	HRP	Heat waves harm my personal health; Heat waves harm animals and plants around me	1 (totally disagree) to 5 (totally agree)	H2b, H3, H4
Efficacy-related attribute	ERA	I am in control of my own life; I will succeed if I make an effort	1 (totally disagree) to 5 (totally agree)	H1a, H2a
Resource-related attributes	RRA1	Income (monthly)	Under 1000€ to above 5000€	H1b, H2a
	RRA2	Employment	Yes/No	
	RRA3	Knowledge (score from 10 questions)	Low (0–4) Moderate (5–7) High (8–10)	
Demographic characteristics	DCV1	Age	Below 65/above 65 years	H4
	DCV2	Gender	Male/female	
	DCV3	Living alone	Yes/no	
Indoor temperature	INT	Indoor temperature from data loggers during heatwave	Actual mean temperature in °C	H2a, H2b

Table 9 Descriptive statistics of data sample ($N = 431$) and heat adaptation behaviour.

	n	%	*M* HAB	sd
Age (DCV1)				
Under 65 years	364	84.5	6.34	1.62
65 years and older	67	15.5	5.1	1.52
Gender (DCV2)				
Male	169	39.2	6.07	1.73
Female	262	60.6	6.19	1.62
Living alone (DCV3)				
Yes	154	35.7	5.92	1.7
No	277	64.3	6.14	1.64
Income (RRA1)				
Under 1000€	36	8.4	5.97	1.81
1000–2000€	91	21.1	6.15	1.63
2000–3000€	89	20.6	6.22	1.6
3000–4000€	62	14.4	6.19	1.72
4000€ and above	71	16.5	6.18	1.5
No answer	82	19		
Employment (RRA2)				
Yes	312	72.4	6.22	1.65
No	119	27.6	5.95	1.69
Knowledge (RRA3)				
Low (0–4)	41	9.5	5.83	1.84
Moderate (5–7)	268	62.2	6.02	1.68
High (8–10)	122	28.3	6.52	1.52

M mean, *sd* standard deviation, *HAB* heat adaptation behaviour.

(Shapiro–Wilk test, $p > 0.05$) and there is the homogeneity of variance (Levene's test, $p > 0.05$). However, there is no statistically significant result between the ERA and the HAB variables ($p > 0.05$). Hypothesis 1a could therefore not be supported.

The same results were found for hypothesis 1b ('The RRA are positively related with heat adaptation behaviour') with the factors income and employment. Both ANOVAs did not show any significance. However, the heat adaptation behaviour differed significantly for the different groups of knowledge levels, $F(2, 462) = 4880$, $p = 0.008$, $f = 0.21$. Tukey post-hoc analysis revealed a significant difference ($p < 0.001$) between heat adaptation behaviour of the group with highest knowledge with the groups of low or moderate knowledge. Mean level of heat adaptation behaviour slightly decreased from high to low knowledge (−0.69, 95%-CI[−1.36, −0.03]), and from high to moderate knowledge (−0.48, 95%-CI[−0.88, −0.07]). Hypothesis 1b could therefore be supported for knowledge as the independent variable.

To test hypothesis 2a ('The indoor temperature during a heat wave is related to the efficacy-related attribute and knowledge'), two linear regression analyses were conducted to analyse the relationship between indoor temperature on self-efficacy and knowledge. However, both regression models did not show statistically significant results. Therefore, hypothesis 2a could not be supported.

A linear regression analysis was conducted to test the relation of indoor temperature and heat risk perception according to hypothesis 2b ('Indoor temperature during a heatwave is related to heat risk perception'). The regression did not show significant results ($p = 0.147$). Hypothesis 2b could not be supported.

One-way ANOVA was conducted to test hypothesis 3 ('Heat risk perception is a significant predictor of heat adaptation behaviour'). Data is normally distributed for each group (Shapiro–Wilk test, $p > 0.05$) and there is the homogeneity of variance (Levene's test, $p > 0.05$). HAB differed statistically significantly for the different HRP groups, $F(6, 458) = 3084$, $p < 0.001$, $f = 0.2$. Mean level of heat adaptation behaviour slightly increased from low (value of 1.5) to high (value of 4) HRP (0.98, 95% CI[0.13, 1.84]), and from low (value of 2) to high (value of 4) HRP (0.84, 95% CI[0.018, 1.66]). Hypothesis 3 could therefore be supported.

