Climate, environment and frost damage of architectural heritage

S. Kyllingstad, T.K. Thiis, A. Flø & J. Potac
Norwegian University of Life Sciences, Department of Mathematical Sciences and Technology, Ås, Norway

M. Sykora
Czech Technical University, Klokner Institute, Prague, Czech Republic

1 INTRODUCTION

An important part of the conservation of architectural heritage is the monitoring of material degradation and evaluation of its influences on structural durability, reliability and aesthetics. Local climatic exposure can produce a large variation in deterioration of a building façade. In this paper, Computational Fluid Dynamics (CFD) simulations of wind-driven rain (WDR) on a building is combined with picture analysis of building facades to derive deterministic damage models for freeze-thaw degradation.

2 METHOD

Two-phase CFD-simulations based on the Euler-Euler approach were used to simulate wind-driven rain on a set of apartment buildings in Oslo, Norway. In order to validate the model, simulations where conducted on a test facility where a dataset of WDR measurements exists, along with known geometrical and meteorological data. This is data collected by Blocken and Carmeliet (2007). Droplet size distribution and concentrations were implemented based on rain intensity with equations derived by Best (1950).

Simulations with the validated model were then performed on the apartment buildings with local meteorological data as input parameters. The resulting data were then extracted as contour maps showing the wetting patterns on the facades. A combined map was made displaying the total amount of WDR on a given façade for a whole year.

Frost damage on the facades was documented with picture analysis. Damages were counted and quantified and then combined with the results from CFD-simulations. A regression analysis was performed on this dataset to produce a damage model.

3 RESULTS

Figure 1 shows the results from running the two-phase model on the test facility. The contour map shows the simulation results while the ballpoints show measured values. The correlation between the simulation results and the measured data is satisfactory.

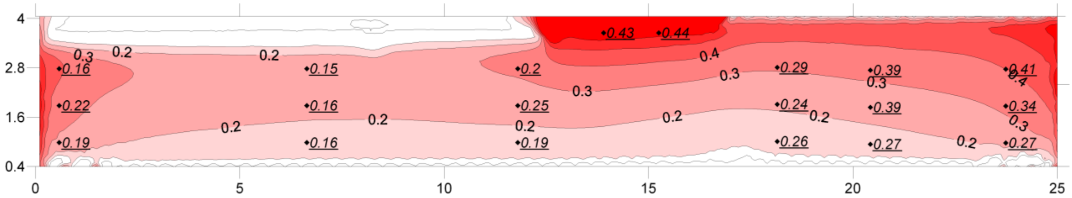

Figure 1. Results from two-phase simulations on the test facility. The contour map show simulation results while the underlined values show the measured results.

Figure 2 a) shows the WDR impingement on the north façade of the middle building from numerical simulations. The highest values of WDR intensity are located on the upper corners of the roof, while the lowest intensities are located in two distinct areas in the center.

A damage function was suggested by combining the results from WDR-simulations with results from picture analysis. Annual average WDR on the façade were plot against annual number of damages per square meter, and a regression analysis were performed.

$$FD_a = 15{,}836e^{(-323{,}85/WDR\ per\ year)}$$

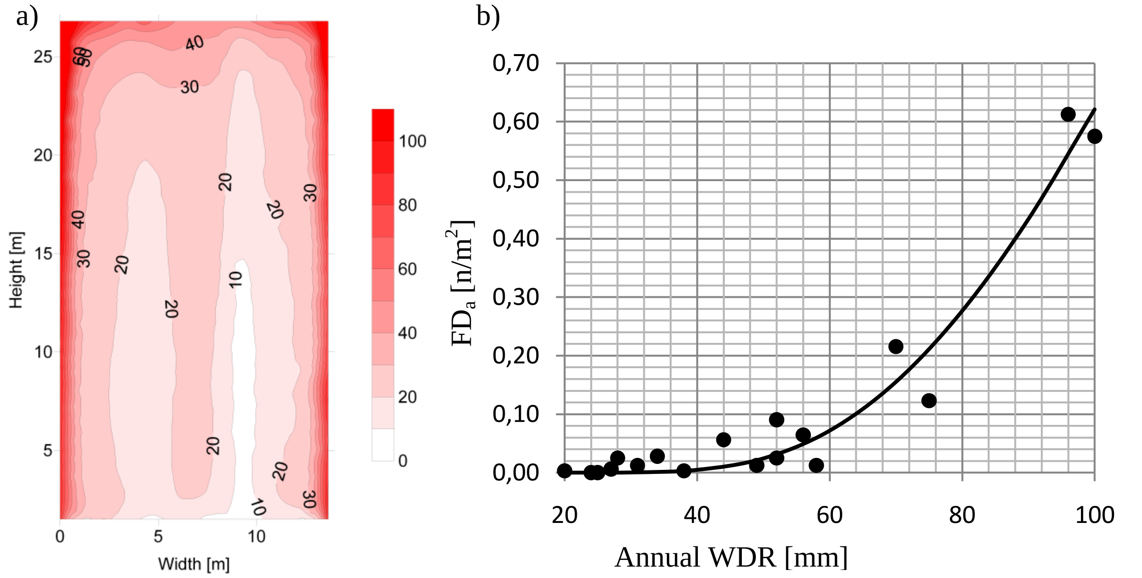

Figure 2. Figure a) shows the total average annual amount of WDR impinging on the north facade. Figure b) shows the annual amount of WDR plotted against the annual amount of frost damage on the wall.

4 DISCUSSION/CONCLUSION

The validation process proved the two-phase Euler-Euler simulation to give satisfactory results when calculating WDR intensity on a façade. Both the shape and values of the WDR impingement distribution from the Euler-Euler simulation results correlate closely to what was measured on the test facility. The correlation between the Euler-Euler simulations and the Langrangian simulations by Blocken and Carmeliet is also strong. Further development of two-phase simulations might include an analysis of the raindrop size distribution criteria. More specifically the number of different raindrop sizes needed for accurate results. A large range of sizes will most likely produce better results, but it also requires increased computer resources and more computation time.

The accuracy of the apartment building simulation results are mainly determined by the accuracy of the meteorological input data. Simulations were simplified by including only the average wind speed and wind directions and not a range of these values.

Regression analysis of the simulation results against the damages on the building shows a good correlation between wind-driven rain and frost damage. However, the formula produced is specific for one kind of brick in a specific climatic environment. The heat transfer trough the building envelope and the evaporation of water is not accounted for. However, the procedure used to obtain such damage functions can easily be applied to other facades with different properties.

References

Best A.C., 1950. The size distribution of raindrops. Quarterly Journal of Royal Meteorological Society 76 1950, 16-36.

Blocken B., Carmeliet J., 2007(b). Validation of CFD simulations of wind-driven rain on a low-rise building façade. Building and Environment 42(2007): 2530-2549