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The effect of high indoor temperatures on self-perceived health of elderly persons

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ABSTRACT

Introduction: Exposure to high ambient temperatures leads to an increase in mortality and morbidity, especially in the elderly. This relationship is usually assessed with outdoor temperature, even though the elderly spend most of their time indoors. Our study investigated the relationship between indoor temperature and heat-related health problems of elderly individuals.
Material and methods: The study was conducted in the Netherlands between April and August 2012. Temperature and relative humidity were measured continuously in the living rooms and bedrooms of 113 elderly individuals. Respondents were asked to fill out an hourly diary during three weeks with high temperature and one cold reference week, and a questionnaire at the end of these weeks, on health problems that they experienced due to heat.
Results: During the warmest week of the study period (14–20 August), average living room and bedroom temperatures were approximately 5 °C higher than during the reference week. More than half of the respondents perceived their indoor climate as too warm during this week. The most reported symptoms were thirst (42.7%), sleep disturbance (40.6%) and excessive sweating (39.6%). There was a significant relationship between both indoor and outdoor temperatures with the number of hours that heat-related health problems were reported per day. For an increase of 1 °C of indoor temperature, annoyance due to heat and sleep disturbance increased with 33% and 24% respectively. Outdoor temperature was associated with smaller increases: 13% and 11% for annoyance due to heat and sleep disturbance, respectively. The relationship between outdoor temperature and heat-related health problems disappeared when indoor and outdoor temperatures were included in one model.
Conclusions: The relationship with heat-related health problems in the elderly is stronger with indoor (living room and bedroom) temperature than with outdoor temperature. This should be taken into account when looking for measures to reduce heat exposure in this vulnerable group.

1. Introduction

Exposure to high ambient temperatures leads to an increase in mortality, as was seen by the heat wave that affected Europe in 2003 and caused more than 15,000 excess deaths in France alone (CRED, 2015; Fouillet et al., 2006). Less than one-third of this figure could be attributed to mortality displacement (harvesting) (Toulemon and Barbieri, 2008). A study that reviewed the relationship between outdoor temperature and mortality in 15 European cities found that for a 1 °C increase in temperature above a city-specific threshold, there is a significant increase in mortality of almost 2% in the north-continental region of Europe, especially among the elderly (Baccini et al., 2008). Other studies have also shown that the elderly ($\geq$65 years of age) are more at risk for detrimental effects of heat and heat waves, including an increase in mortality (D'Ippoliti et al., 2010; Garssen et al., 2005; Hajat et al., 2007; Hajat and Kosatky, 2010) and an increase in the number of hospital admissions (Gronlund et al., 2014; Li et al., 2015),

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specifically for respiratory admissions (Kovats et al., 2004; Mastrangelo et al., 2007; Michelozzi et al., 2009) and admissions for heart diseases (Schwartz et al., 2004). Other adverse health conditions that occur more frequently during a hot period are dehydration, hyperthermia, malaise, hyponatremia, renal colic and renal failure (Josseran et al., 2009). The elderly are more sensitive for heat-related mortality and morbidity since they have a lower threshold for the development of renal failure, and they are often unable to obtain sufficient volumes of water for themselves due to infirmity or impaired thirst, all of which may be exacerbated by both concomitant cardiorenal disease and various commonly used medications (Flynn et al., 2005). Studies on self-reported symptoms due to heat are scarce: a Finnish study showed that the most prevalent heat-related symptoms in a population aged 25–74 were thirst (68%), a dry mouth (43%), impaired endurance (43%) and sleep disturbance (32%) (Nayha et al., 2014). In a Dutch study, the most reported heat-related symptoms among the elderly were sleep disturbance (62%), fatigue (61%) and breathing discomfort (29%) (van Daalen and van Riet, 2010). Since mortality and hospitalisation present only the tip of the iceberg with respect to the impact of heat, it is important to gain insight on self-reported symptoms by these types of studies.