T-tests were used to test hypothesis 4 ('Demographic characteristics are significantly related to heat risk perception'). First, the test was conducted with the two age groups (DCV1) to assess the effects of DCV1 on HRP. There was a significant difference with the younger age group showing higher HRP than the older age group, $t(93.417) = 2.839$, $p = 0.006$, $f = 0.14$. The tests for the factors gender (DCV2) and living alone (DCV3) showed no significant results. Hypothesis 4 could therefore be supported for age as influencing factor.

Results of hierarchical regression model. The testing of the hypotheses showed that hypothesis 1b could be supported for *knowledge* as the influencing factor, hypothesis 2b and 3 could be supported, as well as hypothesis 4 for *age* as further influencing factor. However, as indicated in the section 'Other influencing factors' and from Table 6 with the correlations of all variables, it is known that SHS and health implications do have an effect on heat adaptation behaviour.

Therefore, a hierarchical regression analysis was conducted as shown in Table 7. In step 1, the model implies that HRP is a significant indicator for heat adaptation behaviour ($\beta = 0.142$; $p = 0.013$) which corresponds to the earlier supported hypothesis 3. The other variables in the model step 1 showed no statistical significance, which aligns with the rejected hypotheses 1a and 1b.

Table 10 Pearson correlation between all variables.

Variables	1	2	3	4	5	6	7	8	9	10	11
1. HAB											
2. ERA	0.049										
3. RRA1	0.018	0.093*									
4. RRA2	0.072	−0.015	0.327***								
5. RRA3	0.127**	0.004	0.063	0.057							
6. HRP	0.18***	−0.132**	−0.093*	0.016	0.295***						
7. DCV1	−0.268***	0.09*	−0.103*	−0.551***	−0.097**	−0.135**					
8. DCV2	−0.035	0.031	0.186***	0.028	0.057	0.006	0.075				
9. DCV3	−0.102**	0.018	−0.382***	−0.7	−0.056	−0.025	0.201***	−0.123**			
10. INT	0.176***	−0.049	−0.09*	0.027	−0.045	0.07	−0.203***	0.074	−0.03		
11. SHS	0.337***	−0.131*	−0.106*	0.105**	0.149**	0.382***	−0.329***	0.027	−0.011	0.282***	
12. HIS	0.29***	−0.096*	−0.165**	−0.028	0.118**	0.451***	−0.207***	−0.275***	−0.025	0.043	0.491***

HAB heat adaptation behaviour, *ERA* efficacy-related attribute, RRA1 Income, *RRA2* employment, *RRA3* knowledge, *HRP* heat risk perception, *DCV1* age, *DCV2* gender, *DCV3* living alone, *INT* Indoor temperature during heat wave, *SHS* subjective heat stress, *HIS* health implication score.
***Significant on the <0.001 level, **significant on the 0.05 level, *significant on the 0.1 level.

In Table 7, step 2 of the model ($R^2 = 0.164$), where all variables included in the PADM were added to the model, ERA becomes a significant factor ($\beta = 0.102$; $p = 0.05$). However, the coefficient was smaller than the coefficients of the other two significant variables in this model, which were the age groups (DCV1; $\beta = -0.284$, $p < 0.001$) and the mean indoor temperature during a heatwave ($\beta = 0.187$; $p = 0.001$). This shows a direct influence of age and indoor temperature on HAB, which has not been tested because in the PADM model there were no direct relations between these variables. In step 3 of the model (adjusted $R^2 = 0.217$), additionally to self-efficacy ($\beta = 0.116$; $p = 0.023$), age (DCV1) ($\beta = -0.209$; $p = 0.001$) and indoor temperature ($\beta = 0.156$; $p = 0.004$), SHS at home and the HIS became significant indicators for heat adaptation behaviour with $\beta = 0.157$; $p = 0.014$ for SHS and $\beta = 0.164$; $p = 0.012$ for HIS.

Figure 1, showing the initial PADM for heat adaptation behaviour in Augsburg, Germany, has been adjusted according to the regression model in Table 11. Figure 2 shows the adjusted model with the arrows indicating significant relations and the two added variables SHS at home and health implications during heat waves as additional indicators.

