NATURAL VENTILATION OF PARKING GARAGES

Dimensioning of ventilation units with the assistance of air flow models

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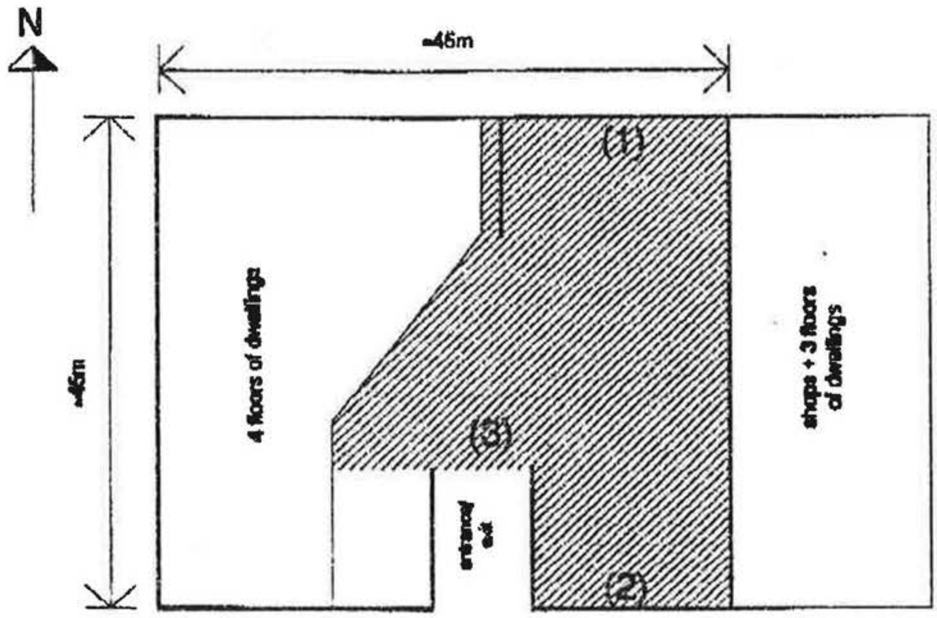
Introduction

Parking garages require ventilation because the exhaust fumes produced by the vehicles have to be discharged. This can be achieved with a mechanical or a natural ventilation system. A natural ventilation system has several important advantages compared with a mechanical system. As a rule natural ventilation systems are simpler, cheaper and have fewer breakdowns, furthermore a natural system requires less maintenance and uses no energy (for air transfer).
For the dimensioning of the necessary ventilation units in a parking garage, the calculating regulations (for The Netherlands) are given in NPR 2443 "parkeergarages" [1]. Recently the department of indoor environment, building physics and systems of TNO Building and Construction Research has carried out further investigations regarding naturally ventilated parking garages. Using a multi cell ventilation model [2] research has been carried out to check if enough natural ventilation can be maintained, while the regulations according to NPR 2443 are not precisely taken into account.
In this article one of these investigations [3] will be discussed. This concerns an investigation by which also the airflow (concentration distribution) is investigated with a so called CFD-Model [4], which stands for Computational Fluid Dynamics.

The parking garage

The investigation relates to a parking garage in a housing and shopping complex.
An ariel view of this complex is given in figure 1. It concerns a relatively small parking garage with 49 parking spaces intended for the inhabitants of the complex. On the west side, above the parking garage, an apartment block is situated, and on the east side the parking garage boarders on the shops.
In the walls of the parking garage no ventilation provisions can be installed, because these walls are under ground level or boarder on other areas (e.g. the shops on the west side). Natural ventilation provisions can only be installed in the roof of the parking garage (see shaded area in figure 1). The part directly next to the entrance/exit is not shaded, because the storage block is situated here and therefore no provisions can be installed
From the above mentioned it seems that due to the possible positioning of the ventilation provisions, a good through ventilation of the west area of the parking garage (under the apartment block) is questionable. In particular this applies to the south/west area, where the storage block hinders a direct air distribution via the entrance/exit. The investigation with the CFD-model is to gain insight into the through ventilation of these areas.



