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Immission Assessment Inside an Industrial Ventilated Room Using CFD

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Nowadays the ventilation design of enclosed spaces is still based on the number of air renewals per hour. This coarse approach was developed in the past but nowadays is a fast and simple computational exercise to determine where and when the Threshold Limit Value (TLV) is surpassed. A rather superficial Computer Fluid Dynamics (CFD) analysis is able to provide insights that are useful to propose measures to keep the pollutants concentrations at safe levels. As illustrative example, the contaminants' level inside a factory is simulated, both in steady and unsteady state, for risk and health assessment to determine the contaminant levels reached as consequence of the normal operation or in case of a sudden release.
The case study is based on an example related to the ventilation of a printing factory for which there are field measurements available in literature. Two pollutants are emitted separately; one continuously during operation and the other only sporadically during cleaning. A good agreement is obtained between the simulations and previous field measurements. This case is an example that a design fulfilling the legislation according to the air renewals tabulated can surpass the threshold limit value in practice. The main conclusion is that the legislation should be based on CFD results instead of general tabulated values, as in some cases the ventilation could be too oversized and in others may result insufficient.

1. Introduction

Pollution in the workplace is very important because the concentration of pollutants affects the workers' health by inhalation. The substance present in the environment penetrates the body with the air breathed. Although natural ventilation is less efficient than localized air extraction, it is a simple option that sometimes is enough to dilute the pollutant released into the environment controlling health, risks of fire and explosion or annoying contaminants. Under certain conditions, dilution provides a level of protection equivalent to that obtained with localized extractors at a lower cost.
Ventilation project designs are nowadays performed according to legislation, i.e. 5-10 air renewals per hour as specified in UNE100011 normative about ventilation for an acceptable quality of air, in air conditioning of rooms. The air renewals per hour is a coarse approach that does not take into consideration the influence of the location of the air outlet and flow rate on the volatile contaminants concentration distribution inside the closed environment of the warehouse. Furthermore, this approach does not identify the regions that are over the TLV, shortcuts or dead zones with low air renewal.
Nowadays, with the increase in calculation power, the dispersion of pollutants in an enclosure can be easily determined by simulation. Simulation results show a quite good correlation between CFD and empirical approaches for contaminants in empty rooms, e.g. Mocho et al. (2017). Murphy et al. (2017) use CFD to determine when is safe to enter in a confined space after being ventilated, e.g. manure pit. CFD is also useful to determine the required ventilation to dilute LNG combustible gases and avoid the risks associated, e.g. Van Wingerden and Salaun (2016).

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A ventilation project fulfilling the legislation available in literature (Gonzalez Casas, 2014) is analysed using CFD. The emissions in a closed space, based on an example related to the ventilation of an industrial installation, are simulated and compared with experimental measurements available in the literature (Viegas, 2011). Two pollutants are emitted separately, one continuously and another only during a given time to determine the concentration of contaminants in the room. The observation of the air renewals regulations in the industrial project does not assure that the posterior measurements in the field would be satisfactory and corrections after the project completion are required with additional and unexpected costs. The offset printing solvents have a faint odour and the solvent exposure may seem acceptable unless it is measured. The CFD simulation predicts cheaply in a virtual environment with lower computer requirements the pollutants level in any installation before its construction. The present study provides a case study about the printing industry showing the potential of CFD in improving the health in the workplace, identifying when the threshold limit values could be overcome.

2. Methodology

The geometry is generated using SolidWorks® based on the data from Gonzalez Casas (2014) and Speed Master (2018) web page (Figure 1). As the goal of the present study is to provide general insights and not to reproduce in detail a particular scenario, only three elements are present: the air input window at the left, the source of emissions machine in the middle and the air output door at the right. The geometry is imported to ANSYS® DesignModeler geometry tool. Chemical and physical data of the solvents are retrieved from OLIStudio® Stream Analyser and implemented in the Materials section of the ANSYSFluent® module (Table 1).