The Netherlands experiences a moderate maritime climate, with mild winters and cool summers. Heat waves are relatively uncommon: it is defined by the Royal Netherlands Meteorological Institute (KNMI) as a period of five consecutive days with maximum temperatures of 25.0 °C or higher, including at least three day with temperatures of 30.0 °C or higher. Only eight heat waves have been registered by the KNMI in the 21st century so far (KNMI, 2015). However, a study has shown that mortality in the Netherlands already increases when daily average temperatures exceed the optimum of 16.5 °C (Huynen et al., 2001). An increase in mortality due to heat was also shown in a study by Gasparrini et al. (2015). In addition, there is a trend that extreme climate events, including heat waves, will increase in duration and frequency in Western Europe in the coming years due to climate change, as postulated by the Intergovernmental Panel on Climate Change (IPCC) (Parry et al., 2007). These effects are stronger in cities compared to rural areas due to the urban heat island effect, which can lead to heat accumulation and temperature differences up to 12 °C in the evening (USEPA, 2013). Within cities, temperature differences between areas are caused by to differences in building density and levels of vegetation. Areas that are the most sensitive to heat accumulation are called micro urban heat islands (Smargiassi et al., 2009).

Studies on the relationship between temperature and mortality or morbidity of the elderly are usually based on outdoor temperature, even though elderly persons spend approximately 90% of their time indoors (EPA, 2009). We identified only few studies that measured indoor temperature in dwellings of the elderly, and these studies did not describe the impact on health (Nguyen et al., 2014; White-Newsome et al., 2012). The aim of our study was to investigate the relationship between indoor and outdoor temperature and heat-related health problems of elderly individuals during the summer months in the Netherlands.

2. Material and methods

The design used was a prospective observational study, carried out from April until August 2012 among a group of elderly individuals.

2.1. Study population

The study was carried out in Arnhem and Groningen, two medium-sized cities in the Netherlands (population 150,000–200,000). Within both cities, four areas were identified with a high level of building density and a low level of vegetation. This identification was based on climate maps that were available for both cities (ERDF, 2009; Klok, 2012). Home addresses of elderly individuals (≥ 65 years of age) within these areas were obtained through the registers of the municipalities of Arnhem and Groningen, and 500 and 572 individuals were invited randomly to participate in both cities, respectively. The response was 70 (14%) for Arnhem and 100 (17%) for Groningen. Out of the responders, we randomly selected 56 persons in Arnhem and 57 in Groningen to participate, suited to the availability of measuring equipment. All participants provided written informed consent.

2.2. Temperature and relative humidity measurements

Each study participant received a home visit in April 2012. Measuring equipment was placed in the living room and bedroom that were most often used by the occupants. Indoor air temperature and relative humidity were measured and logged using iButton Hygrochron temperature/humidity loggers, (type DS1923; Maxim Integrated, San Jose, CA, USA). All iButtons were placed on a small standard, at living height (for the living room) or sleeping height (for the bedroom), away from any heat and ventilation sources to decrease the risk of other factors influencing temperature readings. iButtons do not have a display, so participants could not observe real-time temperatures based on our equipment. Outdoor air temperature and relative humidity were measured using the same devices within radiation shields (Davis Instruments Corp., Hayward, CA, USA). The radiation shields were attached to traffic signs or balconies close to each dwelling, at a height of at least 2.5 m (to minimise the risk of vandalism). Since some dwellings were at a close distance from each other, the number of outdoor temperature measurements was smaller than the number of dwellings. Temperature and relative humidity were measured every 30 min, with an accuracy of 0.5 °C and 0.4%, respectively.

Before the start of the study, the temperatures of all iButtons were simultaneously tested for deviations from the average. The maximum deviation of any iButton was 0.6 °C. Half-term readouts of the equipment were performed in July 2012, and non-functioning equipment was replaced. All equipment was collected and the final readouts were performed in September 2012.

2.3. Heat Index

Apart from temperature, relative humidity can also have an influence on heat perception. Combining values for temperature and relative humidity according to a set algorithm leads to the Heat Index. Various algorithms are available, although the results are relatively similar (Anderson et al., 2013). In this study, we used the algorithm also used by Blazejczyk et al. (2012), to assess whether the Heat Index is a more exact measure to explain heat-related health problems than temperature. This algorithm is:

$$HI = -8.784695 + (1.61139411{*}T) + (2.338549{*}H) - (0.14611605{*}T{*}H) - (0.012308094{*}T^2) - (0.016424828{*}H^2) + (0.002211732{*}T^2{*}H) + (0.00072546{*}T{*}H^2) - (0.000003582{*}T^2{*}H^2).$$

Where HI = Heat Index in °C, T = air temperature in °C, and H = relative humidity in percent. HI = T when $T \leq 20$ °C.

