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To the Minister of Health, Welfare and Sport and the Inspector-General of the Netherlands Food and Consumer Product Safety Authority

Advice from the Director of the Office for Risk Assessment & Research

The health risks of ozone emissions from air purifiers

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Background

In 2022, the Enforcement Directorate of the Netherlands Food and Consumer Product Safety Authority (NVWA) received a question from a consumer about the safety of an air purifier based on ozone; the purifier specified an ozone emission of 25 mg per thirty minutes. Due to the absence of a legal standard for ozone emissions from consumer products, the Enforcement Directorate submitted the following questions to the Office for Risk Assessment & Research (BuRO) of the NVWA:

- What is the health risk of consumer products that generate ozone?
- What is the maximum acceptable emission of ozone from consumer products so that this standard can be used for supervision and enforcement? In supplying your answer, take into account the variation in the spaces in which the product is used.

Approach

In response to the questions from the Enforcement Directorate, BuRO asked the RIVM/WFSR Front Office Food and Product Safety (FO) to perform an assessment of the health risks from ozone emission. The focus of this assessment was placed on air purifiers, because these products were the subject of the original question from the consumer. However, the conclusions apply more generally to all consumer products that emit ozone. FO performed a literature study into the health effects of ozone and the health-based guidance value in the event of exposure through inhalation. Also investigated was the status as ozone as a biocide. In addition, FO was asked to perform an online market survey into air purifiers that emit ozone, and on the basis of the ozone emission notified by the manufacturer, to perform a calculation of the expected ozone concentration in the air. Finally, FO was asked to calculate the maximum permitted ozone emission that results in no health risk.

BuRO also performed a literature study into air purifiers based on ozone and into the dose-effect relationship of ozone (see appendix 1 for the search strategy). BuRO also searched for Safety Gate notifications.

The substantiation describes how the advice was arrived at. Comments were added to a draft version of the advice by an external expert.

Scope

There are two types of ozone-based air purifiers on the market:

- Air purifiers that generate and emit ozone *in situ*, with the aim of treating the air in the surrounding space with ozone.
- Air purifiers with an ozone ioniser in which the input air is treated in the device itself and then blown back out. In the case of these air purifiers, there is no intentional ozone emission into the surrounding space. Ozone emission can take place, but often in far lower quantities than in the case of air purifiers that intentionally generate ozone.

This advices focuses on *in situ* generated ozone in applications that involve direct exposure of consumers through inhalation and is restricted to the health risks for consumers; pets and plants are not considered. The other safety aspects of air purifiers, such as electrical safety, release of a broad spectrum of noise frequencies and UV light are also beyond the scope.

Findings

Hazard identification

This risk assessment focuses on *in situ* generated ozone from air purifiers, to which consumers can be exposed.

Hazard characterisation

- Ozone is an unstable, reactive substance. Ozone is a powerful oxidizing agent and has antibacterial and antiviral properties. At low concentrations (40 µg/m^3) and in a short timeframe (less than one hour), ozone is capable of fighting microorganisms and viruses.
- The main consequence of short-term exposure to ozone through inhalation is irritation of the airways. From an ozone concentration of 160 µg/m^3 upwards, health effects are observed, such as irritation of the eye, nose and throat and breathing difficulties. Effects as a consequence of long-term exposure include respiratory mortality, the occurrence of asthma in children and an increase in respiratory effects in asthma patients. From an ozone concentration of 65 µg/m^3, a link has been established between long-term exposure and the development of asthma in children.
- Although the carcinogenicity of ozone is not clearly demonstrated in human epidemiological studies, a CLH dossier (Classification and Labelling Harmonisation) has been submitted to the European Chemicals Agency (ECHA) for assessment, with the aim of classifying ozone as a genotoxic carcinogen, on the basis of the results from animal studies. It is assumed that there is no threshold value for this effect. For the critical effect of respiratory mortality, a minimum effect level (MEL) of 50 µg/m^3 has been proposed as the health-based guidance value. MEL is the exposure level below which the risk to health is acceptable.
- A limit value of 40 µg/m^3 in air has been adopted by Health Canada for long-term exposure (8 hours per day) indoors. This limit value is derived from a human voluntary study with as its critical end point reduced lung function and subjective respiratory symptoms. FO selected this limit value for its risk assessment, because it is the most representative value for the expected exposure from the use of an ozone-emitting air purifier indoors, in terms of duration and frequency of exposure. This limit value applies both to children and adults and can be directly compared with the ozone concentration in the air. BuRO has adopted this limit value of 40 µg/m^3 for the risk assessment of ozone-emitting air purifiers. This health-based guidance value is lower than the MEL of 50 µg/m^3, as derived in the dossier for classification for the end point of respiratory mortality.

