Wind Driven Rain and Climate Change: A Simple Approach for the Impact Assessment and Uncertainty Analysis

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SUMMARY:
By increasing signs of climate change, growing knowledge about it and the availability of climate data, performing the impact assessment of climate change is becoming more feasible in different fields of science and engineering. However making practical conclusions out of the impact assessment is not easy since there are many climate scenarios for future. This introduces uncertainties in the impact analysis which should be considered. According to different climate scenarios Sweden faces warmer and moister climate. Rain shows strong signals of climate change; more rain in future and stronger and more often extreme raining events, which can increase the risks for buildings and the built environment.

This paper makes a preliminary impact assessment of climate change for wind-driven rain (WDR) on buildings. A simple method from ASHRAE is used to calculate the amount of rain deposition on wall, using the hourly values of rain and wind data from 6 climate scenarios during 1961-2100. Results show that the amount of rain deposition will increase in future, however there are considerable differences in results induced by climate uncertainties. Further research and numerical simulations of WDR is needed to evaluate the preliminary results.

1. Introduction

According to the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2007), which is also confirmed by the Fifth Assessment Report (AR5), climate changes induces increase in climate variability and extreme events. Most of the future climate scenarios point to more frequent and extreme rain events in different parts of Europe which make buildings and the built environment more vulnerable. Signs of extreme climatic conditions and the corresponding high levels of precipitation have already appeared in Europe. For example during 2012 heavy rains in southern areas of Sweden caused flooding, many people were affected and buildings needed to be pumped dry (DN.se, 2012; Guibourg, 2012). Impacts of climate change on buildings in Sweden can often be associated with increased moisture stress. More intense precipitation events in future, changes in the timing of seasonal precipitation, rainfall, and the length of time surfaces are wet can result in increased and/or accelerated deterioration of the built environment (Moonen et al., 2012). Not preparing for these future changes increases risks, costs and the severity of damages, which can badly influence living conditions and economy of the country. Sustainability of the built environment depends on its adaptation to future climate. Adaption measures can reduce the risks of climate extremes and disasters, regardless of the degree of certainty around future changes (Field et al., 2012).

Wind-driven rain (WDR) is known as a damaging moisture source; out of all the exterior hygrothermal environmental loads which directly influence the moisture transport, WDR is the main reason for critical damage to the building performance. WDR affects the hygrothermal performance and durability of building façades enormously. Rainwater is also an agent for most of the physicochemical deterioration processes (Moonen et al., 2012) (Blocken and Carmeliet, 2004). In future climate scenarios, precipitation shows the strongest signals of climate change along with temperature for future climate. Unlike precipitation wind has weak signals of climate change, therefore this study focuses on the rain precipitation in future. To estimate the importance of climate change on the hygrothermal performance of buildings in Sweden and to make the buildings resilient enough it is necessary to perform the impact analysis of climate change for WDR on buildings.

This paper presents a preliminary study about the impacts of climate change for WDR on buildings by using a simple method to calculate the amount of rain striking a vertical surface (ASHRAE, 2009). The main intention is to estimate how much situation for buildings can vary in future by estimating the amount of rain deposition on vertical wall surface. Moreover importance of three climate uncertainties - global climate models (GCMs), initial conditions and spatial resolution - in WDR calculations is considered. An earlier work of the authors looked into WDR and climate change by calculating the Stokes number for the driven rain (Nik et al., 2013). The approach in the present paper differs by using an empirical method which focuses more on characteristics of the wall surface than the driven rain. This study has been performed for the city of Gothenburg in Sweden during the period of 1961-2100.

2. Climate Data

Several climate models and scenarios exist. On a global scale, global climate models (GCMs) are used. GCMs consist of individual model components which describe the atmosphere and the ocean. They also describe the atmosphere-ocean interactions as well as interactions with the land surface, snow and sea ice and some aspects of the biosphere (Persson et al., 2007). Regional climate models (RCMs) are used to downscale results from GCMs dynamically, to achieve a higher spatial resolution over a specific region. The climate data used in this work are mainly results from the RCA3 regional climate model by the Rossby Centre which is the climate modelling unit of the Swedish Meteorological Hydrological Institute (SMHI).

