

Recommendations for air quality standards for nitrogen dioxide and ozone

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LINDVALL T. Recommendations for air quality standards for nitrogen dioxide and ozone. *Scand J Work Environ Health* 11 (1985): suppl 3, 3–9. The acute health effects of nitrogen dioxide and ozone critical to the general population are summarized. For long-term exposures to the former in the outdoor environment a six-month average limit value of 80 $\mu\text{g}/\text{m}^3$ is recommended for the wintertime. When “new” residential areas are planned or when the limit value is used as an air quality standard for the nonindustrial indoor environment, the adequate six-months’ average limit value for the winter would be 50 $\mu\text{g}/\text{m}^3$. For short-term exposures to nitrogen dioxide outdoors a limit value of 320 $\mu\text{g}/\text{m}^3$ (1-h average) is recommended, not to be exceeded more than 12 h per year, each time during a maximum of 2 h. This value should apply only to “old” residential areas in which nitrogen dioxide pollution cannot be reduced without large economical and practical consequences. The value 190 $\mu\text{g}/\text{m}^3$ (1-h average), not to be exceeded more than 12 h per year, should apply to most residential areas, to recreational areas, and to all nonindustrial indoor environments. For short-term exposures to photochemical oxidants, as represented by ozone in nonindustrial outdoor environments, the acceptable short-term limit value should be 120 $\mu\text{g}/\text{m}^3$ (1-h average), not to be exceeded more than 12 h per year. An additional 1-h outdoor ceiling value of 200 $\mu\text{g}/\text{m}^3$ is recommended, not to be exceeded. For the nonindustrial indoor environment a 1-h ceiling value of 100 $\mu\text{g}/\text{m}^3$ is recommended, not to be exceeded.

Key terms: acute health effects, combined effects, health criteria document, limit values, outdoor-indoor exposure relationships, public health, pulmonary function effects, sensitive groups, sensory effects.

Nitrogen dioxide

Health criteria summary

The focus is on nitrogen dioxide (NO_2) because this gas is the most toxic of the oxides of nitrogen present in the ambient atmosphere. As nitrogen dioxide is considerably less soluble in water than, eg, sulfur dioxide is, it more easily penetrates deep into the air passages. The biochemical changes to which nitrogen dioxide gives rise when present at high concentrations are mainly due to its oxidizing properties. The first structures to be affected are the mucous membranes of the respiratory tract and the lung tissues. Other organs may be affected by nitrogen dioxide reaching them from the lungs via the blood.

Studies of the effects of short-term exposure of animals to nitrogen dioxide have mainly been concerned with fairly high levels of the gas. Long-term exposure has resulted in the development of tissue alterations at concentrations down to 600 $\mu\text{g}/\text{m}^3$. As regards pulmonary function, long-term exposure has been found to increase the respiratory rate at the nitrogen dioxide level of 1 500 $\mu\text{g}/\text{m}^3$ (18). The defense of the lung against bacterial infections has possibly been impaired by long-term exposure to 940 $\mu\text{g}/\text{m}^3$ (9, 26).

The relationship between the nitrogen dioxide concentration and the effects on airway resistance is dif-

ficult to interpret because the results themselves are uncertain and the importance of the effects are difficult to assess. There is reason to suspect that short-term exposure (20 min — 1 h) at concentrations below 1 000 $\mu\text{g}/\text{m}^3$ might slightly affect airway resistance or bronchial reactivity in sensitive individuals, perhaps at levels as low as 200–500 $\mu\text{g}/\text{m}^3$ (4, 44), but some studies have not demonstrated any change in airway resistance below concentrations of about 4 700 $\mu\text{g}/\text{m}^3$ for healthy subjects (2) and 3 000 $\mu\text{g}/\text{m}^3$ for asthmatics (40, 41). Subjective complaints have been noted at 1 800 $\mu\text{g}/\text{m}^3$ in healthy subjects and at 900 $\mu\text{g}/\text{m}^3$ in asthmatics (22, 31). It is conceivable that different effect mechanisms in the airways are involved at different nitrogen dioxide concentrations (4). It should be noted that one recent study indicates an increase in airway resistance in healthy persons after 2 h of exposure to nitrogen monoxide (NO) at about 1 200 $\mu\text{g}/\text{m}^3$ and during light exercise (28). This concentration is not unusual in urban areas.