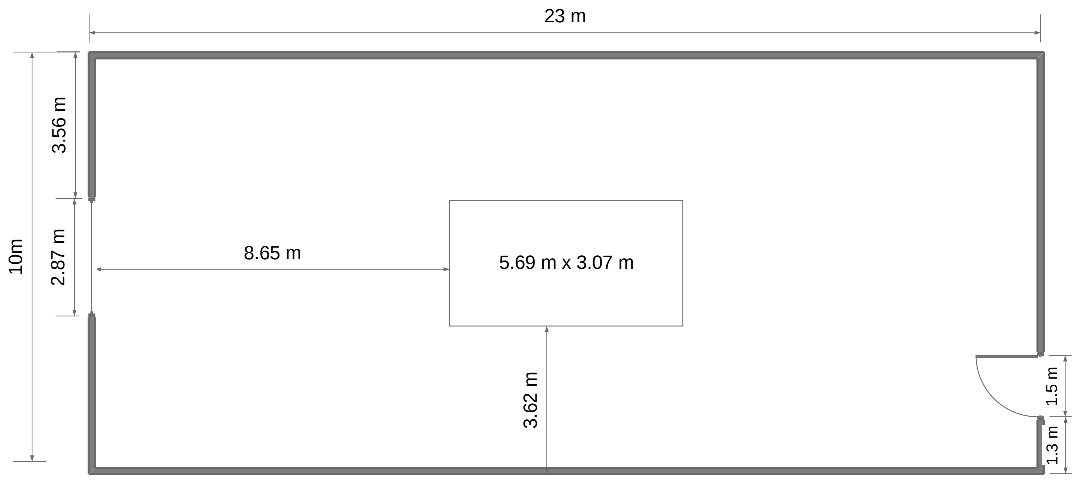

Figure 1: Distribution in the interior warehouse: window (1.32 m x 2.87 m at a height 2.36 m above floor) at the left (air input), the release point at the centre and a door (2 m x 1.5 m) at the right (air output).

The meshing and simulations are performed in ANSYSFluent®. The meshing is with tetrahedral cells, the advanced function size activated on curvature, medium relevance centre and smoothness. A smooth transition inflation is performed in the upper part of the printer where the vapours are emitted. The space becomes discretized in 18,630 nodes obtaining a good average element quality, i.e. 0.84. The solver is pressure-based taking into account the gravity and the viscosity model is the k-epsilon. Once converged the simulation after around 3000 iterations, the post-processing is used to determine the pollutants concentration at a height of 1.75 m to consider the immission for a person height. Although the assessment is performed for the entire room, the results presented focus on this horizontal plane corresponding to the immission that would be sampled with portable device in a field study.

The inlet velocity for ventilation is 0.01m/s, 0.63 m/s and 1 m/s corresponding to 0.12, 7.5 and 12 air renewals/h, i.e. below the minimum recommended, according to regulation (between 5 and 10 renewals/h) and above the maximum recommended respectively. Every time that printing finishes, a cleaning is performed with liquid naphtha (C_9H_{12}) with a flow rate evaporated of 1.22 g/s during 300 s and therefore it is solved in transient. On the other hand, due to the printer operation, a 5 %(volume) aqueous solution of isopropyl alcohol (C_3H_8O) is continuously evaporated corresponding to a flowrate of 0.0283 mg/s and it is solved in steady state. The TLV (Threshold limit value) of 1-ethyl-3-methylbenzene (C_9H_{12}) is 170 ppm in 8 h, while for isopropyl alcohol is 200 ppm, which corresponds to 0.708 mg C_9H_{12}/g air and 0.416 mg C_3H_8O/ g air. The regions where the pollutant concentration surpasses its TLV are represented in red colour in the results figures, whereas the blue colour corresponds to regions with negligible concentrations of contaminants.

Table 1: Pollutants main properties in vapour phase

	C_9H_{12}	C_3H_8O
Viscosity (Pa·s)	$8.293 \cdot 10^{-6}$	$9.240 \cdot 10^{-6}$
Thermal conductivity (J/(s·m·K))	0.01933	0.01633
Molecular mass (g/mol)	120.2	60.1

3. Results

The simulation results show that pollutant concentrations above the TLV (in red colour) at the worker level are only attained close to the printer walls (Figure 2). Nevertheless, this fact is consequence of the space discretization. A dead region is present between the wall of the printer and the first mesh nodes around it and the pollutant exits from this dead region only by molecular diffusion. Figure 3 shows that a region above the TLV is attained above the printer but not where the worker operates. A region of concentration higher than the TLV is always present independently of the air renewals per hour in points close enough to the release source. Therefore, no risks are determined from the printer operation even at low air renewals rates and therefore the ventilation is a suitable option without requiring any other measure. It is interesting to notice that the distribution of contaminants depends on the number of air renewals, for instance at 0.12 renewals/h the pollutant concentration in the right back corner of the printer is lower than for higher renewals values. The different distribution of contaminants is a consequence of different air rates profiles and death zones distribution (Figure 4). The air distribution depending on the placement of the machine and openings would also influence on the indoor air quality and distribution of contaminants (Zhang and Zhao, 2016). The Figure 4 shows also that the air rate at the printer wall is null.

