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Reprint of: On the predicted effectiveness of climate adaptation measures for residential buildings☆

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A B S T R A C T

In a changing outdoor climate, new buildings as well as the existing building stock need to adapt in order to keep providing their inhabitants and users a comfortable and healthy indoor environment, with a minimum or - preferably - no increase in energy consumption. In this paper, the effectiveness of six passive climate change adaptation measures applied at the level of building components is assessed using building energy simulations for three generic residential buildings as commonly built in - among others - the Netherlands: (1) detached house; (2) terraced house; (3) apartment. The study involves both residential buildings that are built according to the regulations and common practice in 2012, and residential buildings that were constructed in the 1970s, with a lower thermal resistance of the opaque and transparent parts of the building envelope. The climate change adaptation measures investigated are: (i) increased thermal resistance; (ii) changed thermal capacity; (iii) increased short-wave reflectivity (albedo); (iv) vegetation roofs; (v) solar shading; and (vi) additional natural ventilation.

This paper quantifies the effectiveness of these climate change adaptation measures for new residential buildings as well as for renovation of the current building stock. The performance indicator is the number of overheating hours during a year. It is shown that exterior solar shading and additional natural ventilation are most effective for this performance indicator. Furthermore, increasing thermal insulation to reduce energy use for heating demands additional measures to prevent overheating.

1. Introduction

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) states that climate change is unmistakably occurring and is already visible in some recent observations of the climate [1]. The global temperature has increased with 0.56 °C-0.92 °C in the last century (1906-2005), and it is shown that 11 of the 12 hottest years between 1850 and 2007 took place in the last 12 years prior to 2007 [1]. The temperatures are expected to increase on average with 0.2 °C per decade in the next two decades. When the concentrations of all greenhouse gas emissions and aerosols would have remained constant at the levels of the year 2000, the expected temperature increase would still be around 0.1 °C per decade [1]. The temperature after the next two decades becomes more dependent on the emission scenarios and is therefore subject to a large uncertainty [1]. Nevertheless, a temperature increase between 1.1 °C and 6.4 °C is predicted until the end of this century, when compared to the temperatures in the period 1980-1999 [1].

The predicted climate change differs per continent, country and even per region [2]. The Royal Dutch Meteorological Institute (KNMI) studies climate change in the Netherlands. A measure to indicate the changing climate is the yearly number of heat waves. The KNMI defines a heat wave as a period of at least five days during which the daily maximum ambient temperature is 25 °C or higher [3]. These five days must include at least three days with a maximum ambient temperature higher than 30 °C. In the period between 1901 and 2009, 38 heat waves have been recorded in the Netherlands, seven of which took place in the last decade of this period (1999-2009) [4]. Moreover, in the future, it is likely that the Dutch climate will be subject to a continuous rise of temperatures; mild winters and hot summers with heat waves will become even more common than in the decade 1999-2009 [5]. While the

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occurrence of mild winters will decrease the energy demand for heating, the increasing number of hot summers can lead to problems regarding thermal comfort and health of building occupants, and to an increase of energy use in buildings with active cooling systems. The effect of climate change on the additional energy use in buildings in summers, and on increased levels of human morbidity and mortality, has been reported in several publications [6-8]. Fig. 1, reproduced from a study by Garssen et al. [9], for example indicates the relation between the average weekly maximum outdoor air temperature and the number of deaths in the Netherlands for each of those weeks. The figure shows a very strong correlation; higher average weekly maximum temperatures result in a higher number of deaths. Since people spend around 90% of their time indoors [10], the adaptation of buildings to the predicted climate change is important to protect people against excessive exposure to high indoor air temperatures, or at least to limit the effects as much as possible. The effects of climate change on the (built) environment and thus on humans, as described above, indicate the urgency to study, analyze and implement climate change adaptation measures at different scales, including the building scale, to limit the consequences of climate change in terms of increased health problems, reduced productivity and increased energy use.

Residential buildings in the Netherlands and in many other North-Western European countries are typically neither equipped with an air-conditioning system, nor with other active cooling systems to reduce the indoor air temperature in hot periods [11,12]. Therefore, the building itself must provide sufficient protection against high air temperatures. Moreover, from an environmental point of view, it is undesirable to apply air-conditioning systems and other active cooling systems on a large scale in these residential buildings, since this will lead to a higher energy consumption and thus to higher emission levels of greenhouse gasses, which will intensify climate change and global warming even more [13]. To protect building occupants from the effects of climate change without increasing the energy use one should therefore rely on sustainable solutions to prevent indoor overheating in residential buildings, but also in other buildings, e.g. offices, schools.