The relatively few epidemiologic studies that have been performed have yielded uncertain results (29, 45, 47, 48). The observed effects can have been caused by pollutants other than nitrogen dioxide. The results of one study suggest that air pollutants, including nitrogen dioxide, at levels near or below the standards adopted by the United States, may be associated with an elevated incidence of acute respiratory symptoms among schoolchildren (39). However the results are inconclusive, and the role of nitrogen dioxide in this context is unclear.

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A number of the epidemiologic investigations performed on children in homes using gas as a fuel in the United States and the United Kingdom suggest that there may be a relationship between the nitrogen dioxide concentration and the occurrence of respiratory diseases (23, 36, 37, 49). The contradictory nature of the results yielded by other studies (15, 30, 50, 55) might be ascribed in some measure to differences in the design and the selection of the subjects, but further investigations are required before reliable inferences can be drawn from these studies concerning any effect of nitrogen dioxide on health.

Risk evaluation

Because the epidemiologic data are incomplete, any evaluations of the risks associated with nitrogen dioxide must, to a large extent, be based on the results of experimental work. According to an assessment by a task group of the World Health Organization (WHO) (57) adverse effects of this gas, such as an increase in the susceptibility to respiratory tract infections, are evident after exposure to about 1 000 $\mu\text{g}/\text{m}^3$.

After going through the more recent literature, I have reached the same conclusions as the WHO Task Group (57). Experiments performed on animals indicate that adverse effects such as increased susceptibility to infections may arise during long-term exposures of about 1 000 $\mu\text{g}/\text{m}^3$ (9, 26) although a recent study has questioned these results (35). The bronchial reactivity of asthmatics also seems to be increased by short-term exposure at about this concentration (4). One vital question is what evaluation should be made concerning the study on asthmatics by Orehek et al (43), who re-

ported that nitrogen dioxide at about 200 $\mu\text{g}/\text{m}^3$ caused increased bronchial reactivity. In an attempt to repeat this study, others could not confirm the results (24). Thus the Orehek data still must be regarded as inconclusive.

The early epidemiologic studies of the effects of nitrogen dioxide are judged to be uncertain. But the few studies that have been conducted on the effect exerted by this gas in the outdoor atmosphere since the 1977 WHO survey are also judged to be uncertain, at least concerning the extent to which nitrogen dioxide is responsible for the reported effects.

The WHO Task Group (57) considered that it is indefensible to wait for the presentation of conclusive epidemiologic data and that the available toxicologic and experimental findings in animals and man must be exploited in an effort to derive reasonable guidelines for acceptable exposure levels for nitrogen dioxide. Because of the high biological reactivity of nitrogen dioxide the Group considered that a large safety margin (3–5) must be applied to the levels where effects have been observed (940 $\mu\text{g}/\text{m}^3$). Support for this cautious attitude is furnished also by some recent studies.

A long-term limit value for nitrogen dioxide of 100 $\mu\text{g}/\text{m}^3$ as an annual average of 24-h values has been found reasonable by Morrow (38) and Ferris (12, 13). It is now the primary air quality standard in the United States (US), and it has been proposed to maintain the standard at that level (54). On the basis of the same information, however, Switzerland has adopted an annual average limit value of 50 $\mu\text{g}/\mu\text{g}$, and the Council of the European Communities has adopted the same value as a guide value (50 percentile) (6). See table 1.

There is no conclusive evidence in the recent literature that would oppose the US long-term limit value for ambient air as long as nitrogen dioxide is considered alone. However, a study by Mostardi et al (39) indicates that nitrogen dioxide concentrations of around 50 $\mu\text{g}/\text{m}^3$ as the annual mean, in a specific combination with other air pollutants, may be associated with the incidence of acute respiratory illnesses. Their results need confirmation by other studies before a safe conclusion can be drawn.