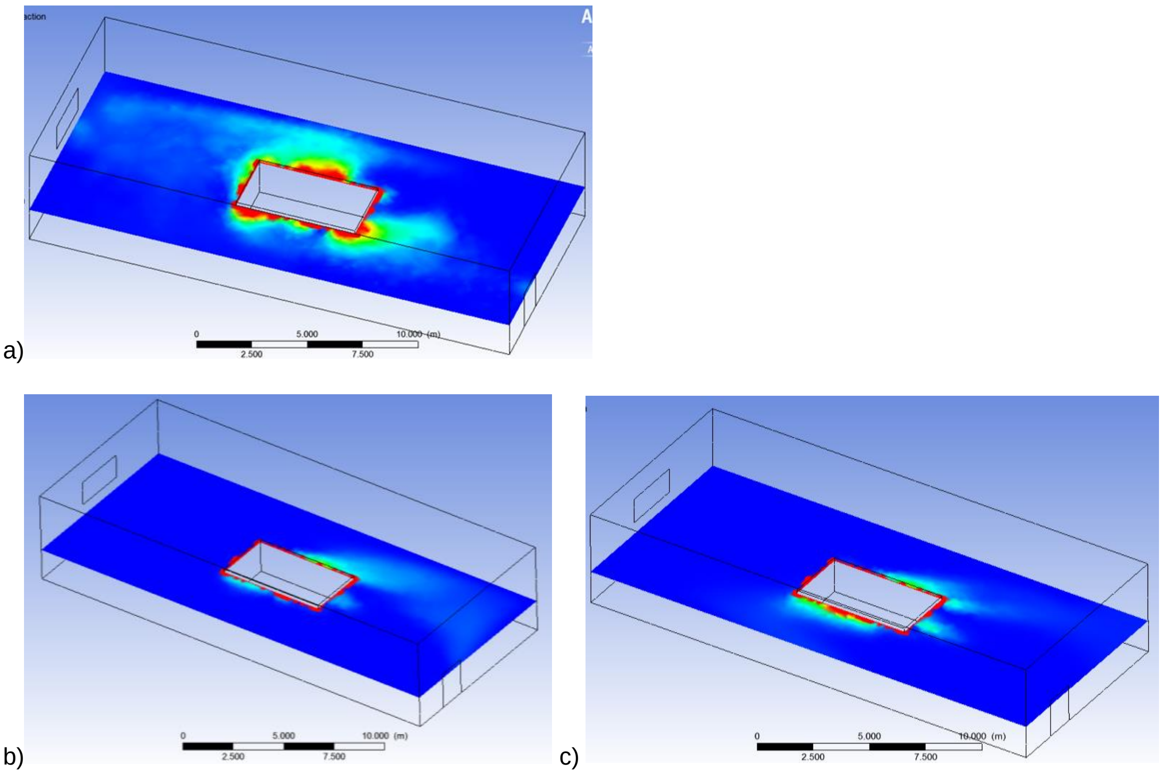

Figure 2: Pollutant distribution at plane Z=1.75 m, regions over TLV in red colour; air renewals/h: a) 0.12, b) 7.5 and c) 12

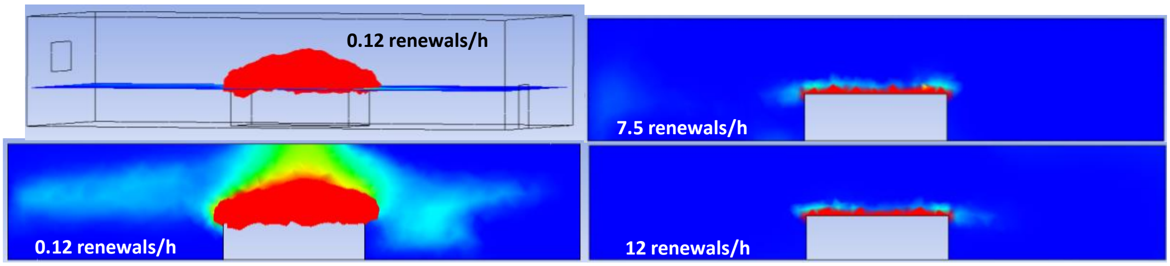

Figure 3: Pollutant distribution on the vertical plane XZ; regions above TLV in red colour