Using the numerically simulated climate data in the building models introduces different uncertainties to the simulations. In this paper three climate uncertainties are considered. The first one concerns the changes in the large-scale circulation determined by the GCM. The second factor relates to the initial conditions which were assumed when running the climate models. The third uncertainty is the spatial resolutions of RCMs, since they can downscale data with different spatial resolutions.

2.1 Global Climate Models

RCA3 has been downscaling three different GCMs to 50km horizontal resolution. The GCMs are: 1) ECHAM5, 2) CNRM and 3) IPSL (for details see (Kjellström et al., 2011)). Different GCMs result in different climate conditions. Based on the previous research the uncertainties induced by GCMs are the most important ones in the hygrothermal simulation of buildings (Nik, 2012).

2.2 Initial Conditions

Climate simulations with global climate models for the 20th and 21st centuries generally start with preindustrial conditions. However the initial conditions are not fully known. Initial conditions are needed for the full three-dimensional fields in the atmosphere and oceans. Also starting conditions for the soil models and sea-ice models are needed. In addition to this there is a need to prescribe the physiography (orography, type of soils, vegetation cover, etc) (Nik, 2010). In this paper three simulations of a climate model (RCA3-EHCAM5-A1B) with three different initial conditions are compared. The evolution of time in these three simulations differs as the initial conditions are not the same. These differences are present throughout the simulations, i.e. both in the 20th and the 21st century.

2.3 Spatial Resolutions

RCMs downscale data from GCMs in different spatial resolutions, down to 5km. Data from two spatial resolutions of RCA3, 50km×50km and 25km×25km, are used in this work. RCA3 is set up so that a 50km grid is covered exactly by four grids in the finer-scale 25km integrations. Considering the availability of very fine spatial resolutions, it is important to investigate the uncertainty induced by different spatial resolutions.

3. Wind-Driven Rain

WDR is known as a potentially damaging moisture source. It especially affects the hygrothermal performance and durability of building façades. Out of all the exterior hygrothermal environmental loads which directly influence the moisture transport, WDR causes more than 90% of critical damage to the building performance (Karagiozis et al., 2003). Consequences of its destructive properties can take many forms. It enhances the dry and wet deposition of pollutants, façade surface soiling and façade erosion. The water layer on the façade can increase collection of pollutants. Rainwater is also an agent for most of the physicochemical deterioration processes, frost damage, moisture-induced salt migration, discolouration by efflorescence, and structural cracking due to thermal and moisture gradients (Blocken and Carmeliet, 2004; Moonen et al., 2012). More than that, WDR is one of the most important boundary conditions for HAM (heat-air-moisture) simulations of buildings (Blocken et al., 2007).

4. Methodology

For analysing WDR on buildings usually comprehensive models are used. In this work a simple model is used to estimate changes in WDR on buildings (ASHRAE, 2009). In this model the amount of rain striking a vertical surface is calculated using the following equation:

$$r_{bv} = F_E \cdot F_D \cdot F_L \cdot U \cdot \cos\theta \cdot r_h \quad (1)$$

Where F_E rain exposure factor [-]

F_D rain deposition factor [-]

F_L empirical constant, 0.2 [kg.s/m^3/mm]

U hourly average wind speed at 10 m [m/s]

θ angle between wind direction and normal to the wall [deg]

r_h rainfall intensity, horizontal surface [mm/h]

r_{bv} rain deposition on vertical wall [kg/m^2/h]

In this work the considered wall is facing west. F_E is influenced by the surrounding topography of the building and height of the building which is equal to 1.2 in this work, for a medium exposure and the building height between 10 m and 20 m. It is assumed that the wall is subject to rain runoff and therefore $F_D = 1$.

By programming in Matlab, the amount of rain deposition on the vertical wall was calculated for 6 climate scenarios in Gothenburg for the period of 1961-2100. Only the west-east component of the wind velocity, $\pm U_0$, is considered to simplify the calculations. The west-east component of wind is stronger than the south-north component in Gothenburg. Probable future conditions for WDR and differences induced by the climate scenarios are studied by looking into the distribution of the rain deposition, r_{bv}, during time. For simpler comparison of data sets, the square weighted moving average of the annual mean values is plotted. The dotted line in FIG 1 shows the annual average of precipitation while the black solid line shows the weighted average. The solid line shows the trend of changes with sufficient resolution. Divergence exists in the beginning of the period which occurs due to the lack of data before 1960 in the calculation of lagging average. However since the focus of the paper is more on the future changes, this divergence can be neglected.