Notes:
- the contour of the parking garage is indicated with thick lines;
- the shaded area gives the possible positioning of the ventilation provisions.
- 1 to 3 are the ventilation provisions modelled in the VenCon ventilation model

Figure 1: Ariel view of the complex

Required ventilation

By ventilating it is necessary, as previously mentioned, that the produced exhaust fumes are discharged properly. As principle pollutant the carbon monoxide (CO) in the exhaust fumes is hereby upheld. The carbon monoxide production is dependent on the following :
- the CO-emission per vehicle
- the traffic load, for example expressed by the amount of in or outgoing vehicles per hour.
- the driving time of a vehicle in the parking garage, especially the time that the vehicle is present with the engine running.

For the CO-emission per vehicle is stated $0,17*10^{-3}$ m^3/s in NPR 2443[1]. Note that this NPR dates back to 1978. During the last few years due to the increased environmental requirements, the exhaust fumes of cars have become considerably "cleaner". The CO-emission in cars nowadays is therefore probably considerably lower than the rates mentioned in NPR 2443. By sustaining the CO-emission according to NPR a certain security margin is built in nevertheless.

Guidelines for the traffic load are given in the literature [5]. Distinction is hereby made between a parking garage for an office complex and for shopping public. For an office complex as peak traffic load is given the situation that one hour before (after) working hours all vehicles arrive (depart). For shopping public a more wider utilisation is taken into consideration. It is assumed that the use of the parking garage in this housing complex is the same as in an office complex. As peak load therefore the assumption is made that in one hour all 49 vehicles depart (arrive).
The driving time is dependent on the average driving distance, the driving speed, the time necessary for parking and a possible waiting time by leaving the parking garage. In this case the driving time is about 60 seconds, considering an average driving speed of 5 kilometers/hour.

By calculations on the basis of the above points, it has been found that for a situation with a peak in the traffic load, the CO-production is $1{,}39 \cdot 10^{-4}$ m^3/s.

The ventilation needs to be sufficient to keep CO-concentrations smaller or similar to the maximum accepted concentration (MAC-value) even by a peak in the traffic load. Taking into consideration complete mixing, the required ventilation can be determined from the quotient of:

- the CO production
- the MAC value of CO in the parking garage minus the CO-concentration in the entering ventilation air.

The exposure of the users in the parking garage can be regarded as short (not more than 15 minutes) and incidental. The MAC value for CO is then 150 ppm. For a city centre literature [6] shows that CO-concentrations in the outdoor air can lay in the neighbourhood of a scale of 20 ppm.
Calculations based on the above mentioned now show that the ventilation, for a situation with peak load, must be approximately 1 m^3/s.

<u>Dimensioning ventilation provisions</u>
As criteria with naturally ventilated parking garages it is frequently considered that the necessary ventilation (in this case 1 m^3/s) needs to be maintained by wind speeds greater or equal to 1 m/s. Lower wind speeds only arise 5% of the time. The chance, that a situation, whereby the ventilation level is lower than that required, occurs in combination with a peak in the traffic load, is then limited.
By the investigation with the multi cell ventilation model is, in relation with the through ventilation in north/south direction of the parking garage, chosen to place ventilation provisions in the roof of the garage at the positions 1 and 2 (see figure 1). In the model the entrance/exit (3) is also modelled as ventilation opening, because this cannot be closed and therefore is always fully open. The so called wind pressure coefficients, with which the wind pressure on the ventilation provisions is simulated, are derived from literature [8],[9].
The model investigation shows that the aforementioned criteria is met in case the net opening of the provisions on position 1 and 2 are respectively 8 and 2 m^2. For the net opening of the entrance/exit 10 m^2 is hereby assumed. The occurring ventilation with these provisions are given as a function of the wind speed for the 4 major wind directions in figure 2.

