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Heat wave vulnerability classification of residential buildings

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Abstract

General circulation models of climate change predict that the intensity and frequency of heat waves will increase, which are a significant threat to public health (Luber and McGeehin 2008). The effect of heat waves on the public health became apparent during the 2003 heat wave in France, where almost 15,000 heat related deaths (excess of 60%) were reported (Pirard et al. 2005). Between 1,000 and 2,200 heat related excess deaths were reported in the Netherlands (Fischera et al. 2004, Garssen et al. 2005). The total heat related excess mortality across Europe was more than 50,000 (Brücker 2005, Kosatsky 2005). In this study, a first heat wave vulnerability classification for overheating is made of four Dutch residential building types, using historical climate data of five heat-waves in the Netherlands. The four evaluated building types are Terraced houses, Corner houses, Detached houses and Semi-Detached houses, of which the geometry was based on the Dutch reference buildings (SenterNovem 2006). Apart from these four building types, ten other variables/uncertainties such as building orientation, ventilation rate, R_c -values and window areas were taken into account using Monte Carlo analysis. For this analysis, 400 cases were generated for each building type using random Latin Hypercube sampling. From this analysis a first classification was made, which from most to least vulnerable was: (1) Detached house, (2) Corner house, (3) Semi-detached house, (4) Terraced House.

Keywords

Heat wave, Building energy simulation, Vulnerability, Residential buildings, Climate change

Introduction

The Royal Netherlands Meteorological Institute (KNMI) has formulated four different climate scenarios (van den Hurk et al. 2006, Klein Tank and Lenderink 2009) in order to describe the expected climate change for the Netherlands. These scenarios predict that mild winters and hot summers will become more common in the future (van den Hurk et al. 2007) which is a result of the continued rise in outdoor temperature. Moreover, research indicates that a major European heat wave, such as in 2003, will become more frequent in the future (Beniston 2004, Kovats and Hajat 2007) and a common event by 2040 (Stott et al. 2004). The urban environment is subjected to this increase in temperature, which can result in adverse effects such as overheating of the indoor environment (Nicol et al. 2009, Sanders and Phillipson 2003).

People spend a significant time of their life inside buildings (Huynh 2010) and the Netherlands should not be complacent about actions to protect the most vulnerable

people e.g. elderly and children against heat related risk (Garssen et al. 2005). Knowledge on the impact of heat waves on the indoor environment is therefore considered necessary.

In recent research on the impact of climate change on the indoor environment, building energy simulation has been used e.g. by Chow et al. (2010), de Wilde and Tian (2010), Crawley (2008). By the use of these simulations Coley and Kershaw (2010) defined a climate change amplification factor, which is used to show that there exists a linear relationship between the increase in outdoor temperature and the resulting increase in indoor temperature. However, it is questioned by de Wilde and Tian (2011) how applicable these factors are for building categories, or complete building stocks, since the factors are unique for each building. On the other hand is proposed by Crawley that simulations can be used to represent entire building stocks (Crawley 2008). This idea of climate change impact studies for complete building stocks has not yet been pursued (de Wilde and Tian 2011).

It is still unclear if certain building types will increase vulnerability for heat waves (Kovats and Hajat 2007). In a heat wave adaption study for dwellings Porritt et al. (2011) showed that based on a UK reference weather year of the 2080s, overheating can be reduced by wall insulation and measures to reduce solar heat gains. Further research was proposed to investigate the effect of different heat wave durations and more extreme weather years (Porritt et al. 2011).

The objective of this study was to analyze which residential building type in the Dutch building stock is most vulnerable for heat waves, using multiple historical climate years where heat waves were recorded. Out of this analysis a heat wave vulnerability was made of four residential building types.

Methodology

In order to obtain an accurate translation of the outdoor environment (during a heat wave) to the building indoor environment, the study adopted Building Energy Simulations (BES) using ESP-r. The study consisted of the following steps:

1. Establishing a typological classification of buildings;
2. Application of BES models on multiple variations (by latin hypercube sampling) on the typological classification of buildings;
3. Establishing a vulnerability classification of building types for heat waves.

For the building typological classification (step one in the methodology) in this analysis four different residential buildings types were evaluated, namely: Terraced houses, Corner houses, Detached houses and Semi-Detached houses. The geometry of these buildings is shown in Figure 1, which is based on the Dutch reference buildings (SenterNovem 2006), where the building component properties are based on both the reference and the example buildings (Agentschap NL 2011).

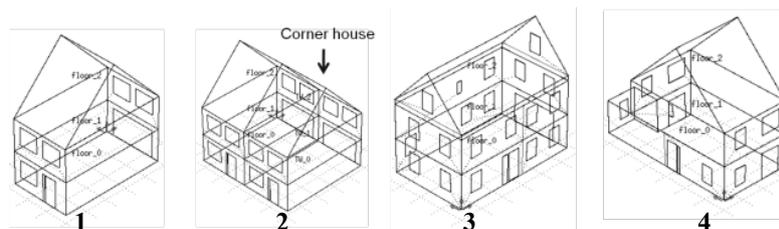


Figure 1. Residential buildings which are classified in four different types. The model geometry is based on the Reference buildings (SenterNovem 2006). The building types are: 1. Terraced house; 2. Corner house; 3. Detached house; 4. Semi Detached house.

