EFFECTIVE VENTILATION

9th AIVC Conference, Gent, Belgium
12-15 September, 1988

Paper 5

VENTILATION STRATEGIES IN THE CASE OF POLLUTED OUTDOOR AIR SITUATIONS

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SYNOPSIS

In former times outdoor air was implicitly equated with fresh air as it was assumed that the mixing and rarefaction process involved with ventilation would always lead to an improvement of indoor air quality. Recently, however, this assumption of "clean" outdoor air quite frequently proved to be wrong. The situation becomes disquieting when the concentration of pollutants like sulfur dioxide, carbon monoxide, hydrocarbons and the like, in outdoor air is higher than in indoor air, since in this case, ventilation no longer makes any sense. The situation becomes critical when pollutant concentration in outdoor air reaches a level which reduces the well-being of the persons living in a building or even involves health risks as a result of air change (in the form of infiltration or ventilation) between building interior (internal environment) and outside environment.

Examples of such situations are smog, the after-effects of the nuclear power plant accident in Tshernobyl, the escape and dispersion of chemical substances after transportation accidents, and other harmful incidents. There is a pressing need to reflect on the potential type and effect of such events and to develop technical, operational and organizational measures which must be taken with mechanical ventilation units in the case of polluted outdoor air situations. In the Federal Republic of Germany, committee 3816 of the VDI Verein Deutscher Ingenieure, (Association of German Engineers), "RLT-Anlagen bei belasteten Außenluftsituationen" (Mechanic ventilation in the case of polluted outdoor air situations) was establiched with the aim of focusing on this subject.

In the case of polluted outdoor air situations, pollutants, as a result of infiltration or ventilation, infiltrate the building interior via mechanical ventilation units or leaks on the building. Time depending concentration of these pollutants in outdoor and indoor air, as a rule, develops quite differently. To avoid health risks, technical measures like filtering, catalytic elimination of pollutants and the like, oper- ational (e.g. switch-off of ventilation units in the of high pollutant concentration in outdoor air; switch-on when the outdoor level has dropped below the indoor level, etc.) and organizational measures (forecasts including preventive measures like emission reduction through vehicle traffic restriction, etc.) must be considered and combined in practical application. A polluted outdoor air situation is present when a ventilation process leads to the intake of pollutants in the interior and to the enrichment of these pollutants to an unacceptably high concentration. The definition of the term "unacceptably high concentration" could be defined, for instance, in accordance with the MAK* values. The measures to recommend will primarily depent on the specitic outdoor air situation, type and quality (leaks) of the building, and the type of mechanical ventilation unit in use.

* maximum allowable concentration at workplaces, recommendations in the Federal Republic of Germany

1. POLLUTED OUTDOOR AIR SITUATIONS

Measures designed to counteract the adverse effects of polluted outdoor air situations via mechanical ventilation units primarily depend on the type of situation. The following four cate- gories are discriminated:

1. Normal case: Regional differences in outdoor air composition have only a minor effect on the outdoor rate required for ventilation
2. Meteorological incidence: Temporary inversion situation causes smog
3. Accidents, e.g. release of chemical substances- during traffic accident
4. Increased emissions limited in the time and region

In view of the subject to cover, categories 2 and 3 are particularly interesting. A smog situation in 1962 in Germany in the federal state of North Rhine-Westphalia causing 156 additional casualties, eventually triggered so-called smog decrees which are valid in several states. These smog decrees include emission-reducing measures but do not provide any information on how to use mechanical ventilation units in such a case. Recently, several such incidents were reported, e.g. the release of toxic gas clouds during the production or transportation of chemical substances as a result of leaks or wrong system handling. This is but one example of a wide spectrum of possible incidents.
Categories 1 and 4 will only play a minor role. Regionally varying carbon dioxide concentrations, for instance, are also measures under normal circumstances. This has only a minor effect on the

outdoor air rate which is needed to maintain carbon dioxide concentration in indoor air below a defined value. Category 4 comprises incidents in which polluted emissions are limited in time and region, e.g. higher traffic volumes in the centre of cities.

Apart from meteorological and geographic constraints, the dispersion mechanisms and interaction between outside environment and interior, the necessary measures depend on the following parameters:

i) related to the incident

   a) duration of effect

   b) time-related development of effects (type and development of effect augmentation and decrease),

   c) area (number of inhabitants) affected by the incident,

   d) type of pollutants,

   e) intensity of effect (e.g. immission in ppm).

ii) related to the object

   a) type and operating mode of the mechanical ventilation unit,

   b) air change (tightness of building, meteorological effect, effect of the mechanical ventilation unit),

   c) type and utilization of the building and behaviour of occupants.