2.4. Questionnaires and hourly diary

All participants filled out a baseline questionnaire in April, which included questions on participants' health status and sensitivity to heat (Supplementary material 1). We used a checklist to collect characteristics of the dwelling, living room and bedroom.

Table 1
Timing of questionnaires, the hourly diary and temperature and relative humidity measurements in the study.

	Baseline questionnaire	7-days questionnaire (n)[1]	Hourly diary (n)[a,b]	Temperature and relative humidity[c]
April	X			
1–7 May[d]		X (109)	X (106)	X
21–27 May[d]		X (107)		X
24–30 July[d]		X (101)	X (98)	X
14–20 August[d]		X (96)	X (97)	X

[a] The number of returned 7-days questionnaires and hourly diaries varied between the different study periods, and is indicated between brackets. The total number of study participants was 113.
[b] The hourly diary was not included in the week of 21–27 May, since this warm period arrived suddenly and there was not enough time to send it to participants beforehand.
[c] Temperature and relative humidity were measured continuously from May onwards, so not only limited to the cold reference week and the three weeks with high temperature.
[d] 1–7 May was a relatively cold reference week, the other 3 periods were study weeks with high temperatures.

Further, we developed a 7-days questionnaire, based on existing questionnaires (Daanen et al., 2010; Harlan et al., 2006; van Daalen and van Riet, 2010; Vandentorren et al., 2006), which aimed at gaining insight in how many hours participants spent in their home, how they perceived the climate in their living room and bedroom during the previous week, which heat-related health problems they experienced (if any) and which measures they undertook to cope with the heat (Supplementary material 2). Participants filled out the 7-days questionnaire after a cold reference week and after three weeks with high temperatures. These three weeks were selected when weather forecasts predicted maximum temperatures of more than 25 °C for the upcoming week. In addition, participants filled out an hourly diary during the reference week and during two of the three weeks with high temperatures (Supplementary material 3). During these three weeks, participants recorded for every hour whether they experienced certain health problems that could be attributable to a high temperature, namely annoyance by heat, breathing discomfort, fatigue, annoyance by heat at night and sleep disturbance. Table 1 presents the timing of the questionnaires, the hourly diaries and the measurements.

2.5. Data analysis

Mean weekly temperatures were calculated for the four measurement periods. A Chi-square test was carried out for the relationship between symptoms reported in the 7-days questionnaire and whether participants considered themselves sensitive to heat. For the warmest week (14 to 20 August), mean daily temperatures and the numbers of hours that participants experienced certain health problems were calculated. The relationships between mean weekly temperature and experienced health problems and perception of the indoor climate were assessed using binary logistic regression (participants were dichotomised as having experienced the health problem, yes or no, and as perceiving the indoor environment as either mostly too warm or unbearably warm, yes or no). The relationship between mean daily temperatures and heat index over the course of one week and daily number of hours with reported health problems was assessed using Generalized Estimated Equation (GEE) Poisson log-linear models assuming exchangeable correlation structures, accounting for clustering of observations within individuals. Correlations between living room and bedroom temperatures, and between indoor temperature and Heat Index were calculated. Analyses on health outcomes or heat perception were corrected for gender and age. A p-value of $<.05$ was considered to be statistically significant, based on two-sided tests. Data were analysed using the software SPSS for Windows (version 21).

3. Results

Characteristics of the study participants, dwellings, living rooms and bedrooms can be found in Table 2. Most participants were self-reliant, perceived their own health as good or excellent and the majority (68%) did not consider themselves particularly sensitive to heat. Air-conditioning was used in only three living rooms and three bedrooms.

3.1. Perception of heat in different study periods

Mean living room, bedroom and outdoor temperatures for each study period, as well as the proportion of study participants that perceived the climate of their living room and bedroom as too warm (dichotomisation of 'mostly too warm' and 'unbearably

Table 2
Baseline characteristics of the study population, dwellings, living rooms and bedrooms ($N=113$).