Apart from these properties other uncertainties as e.g. different orientations, ventilation flows and other climate years were taken into account in this study. In order to account for these uncertainties a Monte Carlo analysis was used. For this analysis 400 cases were generated for each building type using random Latin Hypercube sampling (step two in the methodology). The building properties as well as meteorological conditions were changed within a specified range, as shown in Table 1. For the meteorological conditions five different datasets of historical climate data were selected, namely 1975, 1976, 1990, 2003 and 2006. In these datasets either the length of the heatwave was longer than was the case in 2003, or the maximum temperature during the heatwave was higher than was the case in 2003. In total 1600 simulations were performed which provide a range in possible outcomes based on the uncertainties of the boundary conditions.

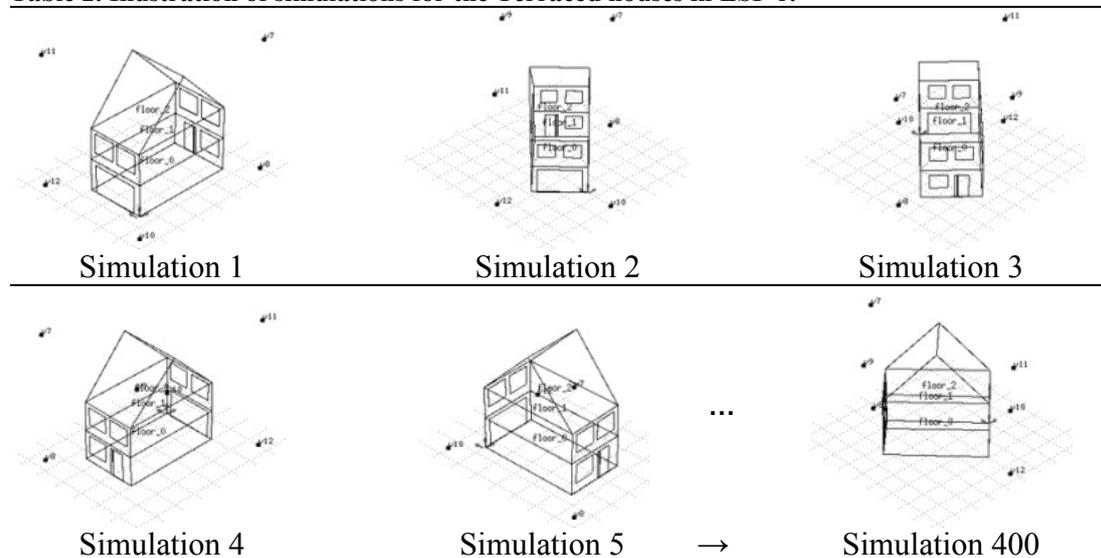
Table 1. Range of parameters in latin hypercube sample.

Parameter	Range
Orientation [°]	45° / 90° / 135° / 180° / 225° / 270° / 315° / 360°
Window area [m ²]	-20% / -10% / 0% / +10% / +20%
Volume of building [m ³]	-20% / -10% / 0% / +10% / +20%
Rc-value walls [m ² K/W]	1.30 / 2.53 / 3.0
Rc-value roof [m ² K/W]	1.30 / 2.53 / 4.0
Rc-value floor [m ² K/W]	1.30 / 2.53 / 3.0
Thickness floors [m]	-20% / 0% / +20%
Glass type [-]	Single / Double layers
Ventilation ¹ [m ³ /m ³ h]	-20% / -10% / 0% / +10% / +20%
Climate year [-]	1975 / 1976 / 1990 / 2003 / 2006

¹) When compared with the minimal required ventilation flow in the Dutch building degree, 1 dm³s⁻¹m⁻² for living room, bedroom, and internal storage (NEN 2001).

An illustration of the input for the building energy simulation is shown in Table 2, showing how the orientation, building volume and window area varies for different simulations. The illustration only shows the input for the terraced house, the input for the other three building types is obtained in a similar manner.

Table 2. Illustration of simulations for the Terraced houses in ESP-r.



Results

A total number of 4 x 400 simulations were executed. In Figure 2 the calculated indoor temperatures during the heat waves for the different climate years are shown. These graphs provide the indoor temperatures for each simulation with the dotted black line, and the average temperature of these simulations with a solid red line. These results are only displayed for the terraced house. It is indicated that the average indoor temperature over the total time span of a heat wave is between 25.7 and 28.8 °C.