The items indicated under ii), especially a) and b), in conjunction with i) make evident that different types of building must be discriminated to address the problem:

a) residential building

b) office building and work-rooms as specified in Arbeitsstätten-Richtlinien* (ASR),

c) Schools, lecture halls and assembly rooms,

d) hospitals.

Table 1 compares the incident-related parameters which characterize outdoor air situations and influence the measures to take with the principal outdoor air situation categories.

situation	approximate length of time	frequency	progress with time	area involved usually	typical pollutants
meteorological incidence, as smog etc. (cat. 2)	days	seldom, about once or twice a year	concentration level nearly constant (plateau)	greater area, city	definable: SO_2 NO_2, CO, dust, particles
accidents, e.g. release of chemical substances (cat. 3)	hours to days	not predictable	fast changes with time, peaks	in most cases small	different, depending on case
increased emission, e.g. during rush hours (cat. 4)	hours	very often at special places as cities etc.	concentration level nearly constant (plateau)	in most cases small	definable: C_xH_y, NOx etc.

Table 1:
Polluted outdoor air situation and parameters characterizing various pollution cases

* workplace guideline in the Federal Republic of Germany

2. AIR QUALITY, RELATION BETWEEN OUTDOOR AND INDOOR AIR QUALITY

The commonly applied criterion to indoor air quality is still carbon doixide concentration (CO_2). Pettenkofer (1) recommended 0.1 % by volume as the max. allowable limt for indoor air. It is true that we know by now that carbon dioxide is a good indicator of body odours and has therefore been incorporated with some justification in many international standards, but Pettenkofer already advocated 130 years ago that air quality could be described much better using the portions of chemical and, in particular, organic foreign matter. Despite these early findings we still do not have a generally applicable and recognized measure of assessment. At the time of Pettenkofer, no appropriate, or at least no reliable measurement techniques for organic compounds were available. Today, it is rather the multitude of chemical substance determined and, to a large extent, the ignorance of their medium- and long-term effects on human organism which hampers the determination of defined substances and maximum values. Recommendations for the handling of mechanical ventilation units in the case of polluted outdoor air situations can only be reasonably substantiated when desired indoor air situations are clearly defined.

A procedure in line with MIK* values (2), MAK values (3), biologische Arbeitsplatztoleranzwerte** (BTL) or resulting from the Gefahrstoffverordnung*** (4), would be conceivable. These recommended values, however, refer to situations or groups of persons who are not affected at all or only to a minor degree by this subject. As long as terms like "recommended, desired, or acceptable indoor air quality" are not defined the maxim in the case of polluted outdoor air situations must be to maintain pollutant concentration in indoor air distinctly below pollutant concentration in outdoor air. Pollutant concentration, in fact, should be so low that no health hazards are expected for risk groups (e.g. persons suffering from cardiac/circulatory diseases, chronic respiratory diseases, and the like) or sensitive groups (senior persons, babies,etc.)

Infiltration and ventilation always leads to an exchange between outdoor and indoor air. In the case of polluted outdoor air situations, pollutant concentration in indoor air will rise the faster and higher

. the higher pollutant concentration is in outdoor air,

. the higher air change n per hour is as a result of infiltration and/or ventilation, and

. the more effective the mixing is of polluted outdoor air with indoor air ("ventilation efficiency").

* maximum immission concentration

** biological workplace tolerances

*** hazardous material regulationsin the Federal Republic of Germany

A first step towards relief from a polluted situation thus consists in emission reduction, a measure provided e.g. in the so-called smog decrees.

Another step consists in all measures designed to decrease air change between the inside and outside. Such an air change depends on leaks in the building envelope, meteorological constraints like wind speed and temperature difference between inside and outside, operating method of the mechanical ventilation unit and user behaviour. Table 2 shows rough comparative values of the hourly air change n for a few examples.

Case	hourly air change n
"tight" buildings*), average weather conditions	0,1 - 0,3
"untight" building*), average weather cond.	0,4 - 0,8
mechanical ventilation, tight building	0,6 - 0.8
frequent window ventilation	av. 1,2 - 1,5
cross ventilation	1 - 3
window ventilation with wind and temperature difference between inside and outside	2 - 10

*) not including additional window ventilation

Table 2:
Hourly air change with a few selected examples

Depending on the individual constraints, these values may vary heavily.