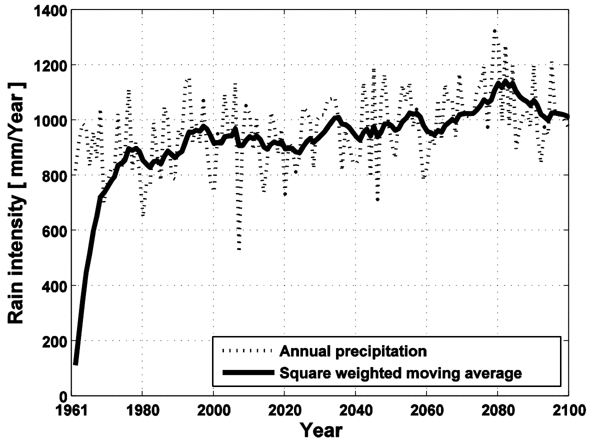

FIG 1. Annual mean precipitation and its square weighted moving average in Gothenburg during 1961-2100. Climate data are from RCA3, downscaling three GCMs with the same emissions scenarios and initial conditions (A1B-3) with the spatial resolution of 50km.

5. Results

As it was mentioned earlier strong signals of climate change are only visible in the rain data and not the wind.

FIG 2 shows the gradual increase in the amount of rain by time, while no considerable changes in the wind velocity are predicted. However climate uncertainties, different GCMs in this case, can affect both the rain and the wind data. Differences are more obvious for rain; although all scenarios point to more precipitation in future there can be differences up to 40% in the annual average of the rain intensity. Differences between scenarios for the WE wind velocity do not follow the same pattern as rain; RCA3-CNRM and RCA3-IPSL show less difference for wind velocity unlike the rain data.

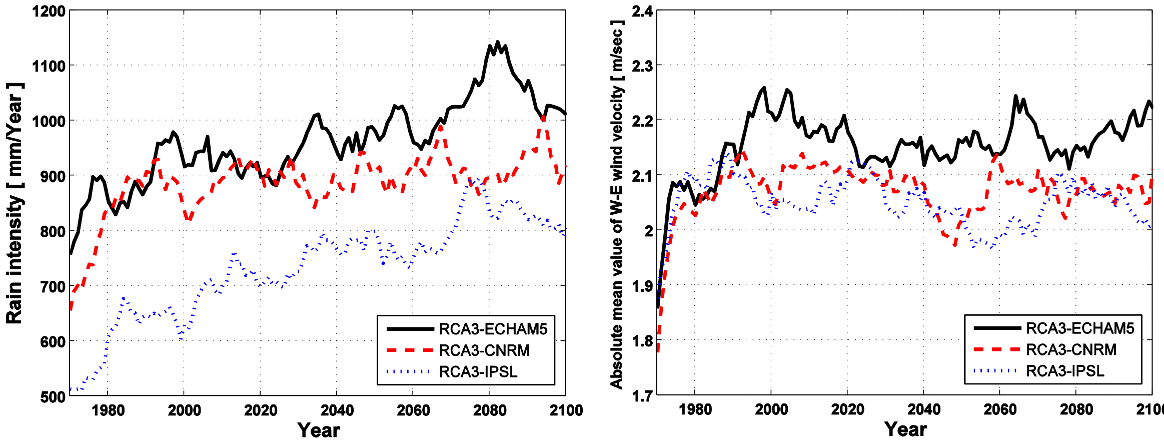

FIG 2. Square weighted moving average graphs for the annual mean value of (left) the rain intensity and (right) the absolute WE wind velocity in Gothenburg. Climate data are from RCA3, downscaling three GCMs with the same emissions scenarios and initial conditions (A1B-3) with the spatial resolution of 50km.