Participant characteristics	
Male sex %	51
Age (years) Mean (±SD)	73.8 (7.5)
Living alone %	55
Self-sufficiency %	
Good	96
Poor	4
Bad	0
Self-perceived health %	
Good or excellent	82
Poor or bad	18
Sensitive to heat %	32
Dwelling characteristics	
Year of construction %	
1930 or earlier	15
1931 to 1969	17
1970 to 1984	20
1985 or after	48
Type of dwelling %	
Apartment	73
Terraced house	27
Primary building material %	
Bricks	79
Concrete	16
Other[a]	5
Living room characteristics	
Floor level %	
0	33
1	26
2 or higher	41
Surface area in m^2 (±SD)	35.2 (15.6)
Air-conditioning %	3
Bedroom characteristics	
Floor level %	
0	28
1	27
2 or higher	45
Surface area in m^2 (±SD)	14.9 (5.5)
Air-conditioning %	3

[a] Other building materials include plaster and glass.

Table 3
Mean (minimum–maximum) of weekly average temperatures for each study period (outdoor, living room, bedroom) and the proportion of study participants that perceived their indoor climate (living room, bedroom) as too warm.

	Mean temperature[a] (Min–Max) °C			Climate perceived as too warm[b] %	
	Outdoor[c] $N=77$	Living room $N=113$	Bedroom $N=113$	Living room $N=113$	Bedroom $N=113$
1–7 May[d]	11.9 (10.9–12.9)	20.9 (17.5–26.6)	19.3 (15.7–25.5)	1.9	2.9
21–27 May	21.5 (20.3–22.9)	24.0 (19.9–28.8)	23.6 (19.7–27.9)	28.3	29.2
24–30 July	20.4 (19.0–22.4)	24.2 (21.0–29.1)	23.8 (20.1–28.2)	36.0	33.0
14–20 August	23.6 (22.7–24.7)	25.4 (22.3–30.2)	25.1 (20.8–29.3)	55.3	50.0

[a] This table shows the weekly temperature of measuring devices (homes and outdoor) averaged over all locations, and the range (the weekly average values of the measuring stations with the lowest and highest temperatures).
[b] The number of returned questionnaires varied from 96 (14–20 August) to 108 (1–7 May).
[c] The N is smaller as the same outdoor sites were sometimes used for multiple nearby homes.
[d] During the reference week, temperatures were such that several participants still used their heaters.

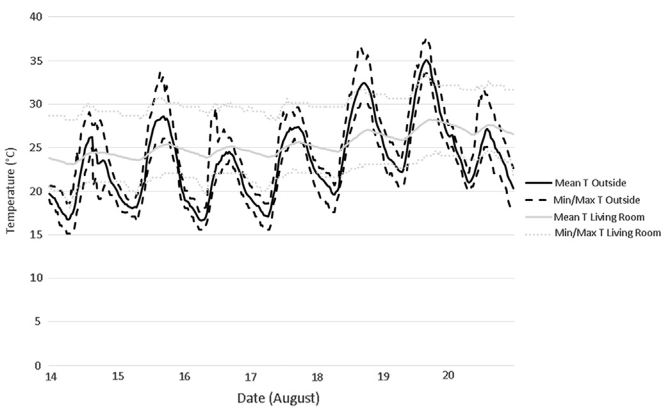

Fig. 1. Mean, minimum and maximum temperature fluctuation between 14 and 20 August 2012 ($N=113$ for living room temperature and $N=77$ for outdoor temperature).

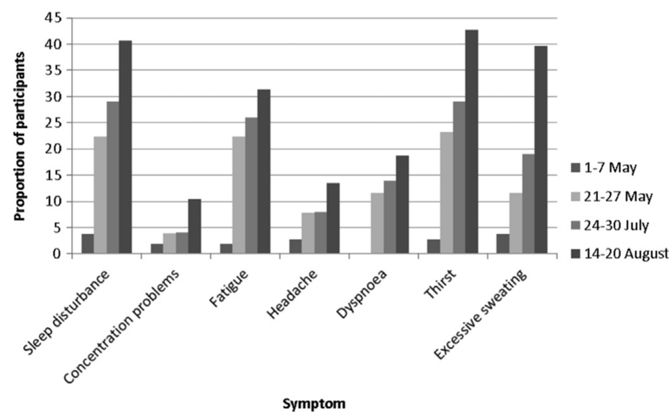

Fig. 2. Proportion of study participants who experienced a certain symptom at some point during each of the study periods.

