Energy Impact of Ventilation and Air Infiltration
14th AIVC Conference, Copenhagen, Denmark
21-23 September 1993

Indoor Air Quality Index

D Creuzevault

Gaz De France, DETN, 361 Ave du Président Wilson,
93211 La Plaine Saint-Denis, France

INDOOR AIR QUALITY INDEX

Abstract

Under-estimating the ventilation flow rate results in increased sanitary risks and damage to the existing building structure. Over-estimating ventilation flow leads to energy waste.

In this context, a number of approaches have been designed to determine indoor air quality indicators. The aim of these is to compare comfort and sanitary quality in different atmospheres.

This document presents four air quality indicators developed by three French teams and one Danish team. We examine the strengths and weaknesses of each design, plus their specific areas of use. Lastly we examine the problems common to each approach.

Preserving the health and comfort of housing occupants and office workers is naturally a very important issue, and the public authorities have laid down certain requirements in the area of ventilation.

It is vital that the connection between buildings and personal health be taken into account as thoroughly as possible. Any underestimation of the necessary ventilation flow rate both increases the sickness ratio and damages existing structures. On the other hand, overestimating ventilation needs wastes energy.

In the light of this problem, a number of bodies have developed indoor air quality indicators to compare the effect of differing levels of pollution exposure on comfort and sanitary quality. These can then be used as a basis for different ventilation strategies. The approaches taken can be classified in two groups:

- indicators based essentially on sanitary criteria;

- indicators based essentially on notions of comfort.

1) INDICATORS BASED ON SANITARY CRITERIA

A global risk rating is calculated, based on the different risks run by exposure to each type of pollutant. Zero risk does not exist when a pollutant is present, so a threshold risk is defined as being the acceptable limit. This apparently simple approach in fact comes up against a number of problems:

- the difficulty of measuring actual exposure. The levels of pollutant concentration normally encountered in a working environment that is not subject to any specific type of pollution are naturally low. However, an occupant generally remains in premises for long periods of time. Pollution levels may be uneven spatially and people may move around inside a building and thus be exposed to differing levels of pollution. Reliable information therefore requires miniature, portable measuring devices. Often, such devices do not exist for measuring pollution in the concentrations encountered. Moreover, to be able to characterize the variations in pollution over a period of time, and in particular to identify pollution peaks, passive sampling is insufficient. The actual exposure is therefore difficult to quantify. Measurement devices and methods need to be improved. These constraints directly affect the relevance of the measurements made.

-the difficulty of evaluating sanitary risk. There are few reliable data concerning the risks run by extended exposure to a given pollutant in low concentrations. We note that:

*it is impossible (for reasons of cost, space, technology, etc.) to measure pollution in a sufficient number of premises to establish significant relations between pollution and sickness;

*sensitivity to a pollutant varies from person to person (the limit values of the risk must therefore take into account the requirements of subacute sectors of the population, e.g. asthma sufferers);

*there are a large number of components present in enclosed premises and potentially at risk. It is therefore impossible to carry out a detailed study for each pollutant;

*the relative risk is very low and therefore difficult to evaluate. Moreover, each illness results from the combination of a number of different factors, formation mechanisms and a sometimes long period of latency. Even for illnesses about which much is known, such as cancer, it is not always possible to precisely quantify the various formation risks. Current knowledge is basically qualitative in nature;

*for two equivalent exposures representing the same levels of pollutant inhaled, the effects will vary depending on the development of the concentration curve in time. Thus one hour's exposure to a pollutant in a concentration of 240 ppm will not have the same effect as 24-hours' exposure to 10 ppm of the same pollutant. Exposure limits cannot therefore be expressed using a concentration value for a given moment, but instead should use an average level that must not be exceeded over a given period, or a maximum value for a given time percentile. Unfortunately, for most pollutants with the exception of carbon monoxide, we only have a very limited amount of data for threshold-exposure levels as a function of time.

The difficulty of setting a recommended limit value is illustrated by the fact that the different authors' recommendations for dioxin vary by a ratio of 1,000 (these deviations result largely from the different perceptions of what is "acceptable risk"). Another example is the doubling, from 1982 to 1983, of the WHO's recommended limit value for 24 hours' exposure to CO_2.

-the difficulty of assessing any possible effects of synergy and neutralization between pollutants. To date, very few studies have been carried out into the effects of pollutant synergy or neutralization on human beings. In some cases, the effect of combining two pollutants is much greater than the simple sum of their effects. This is the case for NO_2 and CO_2, for example. Similarly, the varying degree with which the combination of NO_2, water steam and nitric acid (HONO) was taken into account by laboratories studying the effects of NO_2 on health probably lies at the root of their contradictory conclusions. To take account of this synergy for certain cases, limit values are proposed according to the combination of two pollutants.

Moreover, the simultaneous presence of a number of pollutants implies the permanent interaction of co-factors. To use a radio metaphor, this interaction generates a kind of background noise that could be large enough to block out the signal being studied. Recent progress in logistic regression and multivariable analysis enables only a partial correction of the influence of these co-factors. Extreme caution should be exercised before any causal link is definitively identified. Even when a significant relationship has been established between the concentration of a given pollutant and a sanitary risk, it is not, however, possible to conclude that sickness will directly result from the pollutant studied. A number of epidemiological studies have had their conclusions invalidated due to their failure to take this problem fully into account.