According to relation (1) the amount of rain deposition on vertical wall, r_{bv}, has linear correlation with both the rain intensity and wind velocity. As the distribution of r_{bv} shows in FIG 3, the amount of rain deposition can increase depending on the climate scenario, which RCA3-IPSL shows the maximum increase by time. There is no considerable change in the amount of deposition for RCA3-

CNRM, however sharp changes happen more often after 2050. A previous work showed that the trend of changes for the Stokes numbers in WDR are mostly affected by the wind data, but differences between scenarios are more influenced by the rain data (Nik et al., 2013). One conclusion was that it might be possible to use one wind scenario for WDR calculations and assess the differences induced by climate scenarios only by looking into the rain data. For the calculated r_{bv} in the present paper, differences between scenarios are still more affected by the rain data, however changes of r_{bv} by time can get equally influenced by wind and rain. Although still there are not considerable changes in the wind data by time, but to avoid underestimating the climate uncertainties in WDR calculations, it might better to use different wind scenarios with large differences. The true assessment of the climate uncertainties and the importance of wind/rain data is available when WDR calculations are performed by numerical simulations.

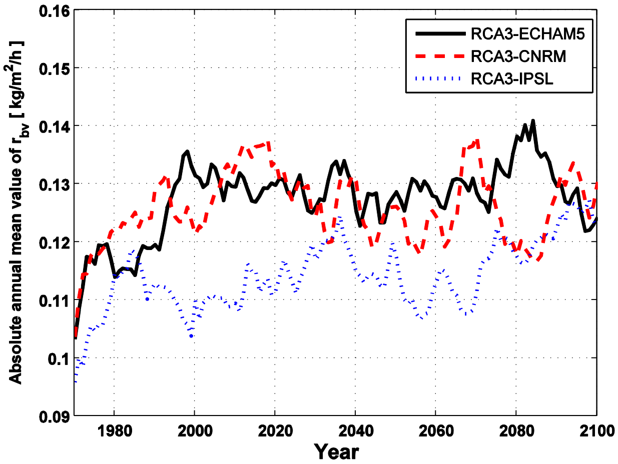

FIG 3. Square weighted moving average graphs for the annual mean value of the rain deposition on vertical wall [kg/m2/h] in Gothenburg. Climate data are from RCA3, downscaling three GCMs with the same emissions scenarios and initial conditions (A1B-3) with the spatial resolution of 50km.

Uncertainties in calculating the rain deposition induced by different initial conditions and spatial resolutions are visualized in figures 4 and 5. Increment of r_{bv} is obvious in FIG 4, specifically for A1B-1 & -2 scenarios. It is interesting to see that using scenarios with different initial conditions can result in considerable differences in calculating WDR. Differences between scenarios are both in the amplitude and the phase of distributions. The patterns of variations are very similar in FIG 5 which compares two scenarios with different spatial resolutions. There is almost no phase shift between the two scenarios since the climate models and the assumptions are unique and the only difference is in RCM downscaling with two different spatial resolutions.

We can get a better image about the influence of climate uncertainties in estimating the amount of rain deposition on a vertical wall by checking FIG 6. It shows the maximum difference due to the climate uncertainties in calculations, for 20-year mean values. For example the GCM graph is the absolute difference between RCA3-CNRM and RCA3-IPSL. Different GCMs can result in differences more than 20%, which cannot be negligible in WDR calculations. For initial conditions the uncertainty decreases to around 15%, which is still high. Difference between the two spatial resolutions of 25km and 50km are less than 7%. These results are in agreement with a previous research which looked into the climate uncertainties in hygrothermal simulation of buildings (Nik, 2012) and calculation of Stokes number (Nik et al., 2013).