warm', versus 'mostly cool' and 'mostly pleasant', according to the 7-days questionnaire), are presented in Table 3. The variation in indoor temperature between dwellings was much larger than the variation in outdoor temperature (8–9 °C vs. 2–3 °C). The proportion of participants that perceived their indoor climate as too warm in each period corresponds well with the mean indoor temperatures for those periods. We decided to carry out subsequent analyses only for the study period between 14 and 20 August 2012, for two reasons: (1) by far the highest mean temperatures (indoor and outdoor) were measured (Table 3), (2) this was the only period with a clearly high mean outdoor temperature for which hourly diary data were available (Table 1). The mean temperature over the course of this week is presented in Fig. 1. Mean weekly outdoor temperature is lower than mean weekly indoor temperature, but outdoor temperature shows more variation over the course of this week and higher peak levels.

3.2. Self-reported symptoms due to heat – 7-days questionnaire

The symptoms that were experienced at some point by the highest proportion of participants during the warmest study period were thirst (42.7%), sleep disturbance (40.6%) and excessive sweating (39.6%) (Fig. 2). Participants who considered themselves more sensitive to heat (baseline questionnaire) reported significantly more sleep disturbance ($p \leq .001$) and excessive sweating ($p=.004$) compared to participants who did not consider themselves sensitive to heat, as shown by a Chi-square test. Thirst did not significantly differ between these groups ($p=.523$).

Using logistic regression, we checked whether there was a relationship between weekly average indoor temperature and symptoms of participants (sleep disturbance with bedroom temperature, other symptoms with living room temperature) on the one hand, and with perception of the indoor climate on the other hand. Of the symptoms, only sleep disturbance had a significantly positive association with temperature (data not shown). Living room temperature was a significant predictor for perceiving the living room as too warm (ratio=1.91, 95% CI 1.25 to 2.93; $p=.003$). A similar relationship was found between bedroom temperature and perceiving the bedroom as too warm (ratio=1.85, 95% CI 1.31 to 2.60; $p<.001$).

3.3. Measures to reduce heat stress – 7-days questionnaire

Participants reported which measures they usually undertook to cope with the heat. In the week between 14 and 20 August, the most common measures were (in order of prevalence): drinking more water (69.8%), reducing physical activity (62.5%), ventilating the house more than usual (natural ventilation) (50.0%), going outside (24.0%), using mechanical ventilation (16.7%) and leaving the city (13.5%). One in four participants in this period reported not to usually undertake any measures.

3.4. Heat-related health problems and temperature – hourly diary

Study participants on average spent 82.1% of their time in their house in the week between 1 and 7 May, versus 76.7% between 14 and 20 August. Fig. 3 gives a visual representation of the relationship between all reported heat-related health problems at home and living room temperature (for 'annoyed by heat', 'breathing discomfort' and 'fatigue due to heat') or bedroom temperature (for 'annoyed by heat at night' and 'sleep disturbance') in the study period between 14 and 20 August. Supplementary material 4 presents the same data, but only for the