Faced with these difficulties, the various specialists attempting to quantify air quality have developed two types of air quality indicators.

-the multigas indicator using the air bacteria count.

-the multigas indicator using the notion of exposure time;

A) Multigas indicator using the exposure time

This indicator, initially defined in the context of an agreement between the French national building federation (FNB) and Gaz de France (GDF), has since been improved with the collaboration of Electricit_ de France (EDF) and the French building and public works experimental centre (CEBTP). It is based on comparing exposure time and limit values.

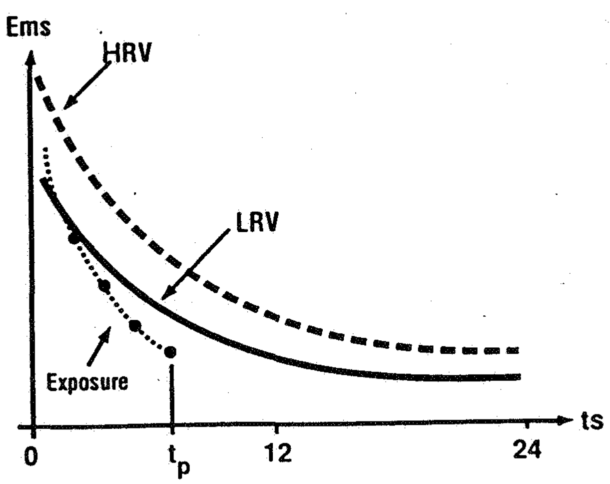
The cumulative exposure to each pollutant is defined for each occupant. This is done using all exposures at given moments for a period corresponding to the time spent in a specific room.

Existing documented methods (legislation and guidelines) use two types of limit concentration values for a given period:

-high-risk value (HRV), above which there is a proven risk to an individual's health which could lead to irreversible physical damage;

-and a limited risk value (LRV), below which exposure to the toxin has only limited effects or no known effects on a person's health.

From these values we can extrapolate a limit threshold curve as a function of time:



The indoor air quality indicator IAQ is calculated using the HRVs and LRVs for a function defined in two parts. For a pollutant p, a period t and premises i, we thus obtain:

If the integrated exposure =< LRV,
IAQ (p,t,i) = (integrated exposure - LRV) / LRV

If the integrated exposure >= LRV,
IAQ (p,t,i) = (integrated exposure - LRV) / (HRV - LRV)

IAQ = max IAQ (p,t,i)

If IAQ = -1, pollution concentration is zero
If IAQ =< 0, the indicator lets us compare levels of comfort
If IAQ = 0, the risk in the premises studied is insignificant
If 0 < IAQ < 1, the sanitary risk is limited
If IAQ >= 1, the risk in the premises is unacceptable

This kind of indicator is well suited to finding an optimal solution by simulation (for ventilation and air source). The risk caused by humidity is taken into account in the calculation of the number of hours of annual precipitation.

The main limitations of this indicator are:

- risk is not identified for aerosols and bacteria;
- the indicator relies on poorly-defined limit thresholds;
- synergy effects are not taken into account;
- it is necessary to induce levels for a number of pollutants during on-site tests (instrumentation difficulties);
- rigorous calculation leads to an infinite number of exposure calculations (over variable periods with a variable time origin). A simplification factor is therefore generally introduced (calculations for periods of 1 to 24 hours only).

B) Multigas indicator using the air bacteria count

This indicator (QI) was developed by the Paris hygiene laboratory (LHVP). It is the result of over 20 years experience of analysing air quality in different types of premises. Indoor air quality is evaluated using the following three markers:

- carbon monoxide (CO). The selected threshold value is 5 ppm. This value was used because it is the threshold for the perception of tobacco smoke;

- carbon dioxide (CO_2). The selected threshold value is 1,000 ppm. This is the room confinement threshold;

- the total bacteria count (TBC). The selected threshold value is 1,000 parts which represents a colony per cubic metre. This corresponds to a 95 percentile of the results obtained for outdoor air. The bacteriological sampling carried out aims to detect staphylococci (mucus and skin); streptococci (digestive tract) and enterobacteria (digestive tract, recent contamination).

The values used could be altered to take into account the specific requirements of the site being studied.

QI = CO / 5 + CO2 / 1,000 + TBC / 1,000

An air quality indicator less than 3 indicates that the mechanisms for extracting pollution from the room are functioning correctly and are well-suited to the type of pollution source. On the other hand, a quality indicator greater than 3 shows that the air quality in the room should be improved and that the systems for extracting pollution need to be re-examined.

This approach takes into account the relative importance of the main factors of pollution resulting from the human metabolism and human activity plus animal and vegetable pollution. The fact that precipitation is not taken into account is compensated by the bacterial parameter.

This indicator has since been put into operation by a number of major French companies including the Paris metro (RATP).