Figure 2 shows furthermore that the ventilation increases somewhat more than linear with the wind speed. This is also a vital advantage of a natural system in relation to a mechanical system. By the dimensioning for a situation with a low wind speed, in this case 1 m/s, the ventilation shall for the largest part of the time be significantly higher than required. In this parking garage this leads to a ventilation 5 or more times higher than required by the average occurring windspeed of about 5 m/s. Hereby the average exposure of users to pollutants and also the possible inconvenience decrease in a strong way.

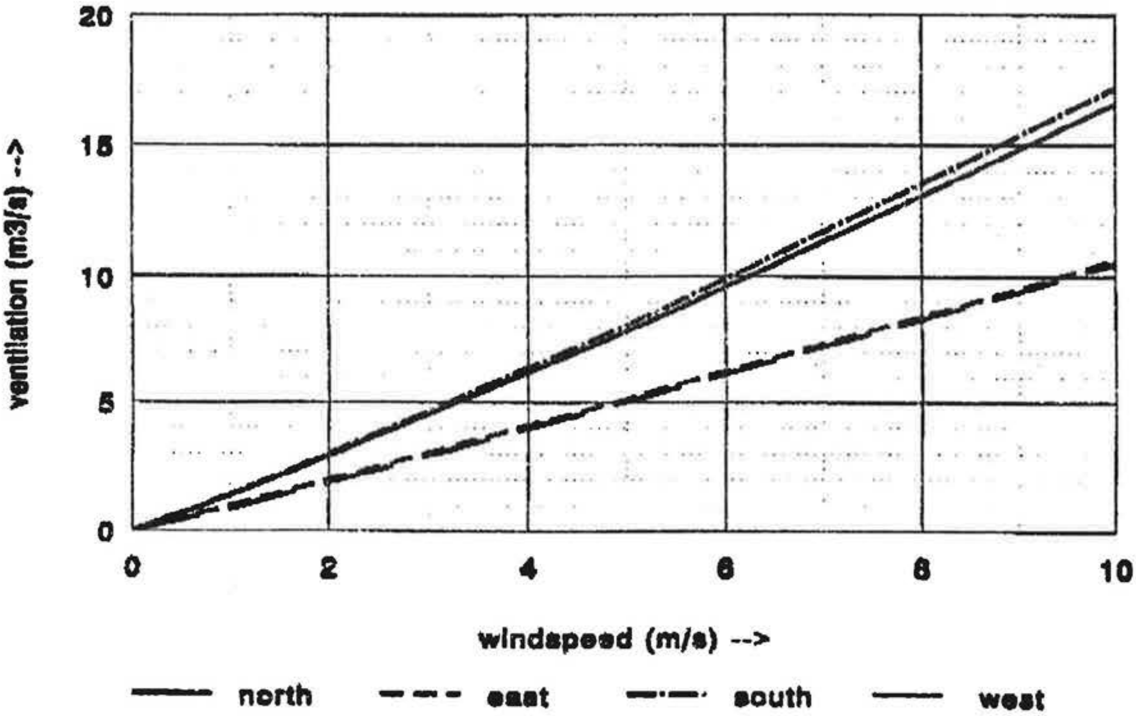
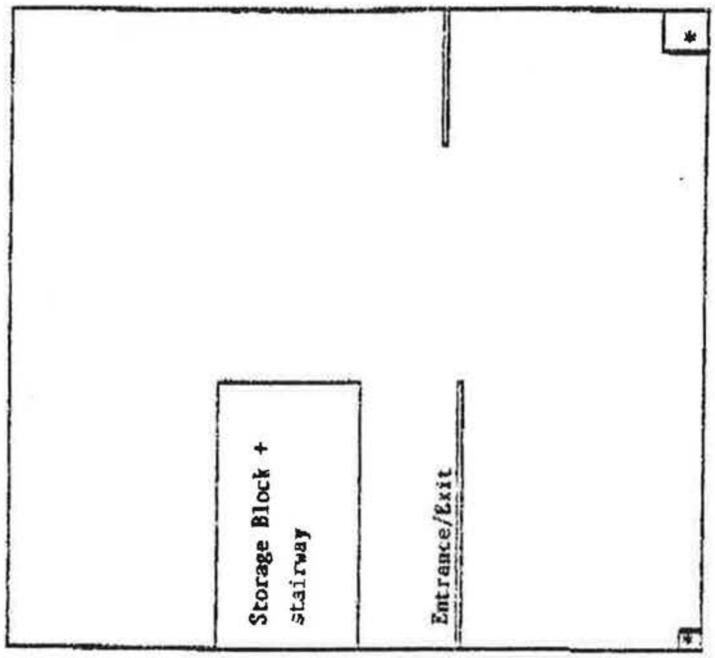