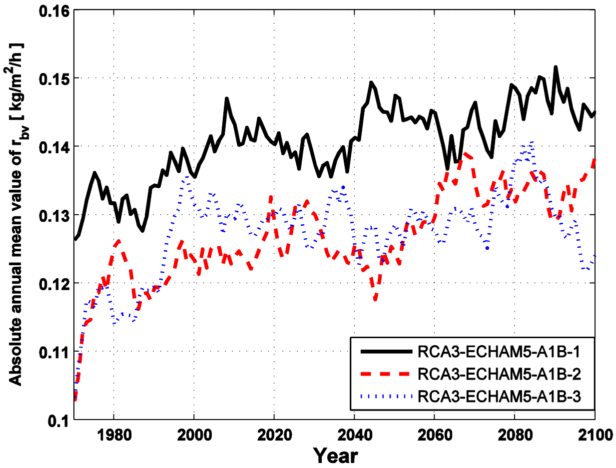

FIG 4. Square weighted moving average graphs for the annual mean value of the rain deposition on vertical wall [kg/m²/h] in Gothenburg. Climate data are from RCA3-ECHAM5-A1B with three different initial conditions and the spatial resolution of 50km.

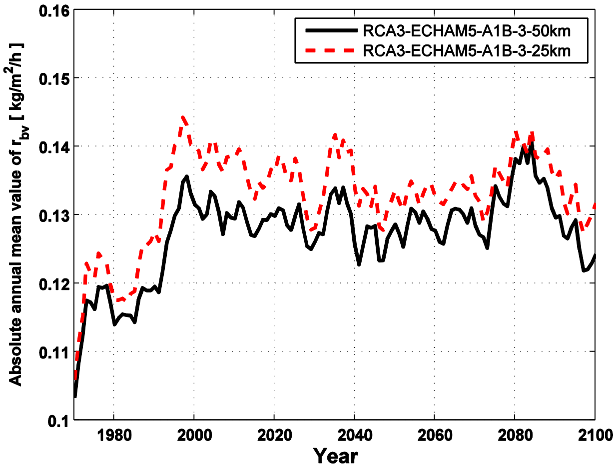

FIG 5. Square weighted moving average graphs for the annual mean value of the rain deposition on vertical wall [kg/m²/h] in Gothenburg. Climate data are from RCA3-ECHAM5-A1B-3 with two spatial resolutions of 25km and 50km.

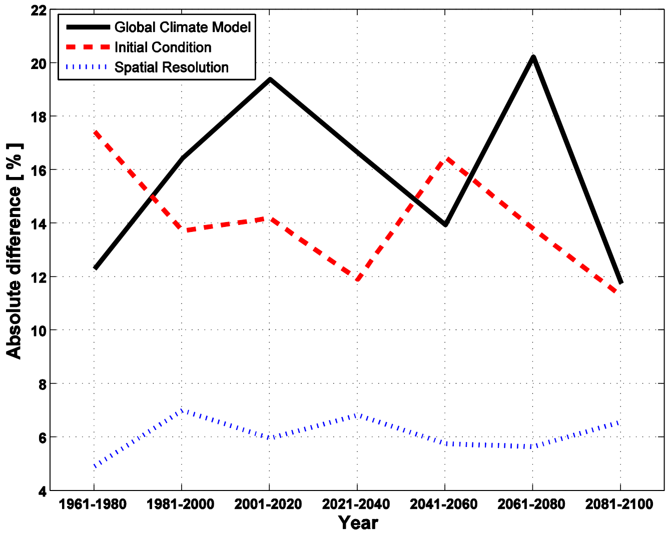

FIG 6. Comparing the importance of the uncertainty factors in WDR calculations; 20-year mean values for the absolute difference of r_{bv} are shown. Graphs represent the scenarios with the maximum difference in figures 3 to 5.

6. Conclusions

The probable effects of climate change on WDR were considered using a simple method to estimate the amount of rain deposition on a vertical wall. The simple method helps to investigate impacts of climate change on WDR and the importance of climate uncertainties before performing the WDR and CFD calculations. Results were in agreement with a previous research which was done by calculating the Stokes number. However this study is still in the preliminary phase and there is a need to perform numerical simulation of WDR.

Based on the results, the most important factor is the selected GCM. Spatial resolution had the least effect on calculations however further research with finer spatial resolutions should be performed. The importance of climate uncertainties in the wind data and its effects on WDR calculation should be investigated more thoroughly in future. It might be possible to use one reference wind data while different rain data sets are used to consider the climate uncertainties. This will help to decrease the calculation time considerably, especially when the CFD models are used to calculate the wind flow around buildings. However in this work the importance of the wind data and its uncertainties was larger than the case of calculating the Stokes number.

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