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Climate-based and material response-based approaches for the impact assessment of climate change on the frost damage of historic brick walls in Tønsberg, Norway.

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The climate of the city of Tønsberg in Norway is cold and humid. As a result, the brick-made historic buildings in this city are threatened by frost damage. Climate change is expected to affect the action of this degradation mechanism. In the current research, climate data resulting from the REMO2015 driven by the global model MPI-ESM-LR were used for periods 1960-69, 2010-2019, and 2060-69 representing the past, present, and future climate conditions. In addition, data from the ERA5 reanalysis for the present conditions, 2010-19, were used to assess the accuracy of the climate model data. Given the climate excitations, the freeze-thaw events were calculated according to two climate indices, i) the events of temperature decrease below 0^{o}C and ii) by considering that freezing occurs below -3^{o}C and thawing occurs above 1^{o}C. Moreover, a material response-based index that takes into account the temperature and the moisture content of a 5mm layer in the exterior side of the wall assembly was calculated. Prior to its calculation proper hygrothermal simulations were performed. According to this index, the critical temperature and degree of saturation that characterize a freeze-thaw event are 0^{o}C and 25%, respectively. From the climate model data and the first climate index, the 0^{o}C crossings that were calculated are 400, 340, and 223 under the past, present, and future conditions, respectively. The respective number of the freeze-thaw events that were calculated by using the second climate index are 49, 31, and 27 which are significantly lower. From the data obtained from the ERA5 reanalysis, the number of freeze-thaw events that were calculated is 425 and 123 for the first and the second climate index, respectively. This difference is attributed to the underestimation of the air temperature in the climate model data, which results in a lower number of temperatures hovering around the examined thresholds during winter. The results of the material response-based index show a minor frost risk for the brick-made wall assemblies which is reduced through the years. The southeast-oriented walls were the ones with the highest exposure to driving rain and the greatest frost damage risk. For this orientation, the number of freeze-thaw events was 6, 3, and 2 under past, present, and future conditions, respectively. Moreover, according to the ERA5 reanalysis, only 1 freeze-thaw event was calculated. This is attributed to the fact that the climate model overestimates significantly the precipitation and the relative humidity compared to the ERA5 reanalysis. In conclusion, it is worth mentioning that both the climate-based and the material response-based indices define a decreasing trend of the frost damage risk of historic brick-made

walls due to climate change. The use of the material response-based index is suggested for a more accurate assessment of the frost damage which can further support proper adaptation measures. Finally, the quality of the results can be improved by using climate data from more climate models and applying bias correction or morphing methodologies on the climate files to avoid systematic errors.