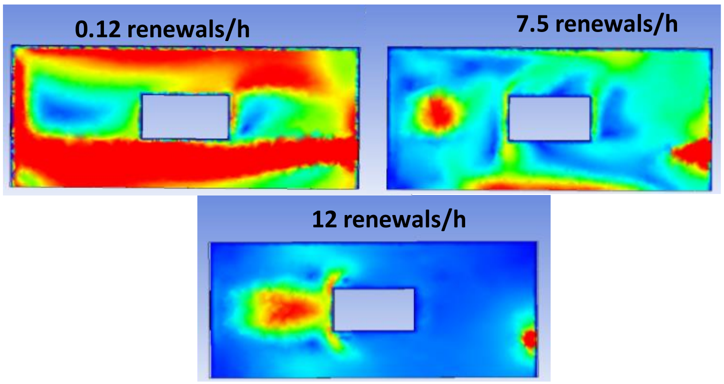

Figure 4: Dependence of the dead zones location on the number of renewals/h (dead zones in blue colour)

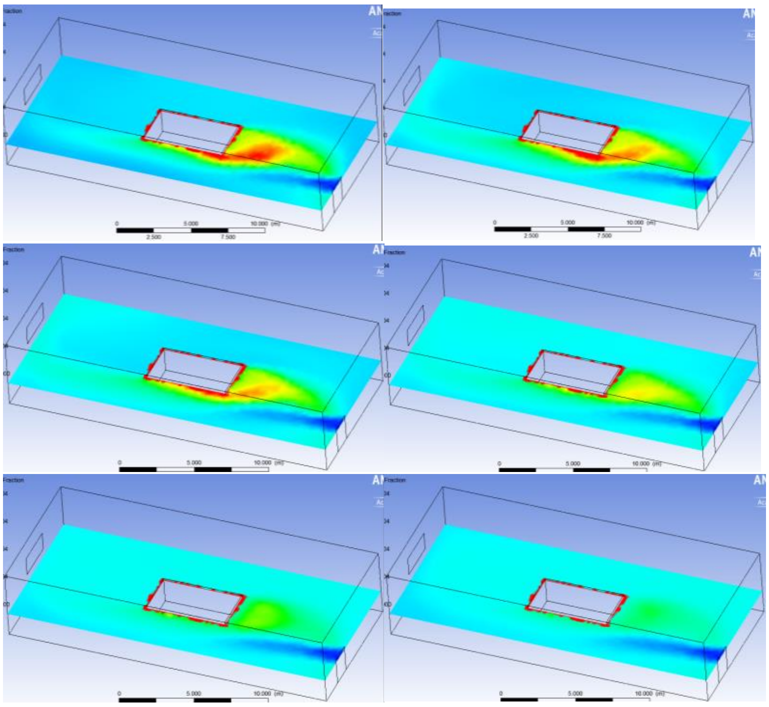

Figure 5: Transient simulation results at 260, 280, 300, 320, 340 and 360 s for 0.12 air renewals/h

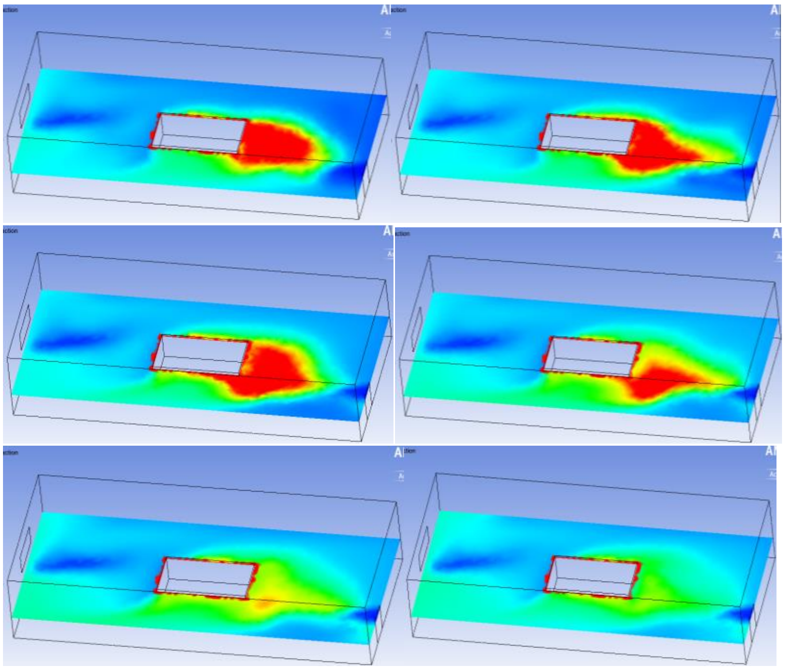

Figure 6: Transient simulation results at 260, 280, 300, 320, 340 and 360 s for 7.5 air renewals/h

