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COMBINING GAUSSIAN AND CFD MODELLING TO ASSESS THE IMPACT OF ROADSIDE SCREENS IN A CASE STUDY IN GHENT, FLANDERS.

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Abstract: In this contribution we will report on a concrete case of an air quality impact assessment in the context of a large shopping mall in the city of Ghent, Belgium. To alleviate the impact of an expected increase of traffic due to the presence of the shopping mall, large road-side screens with/without chicane were proposed as a mitigating measure to shield a residential zone with apartment blocks close to the road. Given the complex geometry, the standard air quality impact assessment procedure in Flanders (using IFDM-Traffic, based on a Gaussian dispersion model, https://ifdmtraffic.marvin.vito.be, was found to be inadequate. Hence, an OpenFOAM-based CFD approach was used to model the impact of the screens and their effect combined with the “background estimate” provided by the IFDM-Traffic application. The aerodynamic effect of the most important vegetation elements was taken into account. Furthermore, given the requirement of impact assessment on annual averaged concentrations, we have performed simulations for 12 wind directions and average wind speed for each wind direction and apply an averaging taking into account the relative frequency of occurrence of each meteo class. This way we are able to assess the impact on an annual averaged basis. Locally, the 6 m screens yield a reduction of the road traffic contribution at ground level of maximally ~50 % at the building facades.

Key words: *Computational fluid dynamics, environmental impact assessment*

INTRODUCTION

Flanders, Belgium, is one of the most densely built-up and populated areas in Europe resulting in a number of major hotspots for traffic and air quality. In these hot-spots, urban developers are increasingly confronted with complex situations requiring very high resolution scenario assessments. These scenario assessments require the evaluation of a number of very specific measures to optimise the urban development plans and minimize the impact on population exposure to traffic-related air pollution. Obviously, such measures preferably target the emission sources, mainly traffic, but sometimes more out-of-the box measures are considered such as screens, vegetation and entrenching or covering roads. In this contribution, we discuss the impact of sound screens for mitigating the air quality impact of increased traffic due to the construction of a nearby shopping centre.

METHODOLOGY

Most environmental impact assessments in Flanders are performed using the IFDM traffic web application developed by VITO https://ifdmtraffic.marvin.vito.be. This online traffic scenario assessment tool allows to calculate the impact of traffic scenario’s on the air quality. The tool is based on the IFDM Gaussian dispersion model (Lefebvre et al., 2013) and uses a fairly coarse receptor grid. Hence, it does not allow to compute the effect of road side screens or other more specific measures on the air quality. In order to assess the impact of the screens we complement the output of an IFDM traffic calculation with computational fluid dynamics simulations specifically for the effect of the road side screens. In the CFD calculations we only take the relevant road segment into account in along which the screens are posted. Figure 1 below illustrates the different variations which were studied : a reference case without screens, a case with 2 screens having a small opening in between (in the form of a chicane) and a continuous screen.

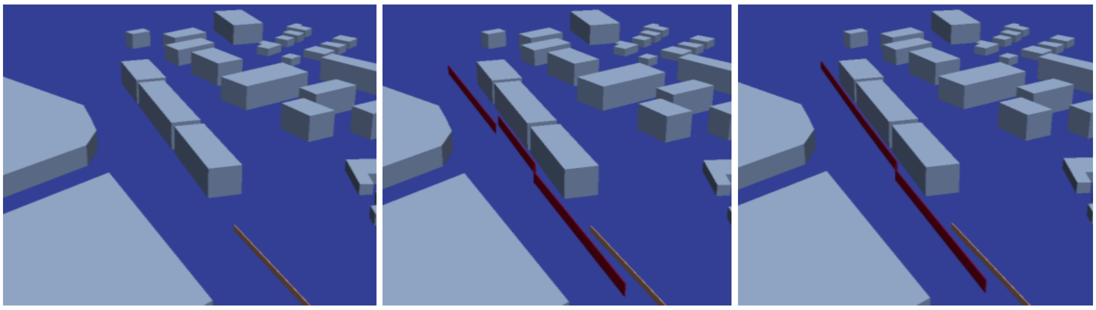

Figure 1. Illustration of the central part of the domain with the three 16 m tall apartment blocks. Left is the reference situation, in the middle the configuration of the screens (red) with chicane, right the one shows the continuous screen. Vegetation is not shown here. The new screens are 6 m height.

