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REENTRAINMENT OF POLLUTANTS FROM EXHAUSTED AIR - DISCUSSION OF DIFFERENT TYPES OF REGULATORY REQUIREMENTS

Jerzy Sowa, PhD

Warsaw University of Technology,
Institute of Heating and Ventilation,
00-653 Warsaw, Nowowiejska 20, Poland.
E-mail: jsowa@hetman.iis.pw.edu.pl

SYNOPSIS
In many existing ventilation systems unintentional reentrainment of pollutant, due to improper location of exhaust and air intake, decreases quality of indoor environment. Unfortunately, the more precise method of assessment of exhaust plume behaviour, the more difficult potential application in regulatory codes and standards. The aim of the paper is to discuss advantages and disadvantages of different types of the models and their applications in regulatory requirements. Discussion addresses two standards: BSR/ASHRAE Standard 62-1989R Public Review Draft (August 1996) and new Polish building code. The conclusions highlight that at the moment there is no good procedure (simple and precise enough) to be commonly used in standards. The necessity for further research is pointed out.

1. INTRODUCTION

Practice indicates that even in cases when comfort mechanical ventilation systems operates only on fresh air some pollutants might be unintentionally recirculated because of improper location of exhaust and air intake. As pollutants also can be introduced to the buildings with infiltrating air, operable doors and windows that are a part of a natural ventilation system shall be treated as outdoor air intake. The problems mentioned above are very well known to industrial ventilation specialists. Although in cases of their interest exhausted gases are discharged by stacks, usually much higher than ventilation exhausts, but waste gases even after cleaning, are much more polluted than air discharged to the atmosphere from typical comfort ventilation systems. Because of this almost all-existing procedures for possible reentrainment assessment were developed originally for industrial buildings. The basic problem for the specialists is to generalise these models (build on limited experimental data) to the form able to cover all possible types and shapes of buildings and all possible combinations of input parameters (intake and exhaust location, discharge velocity, discharge direction, etc.). Moreover, as building codes and requirements have to be commonly understood the available procedures have to be as simple as possible.

2. LOCATION OF EXHAUSTS AND OUTDOOR AIR INTAKES

In number of buildings it is an architect who solves really difficult problem of best intake location. Unfortunately, he usually takes care of aesthetics of the building envelope but rarely understands aerodynamics and ventilation principles.

From engineering point of view, outdoor air intakes shall be located such that they draw on best possible outdoor air. In ideal situation the intake location should be the result of the wide analysis taking into account the following factors:

- shape of the building,
- pollution sources like (ventilation exhausts, plumbing vents, cooling towers, streets or roads, garage entry or loading areas etc.),
- prevailing winds and air flow patterns around the building and building elements,
- location of HVAC equipment inside the building.

Each case needs individual analysis but some very general hints can be formulated (e.g. in [1]). If possible exhaust air should be discharged vertically with relatively high velocity (value > 1,5 times wind speed is recommended) and above all possible obstacles and circulation zones.

In the case of relatively high buildings the air intakes should be located on the lower one – third of the building, high enough above ground to avoid wind blown dust, vegetation and

vehicle exhausts. This not only creates big distance between exhaust and intake but also allows taking advantage of the natural separation of wind flow on the upper and lower half of the building.
In case of low buildings or when protection against wind blown dust and debris is especially important, intakes are located on the roofs. When the building has decentralised air exhaust with number of roof fans and other discharge points, it might be impossible to locate the intake according to the requirements.

3. MODELLING OF EXHAUST PLUME DISPERSION IN BUILDING SURROUNDING

Mathematical modelling of plume dispersion in building surrounding is a pretty complicated problem. Simple analytical models describing turbulent injection of aerosol into another twisted turbulent stream of air, all this close to boundary layer, do not exist. Off course specialists may use CFD method. However, one should remember that preparing input data files for such analysis is usually very time consuming. Moreover, in spite of very rapid development of computers, 3-D simulation software sill can not be installed on commonly used units.
In that conditions full-scale tests at existing objects or physical modelling are the best ways to learn about dispersal of polluted air discharged from "low emitters". Term "low emitter" means that wind flows around building have the predominant influence on pollutant dispersal. Several teams trying to generalise outcomes from their investigations developed empirical models.
In seventies *Nikitin et al.* published in Russia the set equations that allow potential designer to evaluate pollutant concentration at air intake for industrial buildings [4]. The methodology covers both stack and linear emitters (e.g. lines of roof windows). Designer may calculate concentration for points located at roof, back wall or at ground behind the building (local co-ordinates x,y). Main limitations of the method are:

- wind is always perpendicular to longer wall of the building,
- air exhaust discharge velocity is not taken into account,
- gas temperature is not taken into account,
- in all equations concentrations are inversely proportional to wind speed (minimum concentrations are obtained for the lowest limit of wind speed, 1m/s).

