Rain Impact on a Curved Surface High-rise Building

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ABSTRACT: A Particle Tracking Method is used in conjunction with steady state simulations to determine the trajectories and the impact of rain drops on the curved façade of a high-rise building.

The simulation is performed for the upper part of the building comprising a detailed louver system. Rain is trapped at relative high rates on the roof and the penthouse, with Local Intensity Factors (LIF’s) of the order of 1. The upper parapets and upper floors get a fair amount of wetting with LIF’s of the order of 0.6. The wetting decreases downwards reaching values of 0.2 to 0.25 at the level of the louver system.

KEYWORDS: wind-driven rain, Computational Fluid Dynamics, high-rise buildings

1 INTRODUCTION

Wind-driven Rain simulations are performed based on the worst wind-driven rain scenario identified based on the meteorological data available from the local airport. Based on the analysis of these data we identified the critical wind condition occurring for a wind of 10 mph (4.47 m/s) (measured at 10 m height) coming from 223 degrees from North. This wind direction corresponds to one of the horizontal plane symmetry axis of the building. For this wind direction the statistical maximum rain-fall was of approx. 4 mm/hr. The worst wind direction in terms of wind intensity corresponds to approx. 330 deg from true North which is a symmetric situation as well. Therefore our wind-driven rain simulation indirectly addresses both maximum wind and maximum rain cases.

2 METHODOLOGY

2.1 Numerical set-up

The number of cells used for this simulation was 504426. Segregated solution scheme was employed to solve the momentum equations and the pressure equation. For turbulence model, RNG k-epsilon model considering standard wall functions for near-wall treatment was used. The pressure-velocity coupling used SIMPLEC and for the discretizations of momentum, turbulence kinetic energy and turbulence dissipation rate, a first order upwind scheme was employed.

2.2 Particle Tracking Model

After simulating the wind flow field around the building a Particle Tracking Method was employed to determine the trajectories and the impact of rain drops on the main face of the building. Rain drops of various diameters were injected in the flow with an average diameter of approx. 1.8 mm and captured on various pre-defined zones on the building façade, see Figure 1a.
For more details on the procedure and comparisons with restricted laboratory experimental results refer to [1].
The upper part of the tower only was simulated and the louver system was detailed for 3 floors of the building: floors 5, 6 and 7 from the top of the building, as represented in Figure 1.

![Figure 1a) Raindrop trajectories](image1.png)

![Figure 1b) Trapping zones](image2.png)

For the detailed louver system, the inner wall, and the slab area between the louvers and the inner wall and outside the louvers have been modeled in detail. The rest of the building façade was simply modeled as porous wall regions. The detailed region provides information on the rain penetration inside the curtain wall while the rest of the porous wall zones provide general wind-driven rain information on the rest of the upper part of the tower.

A description of the trapping zones used is given in Figure 1b. The mass flow rate impacting every zone is then divided to the initial rainfall of approx. 4mm/hr and the Local Intensity Factors (LIF) on any of the trapping zones are obtained.

3 RESULTS
The estimated penetration of rain inside the curtain wall is minimal. The current simulation results show that there is practically no rain trapped on the inner wall surface. This result is in formal agreement with flow visualizations produced in the wind tunnel. The wind flow, and therefore the raindrops transported by the flow comes to a halt at the stagnation point on the front part of the building. From here the mean flow field and raindrops deviate laterally around the building face or up above the parapets following paths towards the wake of the building. While heavier particles tend to penetrate on the cantilever slab zone in front of the louvers and in between louvers and the inner wall, the lighter ones follow the path around the building described before, see Figure1a. Therefore wetting will occur on the slab zone (mostly outside of the louvers) but not at any extent on the inner wall.

3.1 Louver system

For the louvers system the maximum rain impact is noticed on the cantilevered slab in front of the louver system (LIF = 0.96), see Figure 2a for raindrop trajectories and Figure 2b for LIF’s. Light wetting occurs on the slab between the lovers and the inner wall (LIF_{max} = 0.157).
The numerical wind-driven rain results are consistent with the wind tunnel pressure measurements. For the same wind direction the differential pressure distribution show only minimal positive values corresponding to taps 65 to 75. Positive differential pressure values usually correspond to flow being entrained in this space. However, as mentioned before the positive values are minimal, see Figure 3a, and therefore the wetting in this space is light, as predicted by the numerical simulation.

Another case that might present some interest (for the louvers system) is the symmetric case for which the wind approaching the tower faces one of the 3 gaps and therefore would impinge directly in the space between some of the louvers. Wind tunnel measured differential pressures for this case are plotted in Figure 3b. Some areas of positive values are noticed for taps 1 to 16 and 70 to 85 in the immediate vicinity of the front gap. The existence of these positive values implies that some secondary flow will tend to penetrate into the gap between louvers. However, the louver arrangement for this case and in these two areas would prevent the rain penetration. It is estimated that only light particle would penetrate in the inner space and therefore the wetting in this region would still be light. While an additional simulation would produce quantitative estimates of LIF’s for this case we can only infer that the differences would not be important.

Fig. 3: Wind tunnel measured differential pressures corresponding to a) 343 deg. from true North; b) 283 deg.

A factor that should be taken into consideration is that the numerical simulation only provides estimates of rain impacting various surfaces but does not take into consideration the run-off. If we conservatively assume that all the water impacting (for example the louvers) would run-off
onto the slab, the effect would be a cummulation of LIFs from louvers and slab that would give: 0.209 (upper level louvers, Figure 4a) + 0.157 (the upper level exterior slab, Figure 2b) = 0.36.

Figure 4. LIF's a) Upper part envelope b) Roof

3.2 Top of the building

Rain is trapped at relative high rates on the roof and the penthouse, Figure 4. When looking at the building from the wind face, Figure 4a, it is clear that most of the rain is trapped towards the top of the building: parapet, and upper floors and decreasing downwards.

In regards to the top of the building it is generally expected that the roof area gets a LIF of the order of one (direct rain) while some high LIF values may occur on the top part of the building. The CFD simulation indicates these panels have LIFs of up to 0.566 for the wind direction examined. While this is not unusual for a tall building, [2], it would be important in this project to drain this rain impact water before it migrates down the building and potentially into the louvered system below. For example conservatively using the LIF of 0.6, with a rainfall of 10 mm/hr, the impact rain for each windward floor level available to migrate downwards could amount to approximately 20 kg/min.

Theoretically for rain storms below 20 mm/hr rain-fall the LIFs should not vary dramatically from the ones estimated herein. However, the flow rate wetting of any of the zones will increase proportional to the rain fall rate.

REFERENCES