Even though *knowledge* did not show significance in step 3 of the regression model, hypothesis 1b was supported for knowledge as the indicator. Therefore, in the adjusted protective action decision model, influencing indicators for heat adaptation behaviour are: knowledge, self-efficacy, heat risk perception, indoor temperature, age, health implications and SHS at home.

Discussion and limitations

Contrary to the hypothesized association of the ERA, as well as time and income (RRA1 and RRA2) with heat adaptation behaviour, the results did not support hypotheses 1a and 1b (in parts). This must be seen as a good message for heat adaptation management: low self-efficacy, low income and lack of time are (statistically) no hurdles for taking adaptation measures in this study.

The results of the applied PADM supported hypothesis 1b regarding the relation of knowledge and heat adaptation behaviour, hypothesis 3 showing the influence of heat risk perception on heat adaptation behaviour and hypothesis 4 regarding the influence of age on heat risk perception. These results align with previous research introduced earlier in this paper. Especially the relation between HRP and HAB was found in studies before (Esplin et al., 2019; Arbuckle et al., 2015; Kim et al., 2014; Wolf et al., 2010; Liu et al., 2013). This underlines the importance of risk perception research in combination with climate change adaptation behaviour. As knowledge is significantly related to HAB, it is important to know that education among households is influencing a person's adaptation behaviour significantly.

However, it is important to stress, that indoor temperatures during heatwave did not show significant influence on HRP in the hypotheses tests contrarily to what was expected from the theoretical model and included in H2a and H2b. Therefore, results differ from Lindell and Hwang (2008) and Akerlof et al. (2015) and this could imply that indoor temperatures are not a reliable measure for a characteristic risk area a person is in when it comes to the relation to heat risk perception.

Regarding hypothesis 4, demographic characteristics (age, gender, living alone) being related to heat risk perception, only age was significant. This was an unexpected result since gender and living alone were identified as influencing factors in Akompab et al. (2013), Esplin et al. (2019), Khare et al. (2015), Kim et al. (2014) and Semenza et al. (2008). One reason could be the different countries the studies were conducted in and the different cultures of the participants. People living alone might have

Table 11 Hierarchical regression analysis of heat adaptation behaviour.

Variable	Step1; $R^2 = 0.194$; Adj. $R^2 = 0.038$			Step2; $R^2 = 0.405$; Adj. $R^2 = 0.164$			Step3; $R^2 = 0.466$; Adj. $R^2 = 0.217$		
	β	Std. β	VIF	β	Std. β	VIF	β	Std. β	VIF
ERA	0.108	0.084	1.026	0.131	0.102*	1.036	0.148	0.116*	1.039
RRA1	−0.021	−0.039	1.138	−0.015	−0.027	1.420	0.000	0.01	1.436
RRA2	0.290	0.084	1.118	−0.268	−0.075	1.585	−0.174	−0.048	1.603
RRA3	0.061	0.060	1.084	0.066	0.065	1.091	0.055	0.054	1.094
HRP	0.284	0.142*	1.106	0.185	0.093	1.133	−0.019	−0.009	1.341
DCV1				−1.287	−0.284**	1.566	−0.948	−0.209**	1.677
DCV2				−0.066	−0.020	1.088	0.038	0.012	1.220
DCV3				−0.226	−0.068	1.277	−0.216	−0.065	1.285
INT				0.191	0.187**	1.093	0.158	0.156*	1.169
SHS							0.249	0.157**	1.645
HIS							0.088	0.164*	1.711

Step 1: variables that have initially been directly linked with HAB in the PADM; Step 2: all variables that have initially been included in the PADM; Step 3: All available variables that have been introduced and found as being influencing in the literature.
Std. β standardized *β*, *VIF* variance influence factor.
*Significant on 0.05 level, **significant on 0.001 level.