Figure 2 Ventilation as a function of the wind speed for the 4 major wind directions.

Air flow pattern and concentration distribution

With a CFD-model the air flow pattern can be calculated in a room. In this case the in and outlet flow capacity via (the air speed in) the ventilation openings of the parking garage, as were calculated with the multi cell ventilation model, are used as input. In the CFD-model an equal or unequal source distribution over the floor can be simulated. In this case as source is simulated the CO-production of the cars. The dispersion and concentration distribution in the parking garage as a result of the air flow pattern can then be determined.

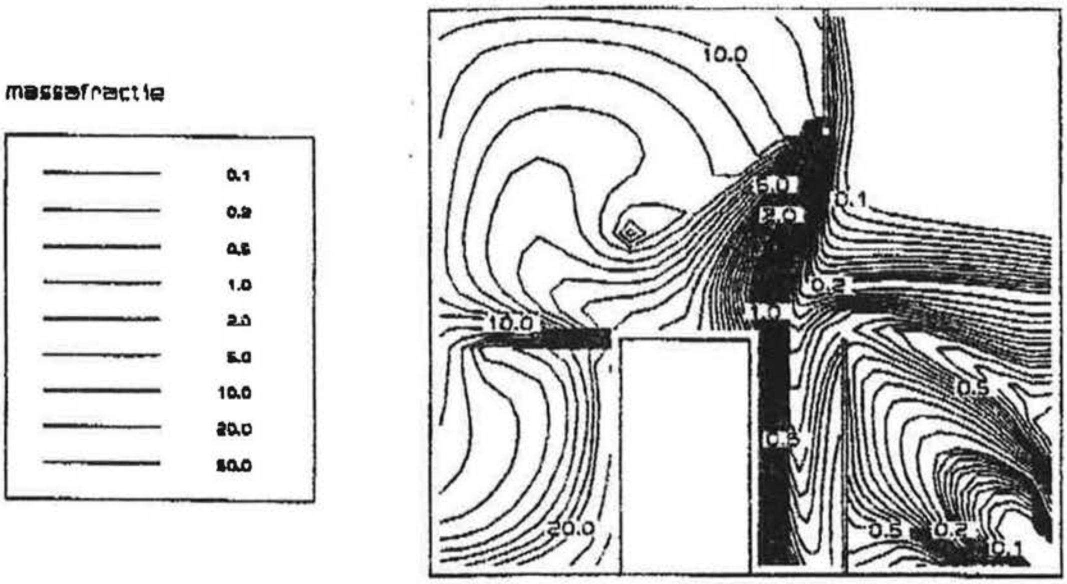
A floor plan of the model of the parking garage used by the CFD-calculations is shown in figure 3. Alongside the entrance/exit the storage block is modelled as obstacles.



* ventilation provisions in the parking garage roof.

Figure 3: A floor plan of the model of the parking garage used by the CFD-calculations.