Another important question, in view of the findings in homes using gas for cooking, is whether or not modern building technology, energy conservation measures, and the use of alternative energy sources for heating and cooking require a limitation in permissible annual nitrogen dioxide values below 100 $\mu\text{g}/\text{m}^3$. It should be noted that, in American homes using gas for cooking, the annual average levels of nitrogen dioxide range between 40 and 115 $\mu\text{g}/\text{m}^3$. It is true that neither du V Florey et al (15) nor Speizer et al (50) could demonstrate any relationship between lung function test results of schoolchildren and nitrogen dioxide levels in the children's homes. But in the du V Florey study the prevalence of respiratory illness was as-

Table 1. Air quality standards for nitrogen dioxide. (1 $\mu\text{g}/\text{m}^3$ = 0.53 ppb)

Country or organization	Concentration ($\mu\text{g}/\text{m}^3$)	Restriction on exceeding stated level
World Health Organization One hour	190–320	To be exceeded not more than once per month
United States One year	100	Arithmetic mean of 24-h values
Japan Twenty-four hours	80–120	Interval for maximum level
Federal Republic of Germany Thirty minutes One year	300 80	98 percentile Arithmetic mean of half-hourly values
European Commission One year One hour One hour	50 200 135	50 percentile guide value 98 percentile limit value 98 percentile guide value
Switzerland One year	50	Arithmetic mean

Table 2. Frequency distribution of nitrogen dioxide concentrations in urban Sweden (1-h averages) in relative magnitudes and applied to the limit range (190–320 $\mu\text{g}/\text{m}^3$, not to be exceeded more than once per month) of the World Health Organization (WHO) (57).

	Percentile						
	50	70	90	95	99	99.9	99.99
Relative magnitude	1	1.5	2.4	3.3	4	5.7	approx 7
WHO, lower limit	33	50	80	110	133	190	approx 230
WHO, upper limit	58	83	134	186	224	320	approx 410

sociated with the nitrogen dioxide levels in the bedrooms of the gas-cooking homes.

In a German hearing on the health effects of nitrogen dioxide (53) HW Schlipkötter pointed out that the animal studies showing adverse effects of nitrogen dioxide at exposure levels ranging from 300 to 900 $\mu\text{g}/\text{m}^3$ have three limitations. These studies were all based on (i) only a few months of exposure at the most, (ii) continuous and constant exposures with no peaks, and (iii) single nitrogen dioxide exposure with no other pollutant present. Since the German limit values are used on a full-year basis, Schlipkötter, to compensate for the fact that low levels in summer permit excessively higher values in winter, suggested an annual average limit value of 50 $\mu\text{g}/\text{m}^3$, or not higher than 80 $\mu\text{g}/\text{m}^3$. The Federal Republic of Germany has now adopted 80 $\mu\text{g}/\text{m}^3$ as the annual average limit value for ambient nitrogen dioxide (56).

After the German hearing some laboratory studies (41) and some epidemiologic studies (14, 23, 39) have given some support to the earlier reports of possible adverse effects on humans in the low-level range of exposure. Generally speaking, one might argue that the reasons for lowering the existing annual average limit value for nitrogen dioxide in the United States to below 100 $\mu\text{g}/\text{m}^3$ are not very strong. On the other hand one might argue as well that for the Scandinavian countries the reasons are strong enough not to accept the US standard. In Sweden nitrogen dioxide pollution is presently lower than in the United States, and a lower limit value (and larger safety margin) can be set without undue costs. An extra safety factor is justified, especially if the standard is to be used as a limit value for indoor pollution. The outdoor-indoor relationships for nitrogen dioxide are still unclear, and adverse effects suggested by some epidemiologic studies refer to nitrogen dioxide concentrations measured outdoors while the exposed populations spend most of their time indoors. Schlipkötter's argument for special protection against excessive exposures during winter have a bearing on Scandinavian conditions too.