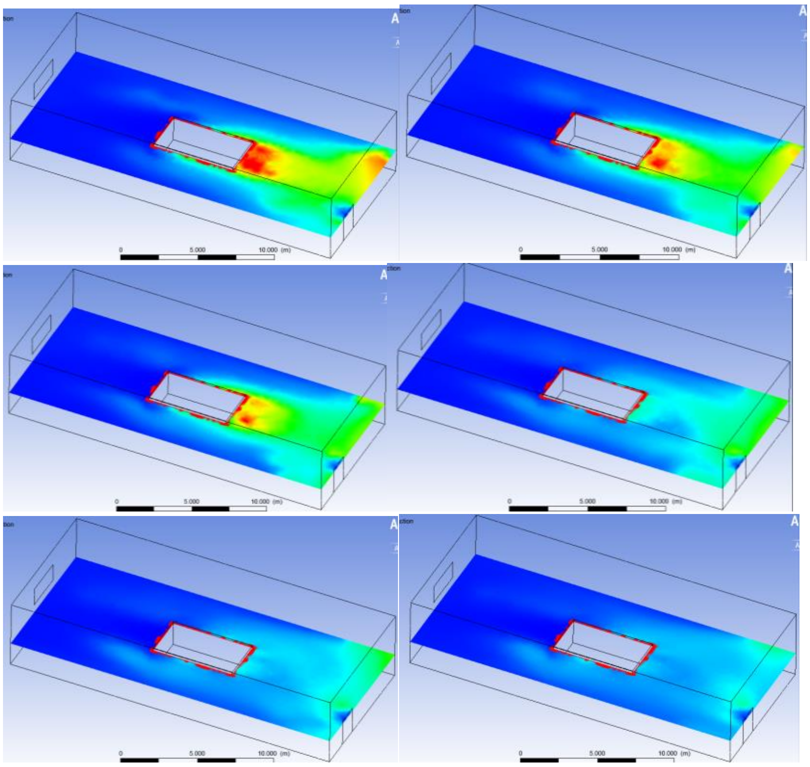

Figure 7: Transient simulation results at 260, 280, 300, 320, 340 and 360 s for 12 air renewals/h

The transient simulations (Figures 5, 6 and 7) show that values above the TLV are attained during the cleaning of the printer independently of the air renewals used. The values above the TLV are located at the right side of the printer, therefore during the cleaning operation the worker should be placed at the left or back of the printer. Therefore, this fact should be considered when the printer is located in place, i.e. worker placed at the back during cleaning. In the same way, the paper exit where the worker spends most of the time should be located at the left. At 300 s when the cleaning stops then its concentration gets under the TLV for low and high air renewals. It is important to notice that for the 7.5 air renewals/h according to the regulations is where the TLV is overcome for a longer time and for a wider region. The results of this study indicate that the most important source of volatile organic compounds exposure in this printing industry is during the cleaning. The same conclusion was attained by Viegas (2011) in real field measurements using a portable VOCs equipment with real-time measurements in a four years study. All measurements were done in the breathing zone of workers while they were performing their tasks, during 5 to 15 min.

4. Conclusions

Standard UNE100011 regulates the air renewals required to avoid health problems for the presence of contaminants in the workplace. A project fulfilling the legislation is analysed using CFD which is able to identify the regions that are over the TLV, shortcuts or dead zones with low air renewal. At the emission source the concentrations are over the TLV but decrease sharply with the distance to the source. Therefore, the individual immission depends on personal factors such as the worker arm's length. However, other factors such as the printer location influences the worker immission, e.g. place the paper output direction to the air input. Between the printer and air output is created some dead zone where higher concentrations are attained. Two solvents are emitted by the offset printer: one during the operation (steady) and another during the cleaning (transient). Although a short period of time, the cleaning solvent reaches concentrations over the TLV at the previously indicated dead zone. The main conclusion is that ANSYS Fluent® is a suitable tool for health and risk assessments in industrial factories attaining the same conclusions as a field study of several years and therefore it should be implemented instead of the nowadays air renewals regulation.

Acknowledgements

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