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On building components' exposure to driving rain in Greece

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ABSTRACT

In this paper, parameters related to building components' exposure to driving rain in Greece are investigated. Annual driving rain indices are calculated for 41 sites in Greece on the basis of average daily climatic data extending over several years, and of the – derived from the daily data – monthly and annual values of wind speed and rainfall. The differences among these three sets of annual driving rain indices are investigated with regard not only to the effect of using data of different time resolution on the estimated exposure levels, but also to the relative contribution of potential error sources to the observed differences among the calculated indices. Furthermore, with the use of the available daily data, the driving rain load burdening vertical building components during wetting periods ("absolute driving rain spells"-i.e. driving rain spells defined on the basis of daily intervals and of daily data for wind speed, regardless of wind direction, and rainfall) is calculated for the studied sites. Afterwards, the images produced for the relative exposure to driving rain at the examined sites by (a) the annual driving rain indices based on daily data and (b) the indices used to assess the rain load during wetting periods, are compared; these images are found to be highly correlated for Greece. The results derived throughout the study are discussed and further conclusions are drawn.

1. Introduction

Moisture accumulation and periodic variations inside building components are related to several aspects of buildings' operation and performance. Indeed, the presence of moisture inside building components is related to the occurrence and acceleration of several building materials' deterioration processes and types (Fagerlund, 1996); the resulting damages are related to not only aspects of the building components' functionality (e.g. decrease of the thermal insulation capacity (Jerman and Černý, 2012), fungal growth on building materials' surfaces (Sedlbauer, 2001)), but also to the service life of constructions (e.g. moisture in reinforced concrete elements is related to the initiation and development of the reinforcement bars corrosion (Steffens, 2000)). Furthermore, moisture in building components is related to the indoor air quality, which is critical for the living conditions in the buildings; moisture-induced damages in building components have been correlated, in several studies, to respiratory and skin symptoms among the buildings' occupants (Bornehag et al., 2001, 2004, 2005; Meklin et al., 2002). Furthermore, via the deterioration processes that are induced or facilitated by its presence inside and on the surface of building components, and the resulting maintenance, repair and replacement needs, moisture has a strong impact on both economic and environmental costs during the life cycle of buildings. The multidimensional and extended impact of moisture in building elements on the overall performance of buildings leads to the need of at least the estimation of building components exposure levels to moisture loads resulting from various sources. In fact, the calculation or the estimation of the actual moisture load that burdens building components, especially when areas of the building envelope that are expected to be subjected to severe stress are under consideration, is preferable. The main cause of water penetration into vertical building components above ground is driving rain; therefore, in this context, the study of the building elements exposure to driving rain is of great importance for the estimation of the expected moisture loads and the subsequent adoption of adequate measures.

In fact, driving rain on building facades has been the focus of several studies in the last decades. The "moisture load" resulting from driving rain depends actually on not only the rainfall intensity and the wind speed, as the latter two parameters are recorded in meteorological stations, but also on the raindrops trajectories around the buildings under study. As a result, the complexity of the phenomenon increases greatly: among others, factors related to the region's climate and to the geometrical characteristics of the building surface under study, as well as to the formation of the urban surroundings, influence driving rain on building envelopes. Several methods have been developed and employed for the estimation of parameters related to driving rain on building facades. These methods (experimental, numerical and semi-empirical (Blocken and Carmeliet, 2004)) are characterized by various approaches, structures and levels of complexity, produce results of different levels of accuracy, reliability and

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generality (depending also on the context of the study and on the time resolution of the available climatic data) and are, in some cases, aiming at the derivation of varying types of results (qualitative or quantitative study of the phenomenon, exposure to driving rain or rain load on a façade, results concerning specific buildings or efforts to derive widely applicable mathematic formulations and conclusions, etc.).

Several studies of vertical building components exposure to driving rain have been based on driving rain index (DRI), i.e. the product of horizontal rainfall and wind speed during the rainfall; the index produced when these two climatic parameters are calculated over the year is the annual driving rain index (aDRI). The aDRI at a site can be calculated on the basis of climatic data of various time resolutions (average annual, average monthly, average hourly, etc.). The annual driving rain index that is calculated on the basis of average annual wind speed and average amount of total annual rainfall is proportional to the amount of water on a windward vertical surface (Lacy and Shellard, 1962) and provides an estimation of the respective site's exposure to free driving rain (rain through the vertical plane in an unobstructed flow field). This fact provides the possibility for this, simple in its calculation and based on readily available data, index to be used for the comparison of the exposure to driving rain among various sites to be made; in fact, the aDRI calculated on the basis of average annual data is the basis of the classification proposed by Lacy (sheltered areas, moderately exposed areas, severely exposed areas); based on this classification, driving rain maps for several countries have been produced, e.g. Sweden, United Kingdom, Canada (Boyd, 1963), China (Sauer, 1987), India (Chand and Bhargava, 2002), Nigeria (Akingbade, 2004), Turkey (Sahal, 2006), Greece (Giarma and Aravantinos, 2011) and Spain (Pérez et al., 2012). Also, the aDRI based on average annual values of climatic data can be used to represent the wetting potential in the context of a moisture index comprising both wetting and drying parameters (Cornick and Dalgliesh, 2003); in a recent study (Giarma and Aravantinos, 2011), this moisture index has been calculated for several sites in Greece.