In USA the results of works carried out by *Halitsky, Wilson, Chui* and others built the combined ASHRAE procedure. Methodology is looking for minimal dilution that may occur when the wind almost directly ("stretched string" distance) transport pollutants from exhaust to air intake. Method takes into account apparent initial dilution at roof level, dilution due to distance between internal turbulence and additional dilution due to stack exhaust. Main limitations of the method are:

- method do not give the opportunity to calculate dilution for conditions other than critical, other wind direction and wind speed,
- method allow to calculate the shape of recirculation zones only for wind perpendicular to walls.

During works on Public Review Draft of BSR/ASHRAE Standard 62-1989R [2] the simplified version of ASHRAE model has been developed. General principles are common but number of additional assumptions were made (e.g. wind speed equals 2,5 m/s, exhaust is on

the roof level etc.). These assumptions can of course be listed as disadvantages of the method but one great advantage appeared - the simplicity.
Full comparison of the models mentioned above is not easy but even very simple example (fig. 1) can show the differences between results from presented methods. The volume of 500 l/s of polluted gases is emitted from industrial building through the stack with negligible height. Gases are discharged vertically with the velocity of 5 m/s.

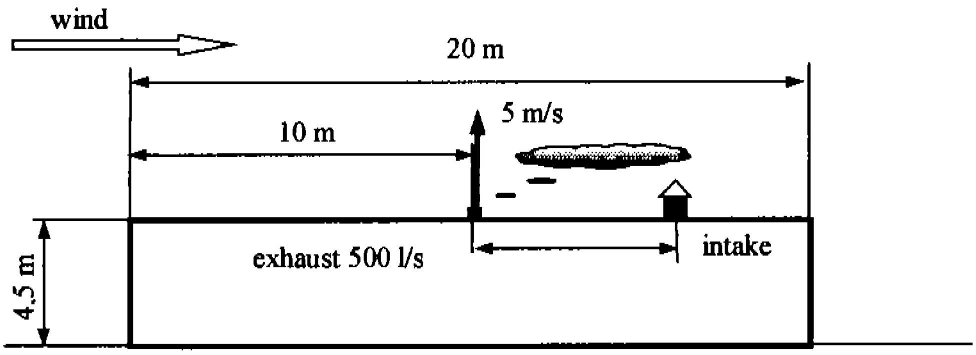

Figure 1. Scheme of analysed industrial building.