In this study, the effectiveness of passive climate change adaptation measures is assessed when applied to typical Dutch residential buildings assuming an expected future climate year. A passive measure is defined as a measure which does not use energy once it has been implemented. In the past, several publications have addressed possible climate change adaptation measures on city, neighborhood, street or building scale (e.g. Refs. [4,14-23]).

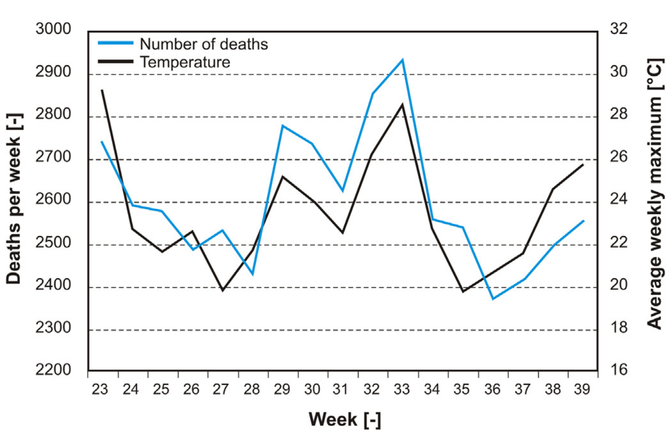

Fig. 1. Mortality and average maximum temperature per week in the Netherlands during June-September 2003 (modified from Ref. [9]).

Porrit et al. [17,18] studied the effect of a range of passive climate change adaptation measures for residential buildings (late 19th century Victorian terraced houses with solid walls) in the UK using the dynamic thermal simulation program EnergyPlus. Among others, they studied the effect of building insulation, shading and natural ventilation. They concluded that the application of one or more passive adaptation measures may reduce the number of overheating hours with 32-99%, depending on the type of adaptation measure, and on the number of adaptation measures that are implemented simultaneously. Coley et al. [19] studied several adaptation measures for a well-insulated residential building (large house) and a school building in the UK. They analyzed both hard (structural) and soft (behavioral) adaptation measures and concluded that behavioral adaptation measures, such as opening and closing the windows at appropriate moments (night ventilation, additional daytime ventilation), shifting school hours with two hours forward, can be just as efficient as the application of structural climate change adaptation measures, such as increasing the thermal mass and adding external solar shading. Note that in the aforementioned studies only one type of residential building and only one construction period (and thus thermal resistance of the building envelope) was studied, while the study presented here

Table 1
Overview of adaptation measures studied.

Adaptation measure	Description	Abbreviation
Increased thermal resistance	The thermal resistance of all external building surfaces is increased to $R_C = 5.0$ m^2 K/W and $R_C = 6.5$ m^2 K/W, for RC50 and RC65, respectively. This measure is implemented by increasing the thickness of the insulation layers.	RC50, RC65
Changed thermal capacity	The thermal capacity is lowered, since the base case is a heavy building. The thermal capacity is changed by replacing the limestone inner leaf by an inner leaf of wooden sheeting. In addition, concrete ceilings are replaced by wooden constructions.	TM_low
Increased short-wave reflectivity (albedo)	The short-wave reflectivity value of the external surfaces is increased from the default value of 0.3-0.6 and 0.8, for configuration SWR06 and SWR08, respectively.	SWR06, SWR08
Vegetated roof	The default roof constructions are extended to incorporate a vegetated roof with a Leaf Area Density index of 5.	VR
Solar shading	Exterior solar shading is applied for all windows on the east, south and west side of the facades. The solar shading is automatically lowered when the solar radiation on the window is at least 150 W/m2.	SH
Additional natural ventilation	Additional natural ventilation is provided by opening (parts of) the windows. The windows will be opened when the indoor air temperature is above 24 °C, but only when the indoor air temperature is higher than the outdoor air temperature. In one measure (NV_all) the windows can be opened the entire day (24 h), in the other case (NV_day) the windows can only be opened between 08:00-20:00 h.	NV_all, NV_day

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