The through ventilation and concentration distribution is investigated for the situation with extra provisions in the roofing area (see ventilation investigation mentioned earlier). For the most unfavourable situation (west wind and a wind speed of 1 m/s) this concentration distribution is given in figure 4. During these circumstances the outlet of polluted air takes place via the entrance/exit, whereas the air inlet takes place via the 2 roof grilles. It is noted that the given concentration distribution is regulated on the concentration in the outlet flow (concentration in outlet flow is considered 1). The total ventilation is under considered weather conditions approximately the same as the required ventilation (see figure 2).
The concentration in the outlet flow is therefore approximately the MAC-value, while the local occurring concentrations correspond with the values according to figure 4 multiplied with the MAC-value. Note that a figure like figure 4 is usually printed in colour and is then easier to understand.



Note: the contour lines, situated between the contour lines with labelled values, increase with the differences in these values divided by 10.

Figure 4: Concentration distribution at a height of 1,5 m (in the breathing zone) by westerly wind and a wind speed of 1 m/s

From figure 4 it is clear that the through ventilation of the westerly half of the parking garage is inadequate. This applies namely to the south/west corner, where the concentration levels vary from 10 to 20 times the MAC-value. As a result of the inadequate internal mixing in the parking garage, the ventilation should actually be increased by a factor of 10 to 20 for maintaining acceptable CO-concentrations. This however leads to an unrealistically high ventilation level. Another possibility is to improve the internal mixing by applying "a mixing" fan. This possibility has been investigated with the CFD-model. Hereby the following two options are considered, namely:

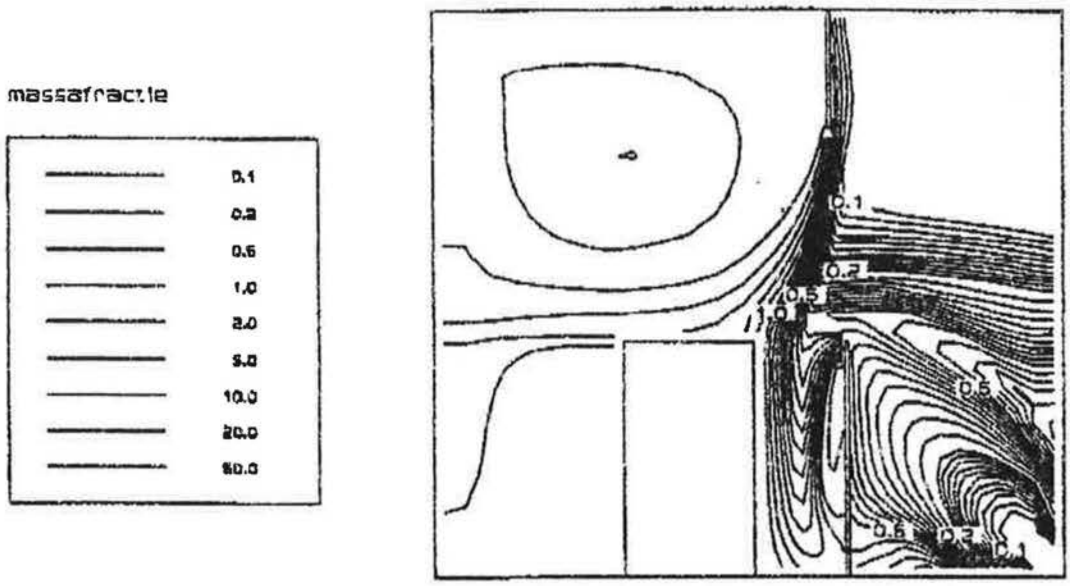
a) application of a "mixing" fan, that transfers an air flow of 1 m^3/s along the west wall from south to north.
b) application of a "mixing" fan, that transfers an air flow of 0,5 m^3/s from the easterly half of the parking garage to the westerly half.

The calculated concentration distributions of these options are given in respectively the figures 5 and 6. From this it is evident that with both options the CO-concentration are reduced and remain limited to a maximum of approximately 1.5 times the MAC-value.