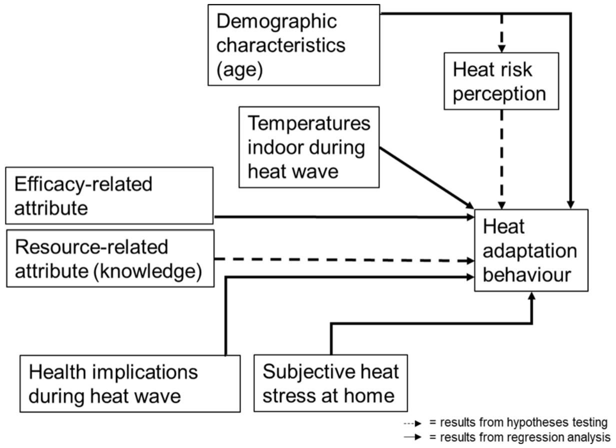

Fig. 2 Adjusted PADM for heat adaptation behaviour in this study. Figure shows flow of inormation in the adjusted PADM for this study. Boxes show variables, arrows show results from regression analysis and dotted arrows show results from hypotheses testing.

enough social interaction with people not living in the same household in this study. For the households in Augsburg this means, when communicating about heat risks and heat adaptation advantages, the audience has to be differentiated by age rather than by gender or living situation, which makes the information spreading for government institutions easier to allocate.

After testing hypotheses, hierarchical regression analysis was conducted to include further variables which were identified as relevant in the literature. Step 3 of the model shows a significant influence of the ERA on heat adaptation behaviour, in agreement with the theory of the PADM. People who think their life rather depends on fate, accident or other people that take decisions for them, rather tend to not take adaptation measures. Taken into practice, this might be a problem when adaptation measures should be fostered because counteracting against an external LOC is challenging to handle as it is an intrinsic convincement.

Furthermore, age shows a negative effect, meaning younger people rather tend to adapt to heat which has already been introduced for hypothesis 4 that was supported in this study.

In step 3, the indoor temperature during heatwave showed a significant effect, which aligns with Kussel (2018) and White-Newson et al. (2012). It is important to stress that in this study as well as in the literature higher indoor temperature during a heatwave leads to a higher probability of taking adaptation measures. This leaves advice to authorities and governmental institutions that to some extent, households tend to adapt to rising temperatures autonomously.

The same applies to the further significant factor, SHS. This implies that the higher a person reported his or her SHS level at home, the higher the probability that he or she takes adaptation measures at home. Furthermore, similarly to Esplin et al. (2019) and Kim et al. (2014), the health implications of the participants were a significant factor for heat adaptation behaviour. These factors contribute in some kind to a self-balancing system of adaptation in private households.

In the hierarchical regression model, the RRA, as well as gender and living alone do not show significant effects. Surprisingly, in step 3 of the model, heat risk perception is not a significant factor either. However, as hypothesis 3 was supported, it should still be taken into account and seen as relevant for further research.

For practitioners developing heat action plans, all these factors help to decide on the content of such plans. The introduced variables should be paid attention to as indicators for action thresholds. This helps to prevent health consequences caused by heat that can lead to higher mortality. This information can be included in municipal heat action plans but also in community groups taking care of each other. It is also valuable for institutions like retirement homes or home care nursing services.

In the end, this study suggested an adjusted version of the PADM according to the results of the hierarchical regression analysis. It is important to note, that the number of cases in the data set is admittedly sufficient for this study, however, it is not necessarily representative of (German) cities in general. Limitations also include a possible bias of participants of the study who signed up voluntarily and might already have been more sensitized to heat risks due to higher bedroom temperature, education, health profiles, etc. A possible bias could have been caused by the nature of taking a survey online, as this happened over the entire month of July, it is not safe to say that every participant was exposed to the same temperature while taking the survey. Also, because the survey was taken in German and some constructs were taken from studies published in English, they have not been tested in a pilot study beforehand. This leaves room for further research to conduct pilot studies with heat adaptation-related constructs in various languages. Therefore, and to better understand heat adaptation behaviour in German cities, it is recommended to replicate this study in other cities in Germany and elsewhere. Finally, as studies have shown, family members do not always agree with each other when it comes to climate change response (Head et al., 2016), behaviour or consumption decisions (Grønhøj, 2006) or preparation for extreme weather events (Hung, 2018). Therefore, it has to be kept in mind that even though the current study refers to household behaviour, it is rather the behaviour of the household member answering the survey questions.