An approximate value is that, with simple hourly air change, pollutant concentration in indoor air reaches the outdoor air concentration level after approx. 4 to 5 hours, on the assumption that the pollutant had not been present in the indoor air when the air change took place. Given an air change of 0,5 h^{-1} and the same assumption, the value is 8 hours and with an air change of $0,1^{-1}$ it is between 30 and 40 hours.

In practice, conditions, however, are quite different, adsorption and desorption processes play a role, pollutant concentration in indoor air, as a rule, is not zero and certain pollutant sources are also present in a building. As a result, pollutant concentration in indoor air may well rise beyond the outdoor air level (5).

In most cases of polluted outdoor air situations, the pollutant concentration in indoor air will rise as a function of air change with outdoor air (fig. 1). The lower the air change the slower is the rise in indoor air concentration. In the case of smog situations, for instance, concentration in the outdoor air will remain at much the same level throughout several days (t_1 - t_2). At t_3 the recommended concentration limit in indoor air could be exceeded. At t_4 indoor and outdoor concentration is the same. From t_5 onward, outdoor air concentration falls below the recommended limit. Basically, the ventilation effect becomes effective from t_4 onward (improved indoor air through air change), and from t_6 onwart, indoor air once again complies with recquirements.

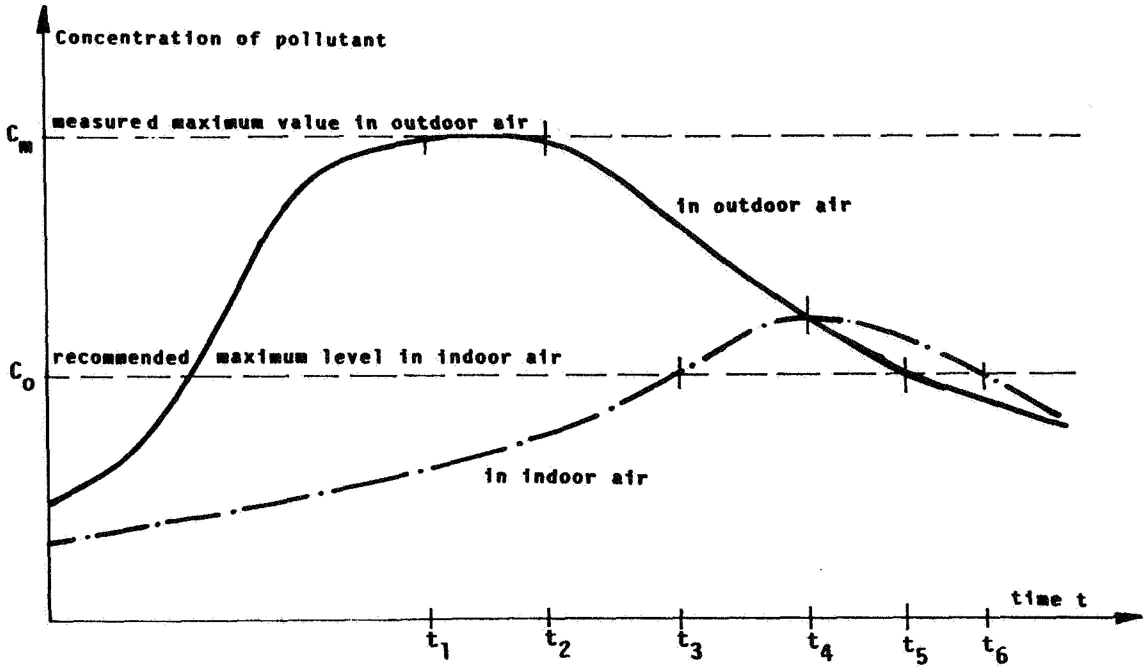

Figure 1:
Diagram of pollutant concentration in indoor and outdoor air with polluted outdoor air situations.

From this diagramm the following principles can be established as countermeasures against polluted outdoor air situation:

1. Upon the occurrence of a polluted outdoor air situation, air change between the inside and outside should be minimized (slow rise of pollutant concentration in indoor air).

2. In the case of a major air change, pollutant concentration in indoor air can be reduced by filtering, catalytic oxidation and the like it appropriate technical facilities are used. Infiltration rate must be minimized.

3. The interval between t_3 and t_6 should be minimized to prevent that the recommended maximum values are exceeded. This interval, if it occurs at all in the case concerned, can be reduced by performing intense ventilation (high air change) only after outdoor air concentration has dropped below the recommended maximum value. It can also be reduced by delaying t_3 as long as possible (see items 1 and 2).

4. The smaller the difference $t_2 - t_1$ and the lower the maximum value C_m of pollutant concentration in outdoor air, the smaller is the probability that pollutant concentration in indoor air will exceed C_o.