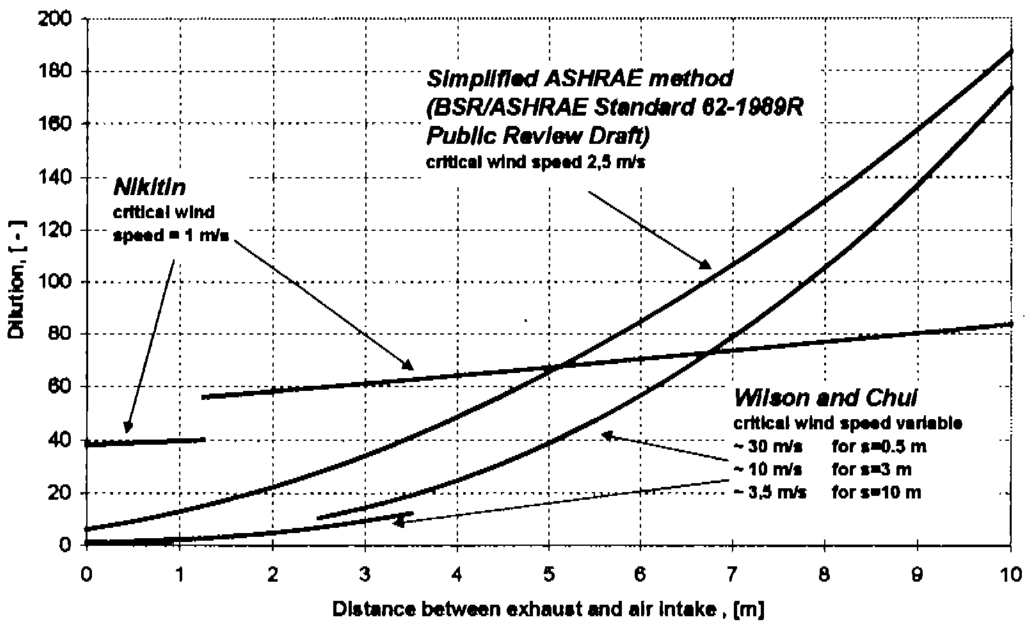

Figure 2. The comparison of dilution of pollutants calculated by different methods (geometry as presented at figure 1).

Analysis of the figure 2 indicates that there are big differences between results obtained using presented methods. The relative errors of the methods (taking the *Wilson* and *Chui* method as the reference one) are:

- for simplified ASHRAE method from ~550% for 0,5 m distance to 7 % for 10 m.
- for *Nikitin* method from ~3700% for 0 m distance to –50 % for 10 m.

Moreover, the differences in assumptions caused that each method estimates critical dilution for other wind speed:

- 1 m/s (constant) for *Nikitin* method,

- 3,5 ÷ 30 m/s (variable) for *Wilson* and *Chui* method.
- 2,5 m/s (constant) for simplified ASHRAE method.

There is no chance to state which method estimates the plume dispersal best in analysed case. One should remember that although presented methods allow designers to perform routine estimation but only full-scale field measurements or physical modelling can provide true answer. This is the suggested procedure for critical applications (e.g. hazardous pollutants).

4. EXAMPLES OF REGULATIONS CONCERNING LOCATION OF EXHAUSTS AND OUTDOOR AIR INTAKES

4.1. BSR/ASHRAE Standard 62-1989R Public Review Draft

Regulations in BSR/ASHRAE Standard 62-1989R Public Review Draft are generally based on ASHRAE model. The standard distinguishes 5 classes of exhausted air stating minimum dilution factor for each of class (table 1).

Table 1. Dilution factor determined as a function of exhaust air class (on a base of [2])

Exhaust Air Class	Dilution factor, D
Class 1: Air drawn from spaces without unusual sources of contaminants	5
Class 2: Air drawn from spaces that may have mild contaminant intensity,	10
Class 3: Air drawn or vented from locations with significant contaminant intensity,	15
Class 4: Air drawn or vented from locations with noxious or toxic fumes or gases,	25
Class 5: Effluent or exhaust air having a high concentration of dangerous particles, bioaerosols, or gases	50

The model uses the idea of the shortest "stretched string" distance measured from the closest point of the outlet opening to the closest point of the outdoor air intake opening, window or door opening, or property line along a trajectory as if a string were stretched between them.

The standard requires that the exhaust air and vent outlets shall be located no closer to property lines, outdoor air intakes, windows, and doors, both those on the subject property and those on adjacent properties, than the minimum separation distance S listed in special table. The distance is either calculated by simple formula taking into account: exhaust air volume, exhaust air discharge velocity and dilution factor (determined as a function of exhaust air class), or stated as the constant value.

Some exceptions are mentioned, regarding e.g. alternative design (approved by the authority having jurisdiction), unitary or factory packaged heating/ventilating unit and systems operating not simultaneously.

4.2. Requirements of the Polish Building Code

General requirement of the Polish Building Code [3] says that air intakes for ventilation and air conditioning systems should be located at places that allow drawing on not polluted air. In case when contamination exceed permissible values (Stated in Polish Environmental Codes) air should be cleaned before supply to rooms. Air intakes and exhausts should be located outside possible explosion zones, and the distance between them should be not less than 10 m.

In case of compact ventilation and air conditioning units that include both air intake and exhaust, the minimum separation can be less than 10 m, but the design should successfully protect air intake from reentrainment of exhaust air. The Code requires also that exhaust points from mechanical ventilation should be located at least 0,4 m above surface at which they are installed and at least 0,3 m above the line connecting the highest points of the nearest obstructions. As obstruction one regards the elements of the building located closer than 10 m from exhaust (in horizontal projection).
Distance between mechanical system exhausts and windows in dwellings and offices should not be less than 3 m in horizontal projection and 1 m in vertical projection. If the exhaust air contains substances harmful for environment and human health, horizontal distance should be increased to at least 6 m.