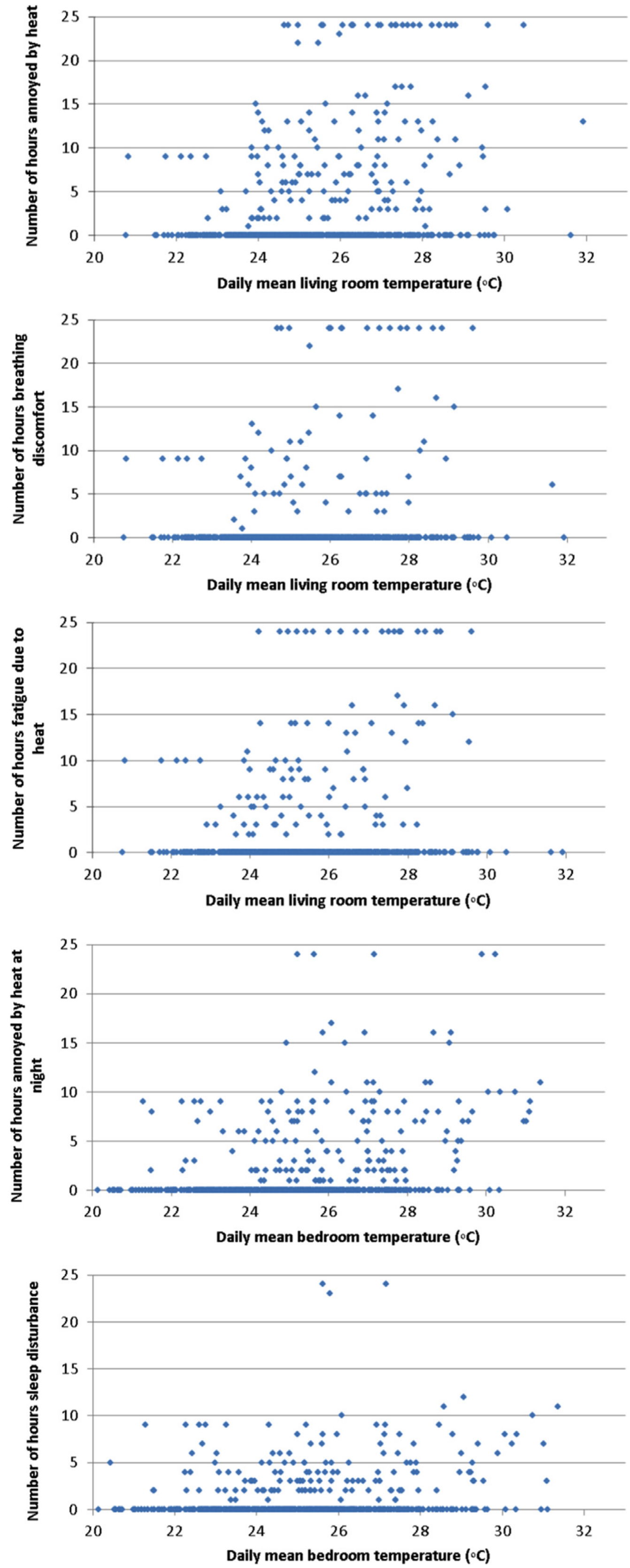

Fig. 3. The relationship between daily reported heat-related health effects and daily living room or bedroom temperature between 14 and 20 August 2012 (N=677 person days).

warmest day within this period (19 August, see Fig. 1). Pearson's correlation between living room and bedroom mean daily temperatures per participant over this study week was .79.

Significant relationships existed between daily temperature and daily number of hours with reported health problems over the course of one week for all evaluated symptoms: between living room temperature and 'annoyed by heat', 'breathing discomfort' and 'fatigue due to heat', and between bedroom temperature and 'annoyed by heat at night' and 'sleep disturbance' (Table 4). Mean daily outdoor temperature also significantly explained all health problems, although the relative increases were smaller compared to the relative increases for indoor temperatures (Table 4). When mean daily outdoor and indoor temperature (living room or bedroom) were included simultaneously in GEE models, outdoor temperature did not significantly contribute (Table 4).

3.4.1. Heat Index

When assessing whether the Heat Index (Blazejczyk et al., 2012) was a better measure to explain health problems than indoor temperature (using the data from Arnhem only, n=56), this resulted in almost identical relative increases and P-values, e.g. for annoyed by heat (indoor temperature: ratio=1.26, 95% CI 1.08 to 1.46; p=.003, and Heat Index: ratio=1.22, 95% CI 1.07 to 1.38; p=.002, for one unit increase in temperature). We calculated the average out of the individual Pearson's correlation for all daily observations in Arnhem over the study period 14–20 August between indoor temperature and Heat Index (n=392 for both living rooms and bedrooms), which was .98 ($p<.001$) for living rooms and .99 ($p<.001$) for bedrooms.