As previously mentioned, the aDRI can be calculated on the basis of data of different time resolution. This difference in the climatic data's time resolution may result in large discrepancies for the calculated indices: for example, the annual driving rain indices based on average annual data could be very different from the annual driving rain indices that are calculated on the basis of hourly data (Cornick and Dalgliesh, 2003). Furthermore, recent studies revealed that even the use of monthly data, instead of annual, might lead to divergences in the acquired values for the driving rain indices, depending of course on the characteristics of the climate at the site under consideration (Giarma and Aravantinos, 2011; Pérez et al., 2012). These differentiations are due to the fact that climatic data of lower time resolution provide a poorer consideration of the co-occurrence of wind and rain and, when the estimation of parameters related to driving rain exposure and loading are under study (with rainfalls being phenomena of sub-hourly, hourly or of the order of a few hours duration), the use of higher time resolution data is considered to provide more reliable results; specifically, in most cases hourly data are considered of adequate time resolution, since they usually permit the successful, to a satisfactory degree, consideration of the actual conditions during rainfalls. Nevertheless, in recent works (Blocken and Carmeliet, 2007; Blocken et al., 2007; Blocken and Carmeliet, 2008), the conclusion that in certain cases even higher time resolution data should be used is drawn. Moreover, hourly records including also wind direction can be used to derive directional driving rain indices, which provide a more realistic picture with regard to the actual exposure of a surface of given orientation at a site (Choi, 1994b, 1999). Given that in many cases hourly data extending over adequate periods of time are not available for big number of sites, some methods for the derivation of directional driving indices on the basis of synoptic data have been formulated (Rydock et al., 2005; Rydock, 2007; Pérez et al., 2013a).

While the driving rain indices depict, at a level of accuracy that depends on the time resolution of the available data and on the scalar or dimensional approach adopted, the exposure of vertical surfaces to driving rain at a site, they cannot be used for the direct estimation of the driving rain loading on the building components at this site. The quantification of this load, in terms of amount and intensity, is a complex task, due to the big number of parameters involved in the related phenomena (formation of the wind pressure field around each building, etc.). For example, the urban geometry in the neighborhood of the building under study has an impact on the rainwater impinging on a building's vertical surfaces (Blocken et al., 2009); also, the building's geometry and the position of the area under study on the building's vertical surface (height, middle part of the surface or near the edges) influence the resulting load (Karagiozis et al., 1997; Choi, 1994a, 1999; Künzel, 1994; van Mook, 2002; Blocken and Carmeliet, 2005; Nore et al., 2007). The calculation of quantitative parameters related to driving rain (e.g. intensity) for specific sites can be found in several studies (e.g. Zhu et al., 1995; Fazio et al., 1995; Rydock, 2006).

In several studies, reviews of the methods used for the quantification of driving rain load are presented (Cornick et al., 2002; Blocken and Carmeliet, 2010; Blocken et al., 2010). One category of these methods is the semi-empirical ones. In a study by Blocken and Carmeliet (Blocken and Carmeliet, 2010), semi-empirical methods for the calculation of the driving rain load are systematically presented and analyzed. These methods are, in their application, interwoven with the use of hourly climatic data. On the basis of one of them (the semi-empirical model in the ISO standard), and introducing a new concept ("absolute driving rain spell"), Pérez et al. (2012) calculated the driving rain load during wetting periods in Spain with the use of daily climatic data (Pérez et al., 2012).

The present paper is focused on the investigation of driving rain-related parameters in Greece, with the emphasis being placed on both qualitative and quantitative characteristics of the resulting moisture loading on building components. In a recent study (Giarma and Aravantinos, 2011), the exposure of building components to driving rain in Greece was estimated on the basis of annual driving rain indices. Specifically, annual driving rain indices were calculated for 31 sites located all over the country, on the basis of average annual and average monthly climatic data. Based on these calculations, a driving rain map for Greece was, among others, produced. Furthermore, the calculated annual driving rain indices were used in the context of a moisture index, which comprises also the consideration of the drying potential; this index was used for the ranking of the examined sites in terms of moisture loading on buildings.

The study presented in this paper aims at further investigating driving rain loading and related parameters in Greece. Specifically, under the light of recent developments in the field of driving rain exposure estimation and calculation, the work presented in this paper is organized around three axes:

(i) On the basis of average daily rainfall and wind speed for every day of a time period extending to several years, provided by the Hellenic National Meteorological Service (Electronic site H.N.M.S.), the annual driving rain indices are calculated for 41 sites in Greece. Then, the average monthly and average annual values of rainfall and wind speed are derived from the available daily data and they are used for the calculation of the annual driving rain indices for the sites under study. These three groups of indices form the basis for the investigation of the impact of using annual, monthly and daily data on the estimated exposure to driving rain in Greece. Specifically, the differences among the three sets of indices are studied; with the performance of an additional series of calculations, the relative contribution of the co-occurrence error (error related to the failure of considering the actual conditions during rainfall events, with the information about the co-occurrence of the two phenomena being lost due to arithmetic data averaging (Blocken and Carmeliet, 2008) and error due