The transfer of the air from the easterly to the westerly half is the most effective. This is shown by the fact that hereby a smaller air flow rate is sifficient. The reason herefor is that actually air of the "clean" (with good through ventilation) half of the parking garage is transferred to the "more polluted" half.
Recommended is to use this "mixing" fan in practice on the basis of the occurring CO-concentrations. The switch on time of the fan will then remain limited to the situations with high traffic loads in combination with low wind speeds. It is expected that in practice the mixing will be better than calculated with the CFD-model. Therefore the switch on time of the fan shall likewise be smaller. This is due to the fact that by the model calculations a few aspects have not been taken into consideration, such as:

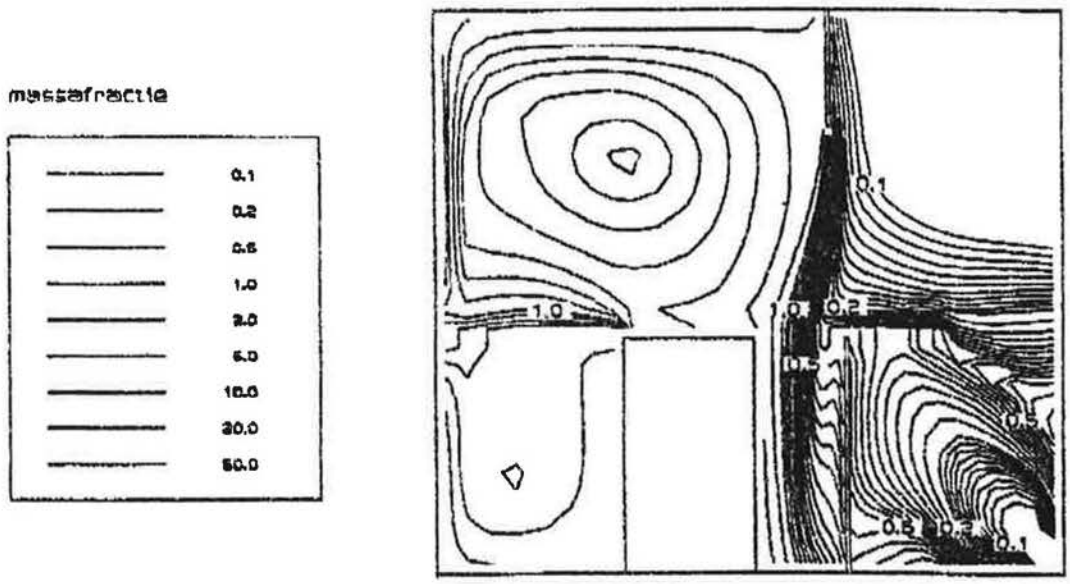
- local differences in the indoor temperature and surface temperatures. Orientating calculations with the CFD-model have demonstrated that a very strong internal air turbulence (mixing) already occurs, if the surface temperature of the west wall deviates 2°C from the air temperature. The CO-concentrations are hereby reduced from 10 to 20 times the MAC-value (see previously mentioned) to 5 or 7 times the MAC-value.
- the mixing due to the driving of the cars.
- the fact that the exhaust fumes are warmer than the air.
- the possible heat emission by the engines.

By not taking these aspects into consideration during the design, a certain safety margin is built in. If the design has to be optimised further, then it is desirable that additional research is conducted to a few of the aforementioned aspects.



Note: the contour lines, situated between the contour lines with labelled values, increase with the differences in these values divided by 10.

Figure 5: Concentration distribution at a height of 1,5m (in the breathing zone) by:
- westerly wind and a wind speed of 1 m/s
- a "mixing" air flow of 1 m^3/s along the west wall from south to north.



Note: the contour lines, situated between the contour lines with labelled values, increase with the differences in these values divided by 10.

Figure 6: Concentration distribution at a height of 1,5m (in the breathing zone) by:
- westerly wind and a wind speed of 1 m/s
- a "mixing" air flow of 0,5 m^3/s from the easterly to the westerly half.