Further limitations may arise from the fact that the calculated values of Cronbach's alpha (0.66 for heat risk perception, 0.6 for ERAs, 0.45 for knowledge about heat risks and 0.71 for SHS) are slightly to considerably lower than the level of 0.7 often considered in the literature as "desired or adequate" (cf. Schmitt, 1996). Cronbach's alpha measures whether items within the instrument (or construct) correlate well with at least *some* other items in the instrument (Gardner, 1995) and thus indicates average interrelatedness of the items in the sample (Schmitt, 1996). Note that a high Cronbach's alpha does not necessarily indicate homogeneity or unidimensionality (cf. Gardner, 1995; Tan, 2009) and that Cronbach's alpha "cannot be seen as a measure of a scale or instrument per se but only of its application to a particular sample of respondents" (Taber, 2018). For a homogenous or unidimensional instrument all items selected to describe that instrument are required to highly correlate with the instrument and thus also which each other. In such a case, a very high Cronbach's alpha value suggests that some items are redundant (Tavakol and Dennick, 2011) and a low value would be indicative of a large measurement error in the test. That's why Cronbach's alpha has high relevance for affective instruments for which "instrument designers (or adaptors) do need to demonstrate that items on a single scale are indeed measuring the same thing" (Taber, 2018). However, for cognitive instruments "testing a range of distinct knowledge facets should not be expected to give high alphas" (Taber, 2018). Berger and Hänze (2015) (also cited in Taber, 2018) consequently regard a Cronbach's alpha value of 0.45 in a pre-test and of 0.60 in the post-test for a knowledge test measuring different physics concepts as acceptable. Though we cannot exclude that high measurement errors have resulted in the low Cronbach's alpha value of 0.45 for the knowledge about heat risks construct in our study, we argue that the bandwidth of knowledge covered in the construct is the main reason. We interpret the rather low correlation values between the items (not shown) by still insufficient and fragmented knowledge about heat risks in the population. With fragmented, we meant that most people have some knowledge but what they know is highly variable. Anyway, a pre-test was not conducted in this study and therefore, it is highly recommended for future research to further investigate the knowledge construct and test its reliability in pre- and post-tests with different groups of respondents. The first step to do so might be to conduct expert interviews. In the final steps, different reliability indicators might have to be tested to assure satisfactory results.

Conclusion

In the future, heat waves will occur more frequently and with higher intensity. An elevated excess number of deaths caused by heat can be observed already today (Watts et al., 2020). Rising temperatures and urbanization challenge cities and communities with regard to health implications caused by extreme heat exposure. Therefore, studies investigating heat adaptation behaviour are necessary to give insight into the complex constructs of adaptation in private households and its influencing factors. This study identified key factors influencing adaptation behaviour towards heat risks. Unlike other studies, this research applied the PADM model and included more variation of investigated factors. The background section additionally shed light on already established theoretical frameworks for the field of climate adaptation behaviour and introduced the PADM in more detail. Additionally to its theoretical implications, this study showed some implications on the practical side.

Adaptation behaviour in households in Augsburg neither depends on a high income nor on a time budget. This is an important fact as it means that not only do people with solvent households tend to take adaptation measures and should therefore be aimed to receive adequate information but the information should be spread throughout all households regarding income situation.

It is also worth noting, that people (subjectively) affected by heatwaves tend to take adaptation measures themselves. That is shown by mean indoor temperature and SHS which are significant factors for heat adaptation behaviour. Furthermore, health implications suffered during a heatwave is an indicator as well which means that people experiencing consequences on their health caused by heat rather take adaptation measures to protect themselves.

Since age and knowledge were identified as significant factors, however, it is necessary to inform older people directly about heat risks. Not only could that lead to a higher risk perception but directly to more adaptation measures taken and therefore to a reduction in health issues caused by exposure during a heatwave. However, the knowledge construct should be re-developed and tested again to assure adequate reliability within the instrument.

The PADM is not only an adequate model to investigate climate change adaptation behaviour but also heat adaptation behaviour specifically. It combines relevant factors appropriately to gain an understanding of their relations. Even though the model has been slightly adapted for this study, in the end, it is recommended to further examine heat adaptation behaviour.

Data availability

The datasets generated and analysed during the current study are not publicly available due to further publications in process but are available from the corresponding author on request.

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Additional information

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