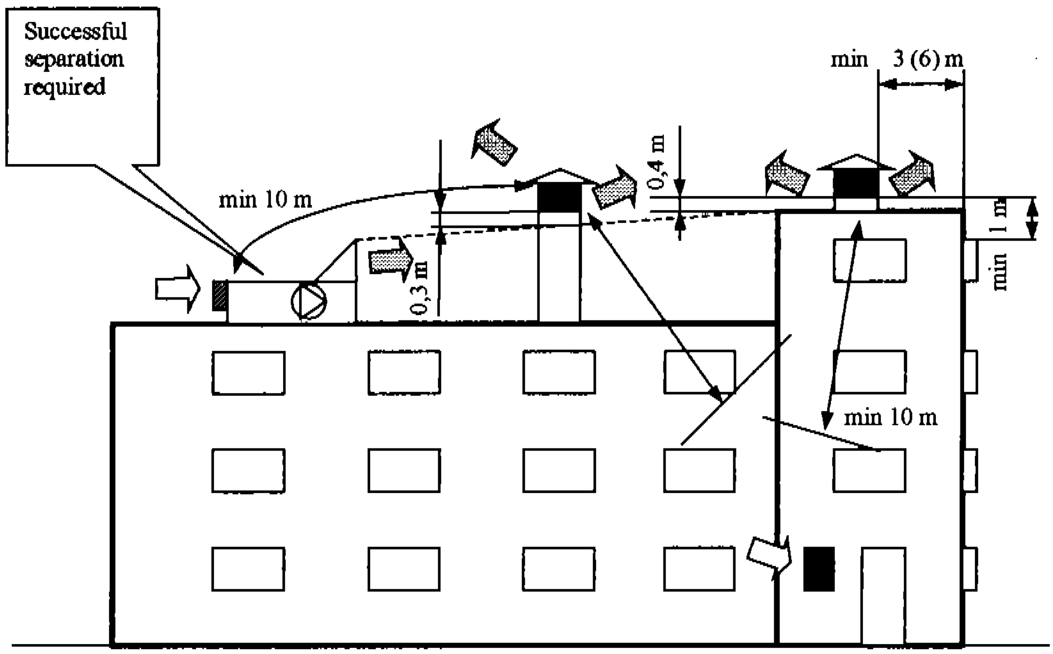

Figure 3. The general ideas of Polish Building Code [3] regarding exhaust and air intake locations.

5. DISCUSSION OF DIFFERENT TYPE OF REGULATORY REQUIREMENTS

The standards described above present two different type of regulation. Public Review Draft of BSR/ASHRAE Standard 62-1989R is pretty thick, with number of appendixes, simple calculation methods and additional notes. It looks like the "first aid kit" for ventilation systems designers. Polish building code looks as it has been developed for verification authorities. There are no explanation notes or calculation methods. The code contains number of simple, easy to check requirements.
Figure 4 presents the comparison of minimum exhaust-intake separation distance required by discussed standards. Negative discharged velocity means that exhaust is directed less than 74° towards the intake. Moreover according to simplified ASHRAE method, discharge velocity shall be set to 0 for vents from gravity (atmospheric) fuel fired appliances, plumbing vents, and other non-powered exhausts, or if the exhaust discharge is covered by a cap or other device that dissipates the exhaust air stream. For hot gas exhausts such as combustion products, an effective additional 2.5 m/s upward velocity shall be added to the actual discharge velocity.

Figure 4 indicates that generally Polish Building Code requires much higher separation distance than proposal of new BSR/ASHRAE Standard 62-1989R. For example presented at figures 2 and 3, depending on the method, dilution factor at 10 m reaches 84 (*Nikitin*), 174 (*Wilson* and *Chui*) method) or 187 (simplified ASHRAE method). All this values are much higher than dilution required by Public Review Draft of BSR/ASHRAE Standard 62-1989R even for effluent or exhaust air having a high concentration of dangerous particles, bioaerosols, or gases. According to simplified ASHRAE method even discharge of polluted gases towards air intake with velocity of 8 m/s allow keeping dilution of 50 at separation distance of 10 m. In this context it is worth to notice that in analysed example, Polish code would not allow to locate air intake on the roof at all.