3. TECHNICAL MEASURES

Accordingly, recommendations for the design and operation of mechanical ventilation units in the case of polluted outdoor air situations depend on a variety of conditions and parameters (especially section 2). Generalizations are only conditionally admissible even though it would be in line with prevention efforts and aversion of hazards to design and structure clear and unambiguous action catalogues which could be immediately applicable in practice in the case of a polluted air situation. The following statements can be made without anticipation the results of VDI committee 3816 "RTL-Anlagen bei belasteten Außenluftsituationen":

1. In the case of a polluted outdoor air situation, any emissions inside which as immission in the outdoor air contribute to the polluted outdoor air situation, should be avoided or reduced. In smog periods this would mean, amongst others,

that smoking and the operation of open fireplaces like gas stoves and furnaces in rooms should, at least, be reduced. They are CO sources whose contribution to increased CO concentration has been proved (5).

2. In the case of polluted outdoor air situation, air chage between inside and outside should be reduced as far as possible and allowable. This means: switching off mechanical ventilation units, closing the windows, and the like. Such measures are particularly recommended for brief polluted outdoor air situations. The associated rise of CO_2 level, indoor air humidity and other factors above the normally applicable criteria (e.g. Pettenkofer number) must and should be accepted.

3. In the case of extended polluted outdoor air situations, the measures indicated in 2. should be complemented by filtering or other types of separation (e.g. scrubbing of SO_2) or elimination of the pollutants. A descriptive example is the filtering of radioactive aerosols and dust following the Tshernobyl accident which, however, entails the problem of appropriate filter disposal.

   The filters commonly installed in mechanical ventilation units, however, do not retain gase matter. Special filters would have to be provided for gaseous matter. For such measures to be useful, however, it would be necessary for the building envelope to present no leaks and for the supply air to actually run via the additional equipment. Attention must be paid to the fact that the scrubbers used in mechanical ventilation units are not optimized for SO_2 precipitation.

4. In the case of polluted outdoor air situations, the circulated air volume must be stepped up. Minimum requirements posed to indoor air quality must be observed (6).

4. CONCLUDING REMARKS

Time is ripe for researchers and engineers to increasingly direct their efforts, apart from the outdoor environment, to the problems of indoor air quality and indoor air flow. Outdoor environment and interior are correlated via several operation mechanisms so that they can not be studied as separate entities. Various incidents and even accidents in the recent past make it necessary to develop and propose measures which must be taken in the case of polluted outdoor air situations. This paper is designed to provide an overview of the pending problems and the approaches to take. Of cours it is important to avoid anything that may lead to polluted outdoor air situations. The various measures discussed, basically demand continuous outdoor and indoor air measurements in order to implement an optimum strategy. In practical application, however, such an expenditure is only feasible to a limited degree. Simple, clear and effective measures are called for.

The author wishes to acknowledge all participants of the VDI committee 3816 "RLT-Anlagen bei belastenden Außenluftsituationen".

The work has been supported by the Project Management for Biology, Ecology and Energy (PBE) of KFA Juelich GmbH on behalf of the Federal Ministery for Research and Technology (BMFT), Bonn.

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Discussion

Paper 5

O.Nielsen (Ministry of Housing & Building, Denmark) When outdoor pollution is heavy ventilation should be minimised and a higher CO_2 accepted. What limits would you suggest under these conditions?

L. Trepte (Dornier System GmbH, W. Germany) The dominant basis for the German ventilation standards is to limit CO_2 concentration to a maximum of 1000 ppm. MIK and MAK values give higher values (for industrial exposure). In the case of special polluted outdoor situations (e.g. smog) when the risk to people is higher, an acceptance of higher CO_2 levels might be recommended, in accordance with the guidelines mentioned above. Up to now there are no defined recommendations for smog, although an upper limit of 2500 ppm might be acceptable. Lower ventilation rates might also lead to complaints of odour.

W. De Gids (TNO Division of Technology for Society, Holland) Are the indoor concentration levels for chemicals already established in Germany?

L. Trepte (Dornier System GmbH, W. Germany) No, not within the ventilation standards, although there are recommendations for some substances such as formaldehyde: the Federal Health Office has set a limit at 0.1 ppm. For other cases, such as workshops, we have limiting values defined by "maximum allowable concentrations" (MAK-Werte) and "biological workplace tolerances" (BTL-Werte) for exposure to chemicals during the normal working day (typically 8 hours/day). However we do need a definition for "acceptable indoor air quality" (for the office environment).