The CFD calculations were performed using a steady stade RANS OpenFOAM solver based on simpleFoam, but extended to include scalar transport and the effects of vegetation on the momentum and turbulence equations (Vranckx et al., 2015). The hexahedral computational mesh was generated in Gmsh (http://gmsh.info/) by extruding a quad-based surface mesh in the vertical. A visual rendering of the quad surface mesh is given in Figure 2 below. Inflow, outflow and side edges in the domain are respectively 8, 20 and 5 times the maximum building height away from the explictly resolved domain, resulting in a domain height of 500 m (mainly due to the presence of a large tower to the south-east of the region of interest as indicated in Figure 2). In the 3D domain, the most important vegetation elements are included as well, however we only considered their impact on momentum and turbulence as it is known that the effect of deposition of pollutants in vegetation is less important w.r.t. their aerodynamic effect on pollutant dispersion (Janhäll, 2015; Vos et al., 2012). Vegetation was modelled with an aerodynamic drag coefficient C_d of 0.2 (Endalew et al., 2009; Katul et al., 2004) and a leaf area density (LAD) of 0.1 m^2/m^3 without employing a vertical structure. The CFD simulaties were only considered for a passive tracer. At the inflow boundary, the standard atmospheric profiles proposed by (Richards and Hoxey, 1993) were used. Turbulence was modelled using the realizable k-epsilon model by (Shih et al., 1994). A constant turbulent Schmidt number of 0.3 was used in the dispersion equation as it is known that lower values w.r.t. the default of 0.7 yield better concentration estimates in the built environment (Tominaga and Stathopoulos, 2007).

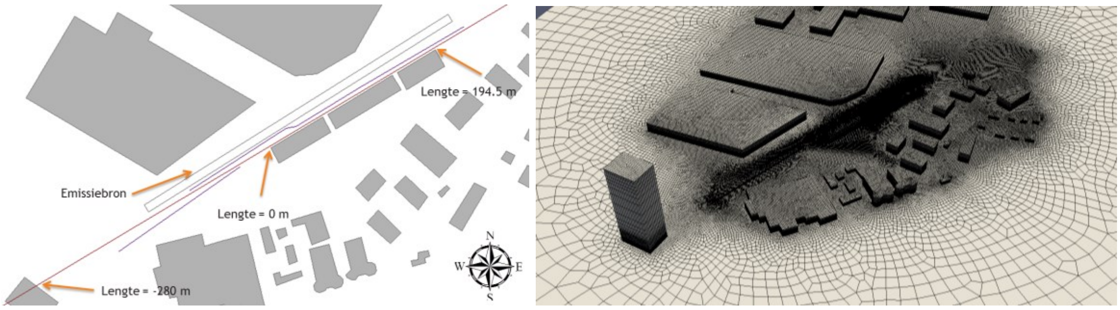

Figure 2. Left: schematic view of the emission source, the building blocks and the screens. Right : Illustration of surface mesh generated by Gmsh which is subsequently extruded in the vertical to generate the 3D hexahedral computational mesh.

To allow for the assessment of the effect on the annual average concentrations, 12 wind directions were used for which steady state simulations were performed using the average windspeed at 30 m and representative upstream roughness lengths for each sector. The winddata was obtained from the 30 m meteo mast at Luchtbal in Antwerp operated by the Flemish Environmental Agency (VMM). The scenario results for the 12 different wind sectors were averaged using their relative frequency of occurrence to yield the effects of the screens on an annual averaged basis.

CFD RESULTS & DISCUSSION

Figure 3 below shows the fraction change in the concentration due to the road segment in front of the building blocks, both in a horizontal plane at 2 m above the ground and in a vertical plane between the screens and the buildings.