Concerning the short-term limit value of nitrogen dioxide, it has been noticed that very few controlled studies have been published recently to reconfirm the earlier reports of sensory effects, as well as of bronchial reactivity in asthmatics at short-term levels of 200 $\mu\text{g}/\text{m}^3$ or lower. Taken together, the results of the different studies must be judged as inconclusive. The health significance of the sensory effects shown in the

same range is not large as long as these effects have not been shown to be related to other, more obvious adverse effects. In spite of these objections the low-level study results together form an argument for a considerable safety factor being applied to the less disputable minimum effect level of around 1 000 $\mu\text{g}/\text{m}^3$. There seems to be no reason to set a higher 1-h limit than the suggested range given by the WHO Task Group (190–320 $\mu\text{g}/\text{m}^3$) (57).

Some of the epidemiologic studies conducted in homes using gas for cooking have indicated possible respiratory effects that may be related to any of the short-term concentration levels of nitrogen dioxide between 80 and 1 000 $\mu\text{g}/\text{m}^3$ (1- to 2-h values), which are said to be typical for gas-using American homes. These data, although still inconclusive, support the opinion of the WHO Task Group that adverse effects are likely to occur during short-term exposures to nitrogen dioxide of at least around 1 000 $\mu\text{g}/\text{m}^3$. Furthermore, the recommendation by the WHO Task Group to use a considerable safety factor seems highly justified as long as the level at which observable respiratory effects may occur in the range of 80–1 000 $\mu\text{g}/\text{m}^3$ is not known.

It would seem that, on the basis of current knowledge on the acute health effects of nitrogen dioxide, the minimum adverse effect level for short-term exposure to nitrogen dioxide should be 900 $\mu\text{g}/\text{m}^3$, for sensitive persons it should possibly be even lower. A large safety factor should be added to this value to protect public health.

In spite of the seemingly different approaches used by different scientists, the short-term limit values suggested by the WHO Task Group (57) and by Ferris (12, 13) fairly well agree. The suggested limits all describe about the same permissible frequency distribution of nitrogen dioxide concentrations (WHO: 190–320 $\mu\text{g}/\text{m}^3$ not to be exceeded more than once per month; Ferris: 480 $\mu\text{g}/\text{m}^3$ not to be exceeded more than two to three times per year, 750 $\mu\text{g}/\text{m}^3$ not to be exceeded).

From 1-h measurements of nitrogen dioxide in Swedish towns, the frequency distribution of concentrations shown in table 2 would hold by and large (personal communication from Dr CE Boström, National Environment Protection Board, Stockholm).

The figures in table 2 are crude and may vary by 10–30 %. On the assumption that the nitrogen dioxide concentrations in the ambient air are log-

normally distributed, the 70 percentile will roughly correspond to the arithmetic mean. However, a log-normal distribution is not always the case, and the arithmetic mean may sometimes correspond better to the 50 percentile. With these uncertainties taken into account, the application of the WHO limit range (190–320 $\mu\text{g}/\text{m}^3$, not to be exceeded more than once per month) to Swedish pollution patterns would roughly correspond to arithmetic mean concentrations of nitrogen dioxide of 50 and 80 $\mu\text{g}/\text{m}^3$, respectively (based on 1-h values).

Recommendations for air quality standards

For long-term exposures to nitrogen dioxide in non-industrial environments the following limit values are recommended:

1. For the outdoor air a six-month average limit value of considerably less than 100 $\mu\text{g}/\text{m}^3$ for winter should be strived for. The adequate level would be 80 $\mu\text{g}/\text{m}^3$.
2. An extra safety factor should be included when "new" residential areas are being planned or when the limit value is used as an air quality standard for the nonindustrial indoor environment. The adequate six-month average limit value for winter would be 50 $\mu\text{g}/\text{m}^3$.