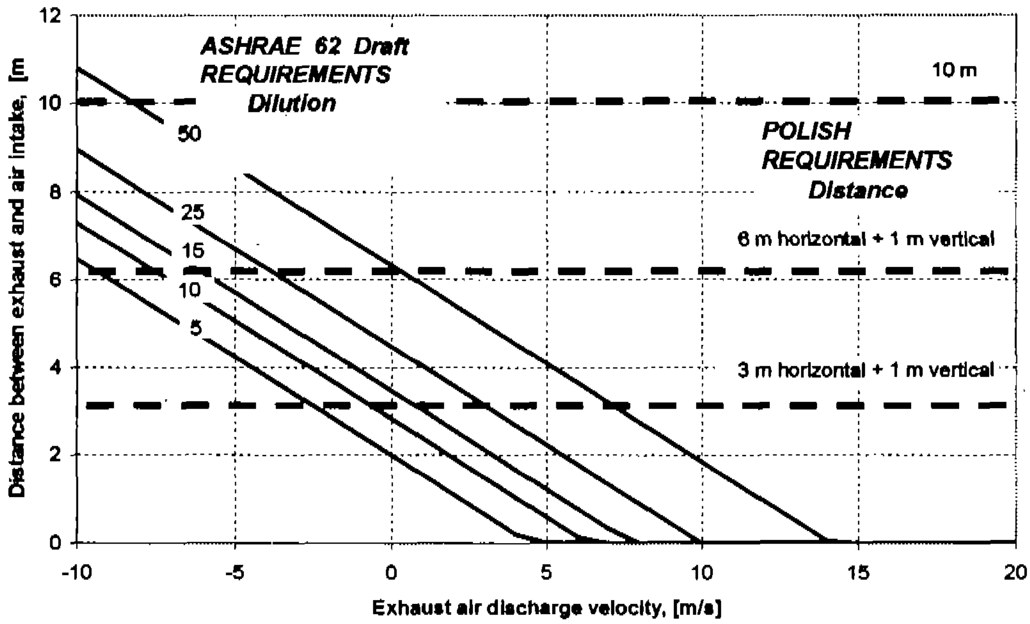

Figure 4. The general ideas of Polish Building code regarding exhaust and air intake locations.

Both BSR/ASHRAE Standard 62-1989R Public Review Draft and Polish Building Code allow drawing some conclusions concerning advantages and disadvantages of different types of requirements protecting ventilation systems from reentrainment of pollutant due to improper location of exhaust and air intake. Brief summary is presented in table 2.

6. CONCLUSIONS

There is very little well-verified and commonly accepted methods for exhaust plume behaviour. Existing models are usually to complex to use them in the regulatory codes.
Authors of ventilation codes willingly use requirements describing location of exhaust and air intake or separation distance. These statements are usually not flexible and probably over estimate potential risk. Simplifications of the models increase uncertainty of estimation and than it is very important to understand that even where the required minimum separation distances are maintained, reentrainment of odours and toxic gases may still occur depending on wind conditions, building geometry, and exhaust design.

It seems that further research should be carried out to prepare more reliable way of incorporation methods of protection against reentrainment of pollutants from exhausted air into the standards and ventilation codes.

Table 2. Advantages and disadvantages of different type of requirements protecting ventilation systems from reentrainment of pollutant, due to improper location of exhaust and air intake.

Type of the requirement		Advantages and disadvantages of the requirement
Concentration of pollutants in air intake or supplied air	Adv:	– addresses the most important factor, – checking is possible.
	Disadv:	– checking is pretty complicated (chemical analysis required), – precise measurements interpretation procedure is necessary, – difficult to apply during designing process, – in case of requirements regarding air intake, at highly polluted areas location of air intake may not be possible.
Minimum dilution factor	Adv:	– addresses very important factor (at not polluted areas possibly critical), – checking is possible (e.g. tracer gases).
	Disadv:	– does not take background of pollutants into account, – precise measurements interpretation procedure is necessary, – without standard method of estimation do not applicable during designing process.
Standard method of estimation	Adv:	– allow wider analysis during designing process, – provides flexibility to the designer or architects.
	Disadv:	– usually do not allow calculation for several emitters, – may create the impression that after analysis reentrainment will not occur in any circumstances.
Location of exhaust air intake or separation distance	Adv:	– allows to formulate very simple and easily understood statement, – checking the compliance with regulation is very easy.
	Disadv:	– difficulties with prediction of all possible situation cause that regulation is usually not flexible. and overestimate potential risk

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