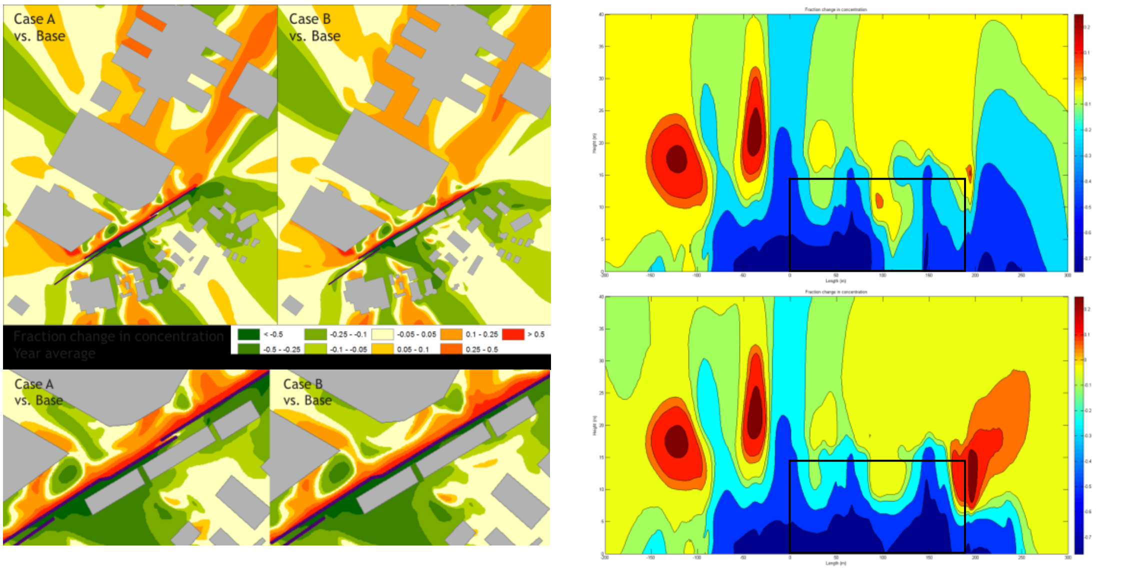

Figure 3. Fraction of change in the road contribution concentration. Left : at 2m above ground, in a vertical plane at curb level in front of the apartment blocks for case a (top) and case b (bottom) w.r.t. the reference scenario (annual average). The location of the apartment block façade is indicated by the black rectangle.

We can see that case B, having a continuous screen, shows reduction of the road contribution concentrations of ~50 % up to about 8 m height in front of the building blocks and still an improvement of ~5 – 10 % at the height of the buildings. The opening in between the screens in case A causes some leakage and yields a more limited reduction of the road contribution in the gap-area, however no increase w.r.t. the situation without screens is observed in the gap.

A number of things should be noted :

- We can observe from the left upper panel in Figure 3 a star –like pattern indicating that the number of wind sectors (12) is likely not sufficient at larger distances from the road. Hence we can only trust the results in the core of the domain, were we want to evaluate the impact.
- Compared to typical patterns in case of screens alongside an open road, where an increase of the concentration levels aloft is seen due to the lifting of the plume, this doesn't seem to show up in the right panel of Figure 3. We should however take into account that these results are averaged using meteo statistics with a dominant SW wind direction parallel to the road. Furthermore, the building blocks themselves are already present in the reference case and hence the effect of the additional screens should be compared w.r.t. this case.

We can therefore conclude that the immediate surroundings of the location of the road-side screens can have a significant impact on their effectiveness and one should not use results for effects of e.g. sound barriers on air quality in open road conditions inside the urban environment, where the mean flow and turbulence conditions are drastically different.

COMBINATION WITH IFDM-TRAFFIC

These results were subsequently combined with the output of an IFDM traffic assessment in which we omitted the single linesource corresponding to the emission source we used in the CFD modelling. In the CFD modelling we only assess the dispersion pattern of this particular source. We therefore assume that the road side screen will only have a significant impact on the concentrations due to the emissions source of the road directly next to the building blocks.