4. Discussion

This study looked at the relationship between indoor and outdoor temperature and heat-related health problems in a population of elderly people. To our knowledge, it is the first large study that focuses on this theme. Heat has an impact on a large number of people. More studies have looked at the association between high temperatures and mortality, but deaths are only the tip of the iceberg. Our results show that living room and bedroom temperatures are associated with substantial increases in reported health problems in the house on a population level well, e.g. for each °C increase in temperature, the amount of hours that people are annoyed by heat is a factor 1.33 higher. The relationship with temperature was observed for both daytime and night-time health problems, including sleep disturbance. A previous study has also shown that temperature of the surrounding area has an effect on the duration and efficiency of sleep (Janssen et al., 2011). Another study showed that skin and body temperature increase during a warm period, to values above 38 °C (van Daalen and van Riet, 2010). Our study showed that indoor temperature is a stronger predictor of health problems than outdoor temperature. The variation in mean indoor temperature over time is much larger than the variation in mean outdoor temperature between dwellings (Table 3). This implies that heat warnings based on outdoor temperatures have a limited potential to assess the health risks of elderly people, since their actual exposure depends more on their dwelling (people tend to spend a large fraction of their time indoors, on average 76.7% during the warm week in our study). Epidemiological studies using outdoor temperature as surrogate parameter for heat exposure probably underestimate the health impact of heat as well. The realisation should be made that temperatures in dwellings can reach high levels, and certain groups of individuals, such as the elderly, are sensitive to the effects of this. Higher temperatures inside dwellings, especially in cities, should therefore be taken into account. Different measures with respect

Table 4
Associations between mean daily indoor (living room or bedroom) and/or outdoor temperature and the number of hours that each participant reported health problems between 14 and 20 August 2012, using Generalized Estimating Equations Poisson loglinear models assuming exchangeable correlation structures, and correcting for gender and age (*N*=97 subjects).

Health problem in living room[a]	**Temperature living room**		**Temperature outdoors**	
	Ratio[b] (95% CI)	*P*-value	Ratio[b] (95% CI)	*P*-value
Annoyed by heat in the house				
One factor model	1.33 (1.20 to 1.48)	< .001	1.13 (1.07 to 1.20)	< .001
Two factor model	1.29 (1.16 to 1.43)	< .001	1.03 (0.97 to 1.09)	.370
Breathing discomfort in the house				
One factor model	1.28 (1.13 to 1.45)	< .001	1.10 (1.02 to 1.19)	.018
Two factor model	1.30 (1.10 to 1.53)	.002	0.99 (0.89 to 1.11)	.847
Fatigue due to heat in the house				
One factor model	1.30 (1.13 to 1.50)	< .001	1.13 (1.06 to 1.20)	< .001
Two factor model	1.26 (1.07 to 1.48)	.005	1.03 (0.96 to 1.10)	.445
Health problem in bedroom	**Temperature bedroom**		**Temperature outdoors**	
	B-value (95% CI)	*P*-value	*B*-value (95% CI)	*P*-value
Annoyed by heat in the bedroom at night				
One factor model	1.28 (1.17 to 1.41)	< .001	1.11 (1.05 to 1.17)	< .001
Two factor model	1.30 (1.19 to 1.41)	< .001	0.99 (0.93 to 1.05)	.728
Sleep disturbance				
One factor model	1.24 (1.10 to 1.40)	.001	1.11 (1.03 to 1.20)	.010
Two factor model	1.21 (1.07 to 1.37)	.002	1.02 (0.94 to 1.11)	.592

[a] This table presents the results of analyses for indoor (living room and bedroom) and outdoor temperature separately (one factor model), and for indoor and outdoor temperature combined (two factor model).
[b] A ratio of 1.33 indicates that, for a mean daily temperature of 1 °C higher, the number of hours that symptoms are reported per day is a factor 1.33 higher. Ratios were calculated by exponentiating the regression slope of the Poisson model.

to building characteristics can be taken to reduce the amount of overheating in dwellings, such as solar shading and additional natural ventilation (van Hooff et al., 2014).

The proportion of participants that perceived their indoor climate as too warm was higher in periods with high (indoor) temperatures. Between 14 and 20 August even more than half of the participants perceived their living room and/or bedroom as too warm, and there was a significant relationship between both living room and bedroom temperatures, and perceiving their indoor environment as too warm. These results underline the magnitude of the problems with heat stress in the elderly population. This is especially striking since the summer of 2012 was not considered warm compared to the average summer temperature in the Netherlands (16.9 °C vs. 17.0 °C, respectively) (KNMI, 2015), and the warmest week did not fit the formal criteria for a heat wave. Indoor and outdoor temperatures will probably achieve even higher values in the future due to climate change (Parry et al., 2007), which may lead to a higher proportion of elderly with heat-related health problems if preventive or adaptation actions are not taken.