For an analysis of the results for all buildings types, frequency counts were made of the occurrence of certain indoor temperatures. The result of this analysis is shown in Figure 3, where on the horizontal axes the indoor temperature is displayed, and on the vertical axes the cumulative frequency over the total number of simulations. It is shown that the occurrence of indoor temperatures higher than 22°C was found to be most likely for detached houses. The residential building type which had the lowest frequency count in indoor temperatures higher than 22°C was the terraced house.

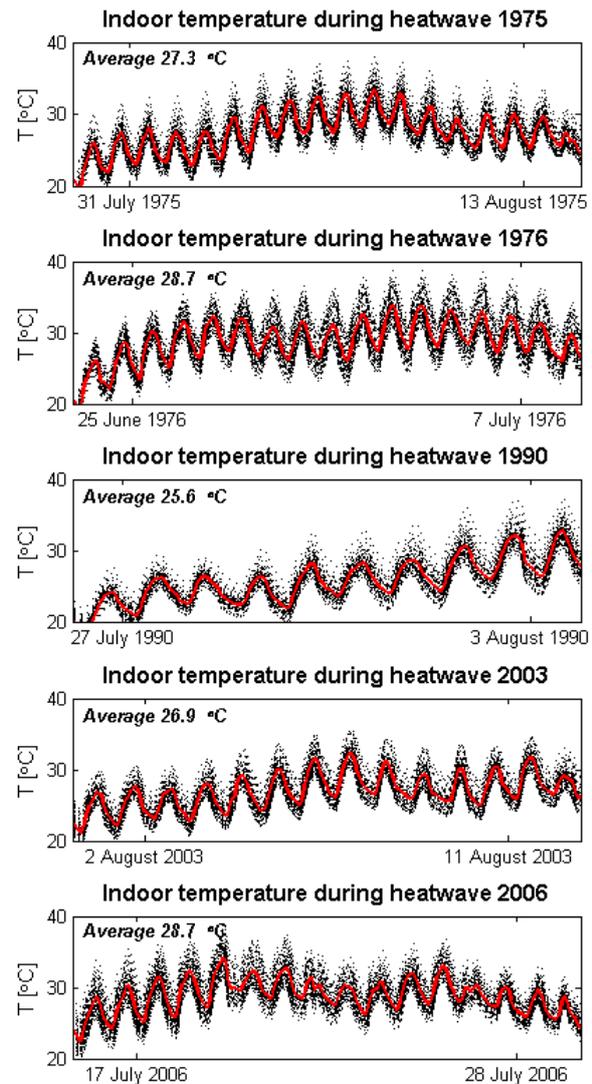


Figure 2: Calculated indoor temperatures for terraced houses for five different heat waves in the Netherlands.

The overheating hours $>25^{\circ}\text{C}$ were counted for each of the 400 simulations per building type. The threshold of this performance indicator is based on the temperature where occupants start to feel 'warm' (CIBSE 2005). The result of this analysis is displayed in Figure 4, which provides the range in overheating hours for each building type. The result showed that the largest number of overheating hours were found for the detached houses, followed by the corner houses, semi-detached houses and terraced houses.

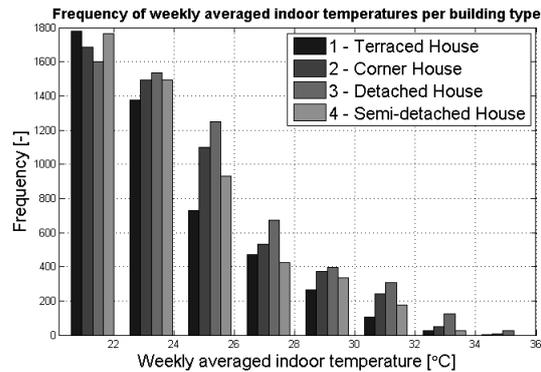


Figure 3: Frequency of weekly averaged indoor temperatures for 400 variations on the specified residential building types.

1. Terraced house
2. Corner house
3. Detached house
4. Semi-detached house

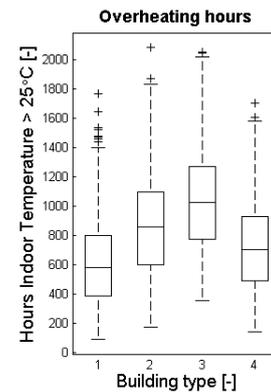


Figure 4: Boxplots which provide the range in overheating hours for 400 simulations per building type.

Conclusion

Based on the results as presented in the previous paragraph a vulnerability classification of residential buildings in the Netherlands was made. This classification from most to least vulnerable was:

- Detached house
- Corner house
- Semi-detached house
- Terraced House

This conclusion was based on the Dutch reference buildings, taking into account the minimal required ventilation flows (NEN 2001) throughout the year. Operable windows were not taken into account. No solar shading devices were implemented in the BES models. Further research is proposed on the impact of these factors on the results of the vulnerability classification

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