The CFD simulations were performed however for a passive tracer using a unit emission of 1 kg/h for the whole source element in the mesh. The resulting concentration pattern was therefore scaled with the true emissions assigned to that road segment, as calculated by a traffic flow assessment taking into account the traffic intensities and fleet composition which the urban development plans would yield. This was done for both the reference case (without the urban development, irrespective of the use of screens) and in case of the urban development (which would draw additional traffic to the road segment). As the main pollutant of interest for the study was NO_2, the NO_x/O_3 chemistry needs to be taken into account as well. Given the traffic composition at the particular line source, the NO_2/NO_x ratio in the emissions was 0.324, however due to transport this composition will change. Given the fact that NO_2 chemistry was not taken into account in the CFD calculations, an estimate had to be made of the NO_2/NO_x ratio to apply to the passive scalar CFD results (which were already scaled up with thhe NO_x total emissions). This correction factor was estimated based on guidelines in the Flemish guideline book for environmental impact assessments (2012) and proportionality under the worst case assumption that an original NO_2/NO_x split of 100 % would also yield a final split of 100%. Obviously it is important to note that this way of including the NO_x chemisty is very coarse and does not take into account effects for example of longer transport times in the presence of additional screens which could results in additional formation of NO_2 w.r.t. the situation without screens.

In Figure 4 below we present the resulting concentration changes for the planned situation (GT) w.r.t. the current situation (BT) for the reference case and the 2 cases with the screens (A & B, see above).

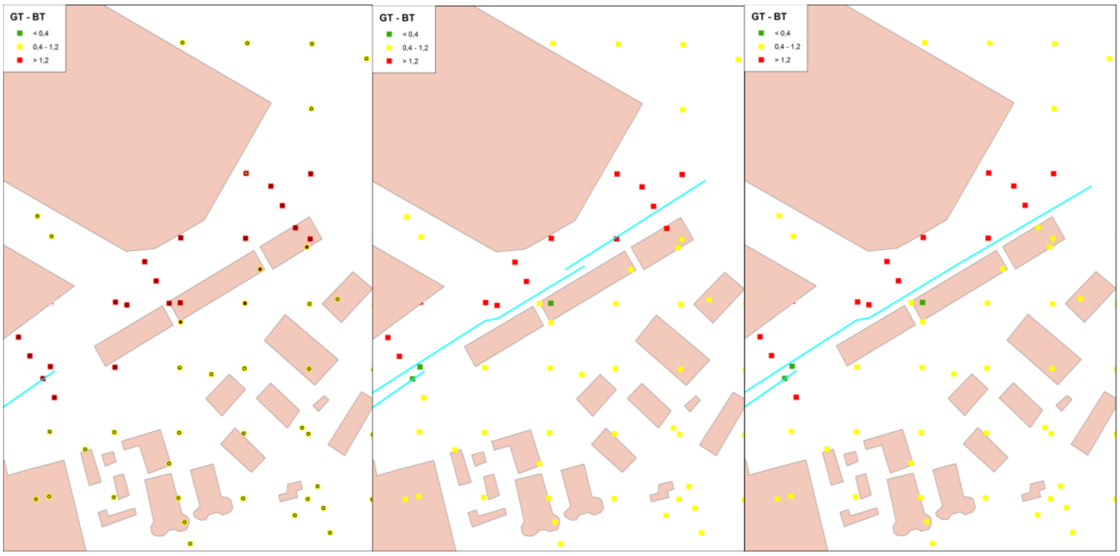

Figure 4. Absolute NO_2 concentration differences [µg/m^3] between the planned (GT) and current situation (BT) regarding traffic intensities. From left to right we see the 3 cases for which the CFD scenarios were elaborated (see Figure 1, i.e. without screens, with an interrupted screen and with a continuous screen of 6 m alongside the road segment). The colour codes (green – yellow – red) correspond to the significance frame in the Flemish environmental legislation of 1 – 3 – 10 % of the NO_2 norm of 40 µg/m^3 at which the impact of the development should be evaluated. In the lowest category (green), the investigation of mitigating measures is less urgent, whereas in the highest category, mitigating measures are considered an essential part of the environmental impact assessment. The circles show the result of the pure IFDM-Traffic calculation, the squares show the results of the combined IFDM-Traffic / CFD calculation.

It was found that in the presence of the screens, for most assessment points where people live, the significance category (see caption Figure 4) decreased from the highest category to the middle category, making the investigation of mitigating measures in addition to the construction of road side screens less urgent.

CONCLUSION

We have presented a combined application of the official Flemish air quality environmental impact assessment tool (IFDM-Traffic, https://ifdmtraffic.marvin.vito.be) with CFD modelling to take into account the impact of roadside screens. This study, though obviously methodological improvements can be made, demonstrates an interesting application of CFD dispersion modelling in a practical environmental impact assessment, subject to typical timing and budgetary constraints in such assessments.

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