In a study that compared urban and rural temperatures (the urban heat island effect) for the 73 largest cities in the Netherlands (Klok et al., 2012), the two cities in our study ranked average. We do not know whether in cities with higher outdoor temperatures, indoor temperatures and reported health problems are higher than in our two study cities. Since the Netherlands experiences a moderate maritime climate, summer temperatures are relatively mild compared to those of many other cities around the world (that experience e.g. a Mediterranean, tropical or arid climate). Whether the number of health problems reported is also higher depends on adaptation of buildings and individuals. As a study by Baccini et al. has shown, optimum temperature in terms of mortality varies between different European cities, based on average climate conditions of those cities (Baccini et al., 2008).

We tested whether the Heat Index was a better indicator than temperature to assess heat-related health problems in the elderly (Blazejczyk et al., 2012), but we found no difference in relative increase in symptoms and *P*-values compared to using temperature in our models. A possible explanation is that the Heat Index is not very sensitive to moderate values of relative humidity, and extreme values (very low or very high) were not found in living rooms or bedrooms within our study (unpublished result). Therefore, we conclude that indoor temperature is an equally good parameter to assess heat-related health problems as the Heat Index in a country with a temperate climate.

4.1. Limitations

The data in our study on heat-related health problems in the house and participants' perception of their indoor climate were based on self-reported data. We asked our study participants to report by the hour when they experienced health problems, but it is likely that some participants filled in this hourly diary only several times a day, which might lead to imprecision, e.g. not remembering exactly how many hours they experienced a certain health problem. In addition, it seems some mistakes were made in filling out the hourly diary, e.g. the reported number of hours of sleep disturbance on a certain day was 24 (Fig. 3), which is unlikely. As we could not be certain which data were reported erroneously and which data purposefully, we analysed all data as we received it. In general however, we feel that our study participants could fill out the hourly diary fairly accurately. The 7-days questionnaire was filled in at the end of the study week, which might also have led to a recall bias.

Since study participants were partly included based on self-selection, this led to a risk that people who were sensitive to heat were more prone to participate in the study, which could increase the frequency of reported health symptoms and possibly bias the association between measured daily temperature and health. The results from our baseline questionnaire (Table 2) imply this is not the case, since less than one in three participants reported that they perceived themselves to be sensitive to heat. Alternatively, the proportion of individuals who perceived their own health as good or excellent is 82% (Table 2), which is most likely higher than average in this age group. Individuals with a lower self-perceived health are more likely to report health problems (due to heat), which would indicate that our results show an under-representation. Even though individuals with poorer health more often live in elderly care centres than in private dwellings, temperatures in many elderly care centres also reach high values (Links et al., 2013).

The response during the warm week in August (14–20) was a bit lower than the response in other study weeks ($N=96$ vs. e.g. $N=108$ in the reference week). This was due to the fact that more study participants were away on holiday during this period, and for that reason we feel as though it does not influence our study results (since the low response did not have a study-related reason).

Because it was challenging to find similar studies in the peer-reviewed English literature, we included reference to Dutch reports.

5. Conclusions

Our study shows that the relationship with heat-related health problems in the house in the elderly is stronger with indoor temperature (living room and bedroom) than with outdoor temperature. This finding seems plausible, since indoor temperature gives a more realistic representation of heat exposure. In addition, we found that more than half of our study participants experience their indoor climate as too warm during a warm summer week in the Netherlands, which indicates that indoor heat is a serious problem. Part of the elderly population in our study usually undertake some measures to cope with heat, such as drinking more water, reducing physical activity and ventilating more (natural and mechanical ventilation), although one in four did not adjust their behaviour at all. Due to the large variation, some elderly are exposed to high temperatures in their dwelling, which requires action by the (local) government. Measures that can be taken to reduce heat exposure are either aimed at reducing the micro-urban heat island effect (Smargiassi et al., 2009), making adjustments to dwellings (Vandentorren et al., 2006), or changing heat-adaptive behaviour in the elderly population (White-Newsome et al., 2011).

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envres.2015.12.012.

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