For short-term exposures to nitrogen dioxide in non-industrial environments the following limit values are recommended:

1. 320 $\mu\text{g}/\text{m}^3$ (1-h average), not to be exceeded more than 12 h per year. In addition this value should never be exceeded more than 2 h in succession. This value should apply only outdoors and then only to "old" residential areas in which nitrogen dioxide pollution cannot be reduced without large economical and practical consequences.
2. 190 $\mu\text{g}/\text{m}^3$ (1-h average), not to be exceeded more than 12 h per year. This value should apply to most prevalent residential areas, to "new" residential areas, to recreational areas, and to all nonindustrial indoor environments.

Ozone

Health criteria summary

Since ozone is less water-soluble than, eg, sulfur dioxide or nitrogen dioxide, most of it penetrates to the lung alveoli. Ozone is a still more powerful oxidizing agent than nitrogen dioxide and reacts strongly with tissues.

In studies performed on laboratory animals, exposure to ozone at concentrations down to 400 $\mu\text{g}/\text{m}^3$ has affected the lung tissue and pulmonary function (1, 51, 52). Increased susceptibility to infections has been induced by short-term exposure at levels as low as 160 $\mu\text{g}/\text{m}^3$ (5, 19).

In experimental studies with man, increased airway resistance has been recorded in resting healthy subjects down to a concentration of 1 200 $\mu\text{g}/\text{m}^3$ (20, 59) and during physical exercise at 200–500 $\mu\text{g}/\text{m}^3$ (7, 28, 33, 42, 46). Repeated exposure would seem to result in the development of tolerance (11, 16). The sensitivity to low concentrations of ozone appears to display a wide intersubject variability (10). Neither a history of disease nor the results of clinical examinations provide an adequate basis for predicting the sensitivity for exposure to ozone (or to other oxidants). When asthmatic patients were exposed to ozone at 400 $\mu\text{g}/\text{m}^3$ during short-term exposure, exercise, and heat stress, no effects on pulmonary function were observed (32). However, when the same research group studied heavily exercising subjects during short-term exposure to oxidant-polluted air, increased effects on forced expiration appeared above 240 $\mu\text{g}/\text{m}^3$ in comparison to levels below that value (33). Boushey et al (3) found that ozone caused increased bronchial reactivity in healthy subjects between 400–800 $\mu\text{g}/\text{m}^3$. Also the well-known phenomenon of adaptation to repeated exposures of ozone was less pronounced in more sensitive persons (27).

The adverse effects observed (33, 34) in controlled exposures to ambient oxidant pollution at ozone levels above 200–240 $\mu\text{g}/\text{m}^3$ support earlier Japanese epidemiologic data. As was reviewed by a WHO task group (58), eg, respiratory irritation among Japanese schoolchildren was observed when short-term photochemical oxidant levels exceeded ozone levels of 200–400 $\mu\text{g}/\text{m}^3$. Kagawa & Toyama (29) reported a correlation between airway resistance in schoolchildren and oxidant concentrations at ozone levels below 560 $\mu\text{g}/\text{m}^3$.

Notwithstanding the incomplete nature of the epidemiologic data, it would appear that ozone at concentrations of 200–400 $\mu\text{g}/\text{m}^3$ can produce irritation of the eyes and the respiratory tract in healthy subjects and impairment of lung function in patients with chronic respiratory diseases.

Risk evaluation

A WHO task group summarized the effects of photochemical oxidants on health as follows (58). The pulmonary function in healthy subjects is affected after short-term exposure to ozone at levels of 700–800 $\mu\text{g}/\text{m}^3$ and perhaps down to 200 $\mu\text{g}/\text{m}^3$. Population studies suggest that short-term exposures to concentrations ranging from 200 to 500 $\mu\text{g}/\text{m}^3$ can impair a child's pulmonary function, increase the frequency of asthma and eye irritation, and lower athletic performance. Exposure to levels ranging from 400 to 1 480 $\mu\text{g}/\text{m}^3$ for short periods can produce further stress in patients with chronic respiratory diseases. The results obtained in man are supported by those of animal experiments, although some adverse effects of ozone at a concentration of 200 $\mu\text{g}/\text{m}^3$ or less have been ob-

served only in animals. The extent to which ozone and other oxidants are responsible for the development of cancer remains to be investigated.

