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Analysis of the predicted effect of passive climate adaptation measures on energy demand for cooling and heating in a residential building

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A B S T R A C T

Both new and existing buildings need to be adapted to climate change, in order to keep providing a comfortable and healthy indoor climate. Preferably, the adaptation measures applied at the building level scale do not require additional energy (i.e. passive measures). Previous studies showed that passive climate change adaptation measures can have a positive effect on thermal comfort in summer and its shoulder seasons in non-air-conditioned residential buildings. In this paper, the effect of these passive climate adaptation measures – applied at building component level – on the cooling and heating energy demand of a terraced house is analyzed using building energy simulations. It is shown that for this particular case the required cooling energy can be limited to a large extent (59–74%) when external solar shading or additional natural ventilation is applied. In addition, it is shown that for a well-insulated terraced house the energy cost for heating is not strongly affected by the application of passive climate change adaptation measures.

1. Introduction

The main conclusions in the reports by the IPCC (Intergovernmental Panel on Climate Change) that have been published in the last decade are clear: climate change is unmistakably occurring. In the latest report by the IPCC it is stated, for example, that the global average land and ocean surface temperature has increased with 0.85 °C (0.65–1.06 °C) from 1880 to 2012 [1]. In addition, it is reported that it is 'likely' that the frequency of heat waves has increased in large parts of Europe, Asia and Australia. Furthermore, in the Northern Hemisphere the 30-year period from 1983 to 2012 was 'likely' the warmest period in the last 1400 years [1].

In the Netherlands, climate change will most likely lead to a continuous rise of temperatures, resulting in milder winters and hotter summers with more heat waves during the summer [2]. While the 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 (e.g. Refs. [3–7]). If active cooling is applied in order to prevent people against excessive exposure to high indoor air temperatures, it is important to minimize the energy use for this purpose as much as possible. Otherwise, the use of active cooling systems will result in an increase in the use of fossil fuels, the emission of CO_2, and a further acceleration of climate change in the future. In a recent report on the impact of climate change on buildings it is stated that the global energy demand for air-conditioning in buildings is expected to increase from nearly 300 TWh in 2000 to 4000 TWh in 2050, if no additional mitigation policies are undertaken [8,9]. Maintaining a healthy and comfortable indoor environment without using excessive amounts of energy should be the goal when designing a new building, now and in the future. However, a too strong focus on only one of the aforementioned aspects might lead to a deterioration of the other aspect (e.g. Ref. [3]).

Although the majority of the 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 [10,11], the presence of small air-conditioning systems to cool one or more rooms of a house appears to be growing [12–14]. In a EU report by Capros et al. [12] it is stated that the use of active cooling in residential buildings is limited in Europe, but will grow "at a fast pace" and will attain a

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share of almost 2% of the total energy use in residential buildings in Europe in 2030. Wu and Pett [13] reported that 10% of the non-domestic building floor area and 0.5% of the domestic building floor area in the UK was cooled in 2006. However, they also stated that the growth in the domestic sector will be the fastest, and that the carbon emissions from these additional cooling efforts will overweigh the reduction in carbon emissions due to a decrease in heating demand in the UK in the future due to the changing climate [13]. Finally, they mentioned that air-conditioning units are often purchased in periods of distress (e.g. during heat waves) and that afterwards the air-conditioning will be used whenever the temperature will rise, even when the temperatures are lower than the ones that caused the distress and initiated the purchase, which will lead to an excessive use of the cooling systems [13]. Aebischer et al. [14] indicated the growth of the energy demand for cooling in Europe, due to – among others – climate change, higher internal loads, application of large glass facades (i.e. higher solar heat gains), higher thermal insulation values, and an increase in thermal comfort standards and expectations (e.g. resulting from air-conditioned cars, trains and public spaces). As indicated also by Wu and Pett [13], in large parts of Europe (moderate climates) the cooling energy demand will be outweighed by a reduction in the heating demand [14]. However, the yearly total amount of CO_2 emission can increase, depending on the percentages of cooling and heating in a specific country, and on the CO_2 intensity of the heating fuels and electricity that are supplied to the buildings [14]. As indicated in the aforementioned publications, the application of (ad-hoc) energy-consuming measures to avoid indoor overheating should be stopped or at least limited, to avoid an increase of energy use and CO_2 emission in the built environment in the near future. Previous studies have shown that passive climate change adaptation measures can significantly reduce the number of overheating hours in – among others – residential buildings that are not equipped with air-conditioning or active cooling systems (e.g. Refs. [15–21]). Note that none of these studies mentioned here assessed the influence of passive climate change adaptation measures on the energy demand for cooling, when an active cooling system would be present.

In this study, the cooling and heating demand of a residential building are analyzed, after which the effect of a range of passive climate change adaptation measures is assessed with respect to both the energy demand for cooling and heating, and for the total energy demand. This study is performed for a typical Dutch terraced house. The simulations are conducted for an expected future climate year, and a selected number of simulations has been conducted for an "average" climate year. A passive measure is defined in this study as a measure which does not use energy once it has been implemented. The following passive climate change adaptation measures are analyzed in this paper: (i) increased thermal resistance; (ii) changed thermal capacity; (iii) increased short-wave reflectivity (albedo value); (iv) vegetation roofs; (v) solar shading; and (vi) additional natural ventilation (see Table 1). In addition, the combined effect of several passive climate change adaptation measures is assessed. Dynamic thermal simulations using EnergyPlus [22] are performed to analyze the effect of the different measures on the yearly energy demand for heating and cooling.

The research was conducted within the Climate Proof Cities (CPC) research consortium, which was one of the research consortia investigating the climate vulnerability of urban areas and the development and effectiveness of climate change adaptation measures [21,23–35]. The methodology will be addressed in Section 2, after which the results of the dynamic thermal simulations will be presented in Section 3. Section 4 (discussion), Section 5 (conclusions), and Section 6 (future work) conclude this paper.

2. Methodology

Dynamic thermal simulations are performed with EnergyPlus to assess the performance of the different passive adaptation measures. EnergyPlus consists of three basic components: (1) a simulation manager, (2) a heat and mass balance simulation module, (3) a building systems simulation module [36]. The development of EnergyPlus is funded by the DOE (Department of Energy) of the US and has been validated extensively in the past (e.g. Refs. [37–40]). In addition, the authors have performed several successful comparisons of EnergyPlus results with data from the BESTEST (Building Energy Simulation Test). More background information on EnergyPlus and validation tests can be found in Refs. [22,36–42].

2.1. Building description

The building geometry of the terraced house is based on an example terraced house in the Netherlands as defined by Agentschap NL [43]. It has one zone for the living room (ground floor),

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 (U = 0.2 W/m^{2}K) and $R_C = 6.5$ m^{2}K/W (U = 0.15 W/m^{2}K), 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 0.3–0.8.	SWR08
Vegetated roof	The default roof constructions are extended to incorporate a vegetated roof with a Leaf Area Index (LAI) 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 indoor air temperature is 21 °C or higher and when at the same time solar radiation on the window is at least 150 W/m^2.	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. The windows can be opened the entire day (24 h).	NV