This type of indicator requiring on-site measurements is well suited to the absolute characterization of a specific atmosphere.

The main limitations of this indicator are:

* the fact that it takes into account a only limited number of pollutants. To ensure the indicator remains valid, its use is strictly reserved for premises where there is normally no particular pollution;

* it does not take into account the duration of exposure. A number of measurements taken for a given moment (notably for bacteria) can be used, however, to refine the analysis by bringing in some element of time;

* a non-standard method is used to sample bacteria levels;

* it impossible to model a type of atmosphere.

It should be noted that a combined sanitary-comfort approach has been developed by the Scandinavian federation of climatic engineering associations (SCANVAC).

2) INDICATORS BASED ON COMFORT CRITERIA

For these approaches, air quality is based on olfactory perception.

A) Single marker indicator

This indicator is the simplest of all. It is based on the assumption that a concentration of a given pollutant indicates the level of risk generated by all indoor pollution. In general, in the residential and tertiary sectors, two pollutants are taken as the pollution trace: carbon dioxide or relative humidity. Ventilation systems regulated by changes in one of these two pollutants are already on the market.

This is the type of approach used by the French national building scientific and technical centre (CSTB) in its comparative studies modelling ventilation systems (notably, humidity regulation).

Where water vapour is concerned, only the risks of condensation (leading to structural damage) are taken into account. A distinction is made between the total condensation time and condensation times greater than 30 minutes.

ded over a given period, or a maximum value for a given time concentration is related to the discomfort linked with body odour. It therefore falls into the category of the perceived quality of indoor air rather than any sanitary quality of this air. The limit values used (1,300 ppm and 2,500 ppm) are well below harmful concentration levels.

This approach is quite well suited to comparative studies of two ventilation systems.

In return for its simplicity, this approach has a number of limitations:

* the relative importance that has to be accorded to the risk related to hygrometry compared with that related to the CO_2 concentration cannot be quantified;

* exposure to various other pollutants is not taken into account;

* insufficient account is taken of the effect of concentrations varying in time. The indicator is soon to be modified to partially overcome this problem.

With this indicator, therefore, it is difficult to characterize a specific type of atmosphere to any absolute degree.

B) Olf and Decipol

This is a sensory approach developed by Professor Fanger (Denmark) in association with professor Bluyssen. It is based solely on the smell nuisance to the operator in certain configurations. The resulting indicator is an evaluation of passive air quality.

A unit termed the olf has been introduced to quantify the intensity of a pollution source. One olf is the level of air pollution produced by the average adult working in the tertiary sector, seated and in a stable temperature and with a hygiene level equivalent to 0.7 baths a day. All odours can be quantified in relation to this reference level. Current olf values for main polluting sources (occupants, smokers, materials, etc.) are listed in tables.

A similar unit, termed the decipol, quantifies perceived air pollution. One decipol is the perceived air pollution in a space having a polluting source of one olf, ventilated by a 10 l/s flow of non-polluted air in stable conditions and in a uniform mixture (ventilation efficiency of 1). This gives us: 1 decipol = 0.1 olf/s.

A curve drawn using a panel of 168 judges in the presence of the bioeffluent of 1,000 subjects shows how air is perceived as a function of ventilation in a given room. It traces the percentage of dissatisfied judges, i.e. the percentage judging the air to be unacceptable just after having entered the room. From these data the curve was drawn for the percentage of dissatisfied judges on the panel as a function of the decipol number.

Based on the proportion of dissatisfied judges for the given room and the intensity of the different smells, we can then deduce the flow rate of air required to dilute this pollution.

These units can also be used to qualify outdoor air.

This approach to premises where people are the main source of pollution (much of the tertiary sector) is mirrored in the ventilation standards expressed as an air flow rate per occupant. It is used in EC recommendations on ventilation requirements for buildings (the COST 613 project entitled "indoor air quality and impact on individuals"), and in European Commission work in standardization, CEN/TC 156 (standard proposal). The advantage of this approach is that it brings a concrete solution and meets one of the main requirements expressed by occupants.

This approach is particularly well suited to studying premises where pollutant concentrations are too low to be measured by ordinary chemical analyses. Moreover, it makes it possible to select materials or equipment that emit low olf levels and assists in resolving the problem of so-called sick buildings.

This approach is the only one to date that has received a consensus of agreement by several countries for the specification and design of ventilation installations using air quality criteria.

The main limits of this concept are:

- it only slightly takes into account the health risks of pollution. Human sensory perception plays an important role in warning us of environmental dangers, but some types of pollution are odourless. Measurements taken in existing buildings have shown that CO_2 and particle concentrations are imperfectly correlated with olf measurements. However, it is also true that when the air quality is perceived as being "poor", there is also an increased risk of toxicity. By increasing ventilation flow rates to dilute odours, sanitary risks are also reduced;

- the intensity of all pollution sources is not always known. In this case it is necessary to call on a panel of experimenters to define the rate of dissatisfaction in the reference conditions;

- it is difficult to simulate conditions. This is a relatively recent concept and the models so far developed have only partially been validated.