Some air quality standards for photochemical oxidants, as represented by ozone, are presented in table 3.

As pointed out by Ferris (12) many of the early studies on the health effects of oxidants may be biased due to errors in the chemical measurements. However, the more recent studies support much of the earlier results in that health effects are observed in the same low-level range as sometimes observed earlier. During recent years airway resistance has been shown to increase during exercise after short-term exposure at concentrations around 200–500 $\mu\text{g}/\text{m}^3$ (7, 33, 42, 46). At 600 $\mu\text{g}/\text{m}^3$ symptoms of discomfort and impaired performance in spirometric tests have been observed (8), and at 740 $\mu\text{g}/\text{m}^3$ airway resistance has been found to increase (17, 21, 25).

The studies which have been published since 1977–1978 do not contradict the conclusions made by the WHO Task Group (58). In fact some of the human studies give extra support to the impression that adverse effects may occur already at ozone levels of 200–400 $\mu\text{g}/\text{m}^3$ during short-term exposure. It has been shown that pulmonary adaptation to ozone takes place at low as well as high concentration levels but that the development of tolerance is less in sensitive subjects.

One dilemma is that there are only small differences between the natural background levels of ozone and the concentrations at which adverse effects on health can occur. Another dilemma, which applies particularly to Scandinavia, is the fact that a considerable proportion of oxidant pollutants originate in other countries and that, even in some rural areas, episodes of comparatively high oxidant levels are not uncommon.

In conclusion, it would seem that, on the basis of current knowledge on the acute health effects of photochemical oxidants, the minimum adverse effect level for short-term exposure to photochemical oxidants, as represented by ozone, should be 200 $\mu\text{g}/\text{m}^3$. A safety factor should be added to this value to protect public health. Since the sometimes relatively high background levels of ozone preclude the use of a sufficiently large safety factor, the air quality standard should include not only a limit value at a defined percentile, but also a ceiling value not to be exceeded.

Recommendations for air quality standards

For short-term exposures to photochemical oxidants, as represented by ozone, in nonindustrial environments the following limit values are recommended:

1. 120 $\mu\text{g}/\text{m}^3$ (1-h average), not to be exceeded more than 12 h per year. This value should apply only outdoors.

Table 3. Air quality standards for photochemical oxidants as represented by ozone. (1 $\mu\text{g}/\text{m}^3$ = 0.50 ppb)

	Concentration ($\mu\text{g}/\text{m}^3$)	Restriction on exceeding stated level
World Health Organization (1 h)	120	Maximum permitted level
United States (1 h)	240	Not to be exceeded more than once per year
Japan	160	Maximum permitted level

2. Since the safety factor for proved adverse effects inherent in the limit value mentioned is small, an additional 1-h outdoor ceiling limit value of 200 $\mu\text{g}/\text{m}^3$ is recommended. This value should not be exceeded.

3. For nonindustrial indoor environments a 1-h ceiling limit value of 100 $\mu\text{g}/\text{m}^3$ is recommended, not to be exceeded.

No limit value is recommended for long-term exposures to ozone.

Acknowledgments

This work was supported by the Swedish Environment Protection Board and the Swedish Council for Building Research.

The author is solely responsible for the conclusions in the report. Valuable comments have kindly been given by Dr B Berglund, Dr U Berglund, Mr CE Boström, Dr G Bylin, Dr B Ferris, Jr, Dr C du V Florey, Mr P Grennfelt, Dr S Horvath, Dr R Letz, Dr D McKee, Dr G von Nieding, Dr G Pershagen, Dr M Piscator, Mr T Rehn, Dr H Richmond, Dr F Speizer, Dr J Spengler, and Dr HM Wagner.

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