Legislation

- At present, ozone generated *in situ* is exempted in the Netherlands from the Plant Protection Products and Biocides Act. In June 2023, at EU level, ozone was approved as an active substance for among others product type 2: disinfectants and algaecides not intended for direct application to humans or animals. In the subsequent phase, authorisations can be applied for at national or European level for the individual biocides based on *in situ* generated ozone. It is expected that it will be another 5 years before the evaluation and authorisation at national level is completed. If the proposed harmonised classification of ozone as acutely toxic when inhaled, carcinogen, mutagenic and toxic for target organs in the event of single or repeated exposure is officially adopted, it is expected that thereafter, *in situ* generated ozone will no longer be permitted at locations accessible to consumers.
- As long as *in situ* generated ozone is not covered by biocide legislation in the Netherlands, the Commodities Act applies. Under the Commodities Act, non-food consumer products may only be placed on the market if their intended use does not result in a health risk.

Exposure estimate

- No Safety Gate notifications were published in the period January 2018-February 2023 relating to ozone emission from air purifiers.
- The online market survey performed by FO revealed that air purifiers based on ozone are supplied for various living areas, cabinets and refrigerators, cars, shoes and cat litter trays. The reported ozone emissions varies between 0.24 and 32,000 mg per hour. The reported use time varies considerably, from several minutes to 3 hours and sometimes continuous. A scenario was selected for use of 1 hour per day. Using Consexpo, on the basis of the reported ozone emission, FO calculated the ozone concentration in various spaces after 1 hour's use of these air purifiers. In these calculations, account was taken of the fact that ozone is a reactive substance with a half-life of 20 minutes. The calculated ozone concentration varies between 12 and 4,000,000 μg/m^3.
- The literature study reveals that an air purifier with an ozone emission of 137 mg per hour generates an ozone concentration of 580-1300 μg/m^3. It follows from Consexpo calculations that an ozone emission of 100 mg per hour delivers an ozone concentration of 200-510 μg/m^3, depending on the space and ventilation rate. These ozone concentrations are in the same order of magnitude. This shows that the ozone concentrations calculated using Consexpo are realistic values but that there is a certain degree of uncertainty about the actual concentrations from the different air purifiers.
- On the basis of parameters for different spaces specified by BuRO, FO subsequently calculated at what ozone emission the health-based guidance value of 40 μg/m^3 is reached. Multiple scenarios were calculated by FO (see substantiation). A conservative scenario was selected: a period of use of 1 hour, low ventilation rate and small space (car, toilet) and small living space such that this scenario offers protection for all intended uses. For small spaces of 2.4 m^3 (car, toilet), at an ozone emission of 0.3 mg per hour, an ozone concentration higher than 40 μg/m^3 can occur. For other spaces (from 20 m^3 upwards), the health-based guidance value can be exceeded at an ozone emission of 3 mg per hour and higher.

Risk characterisation

- With the exception of a single air purifier for a car, use of the other air purifiers from the online market survey resulted in (considerable) exceeding of the health-based guidance value.

- For air purifiers for small spaces (up to 2.4 m^3) at an ozone emission of 0.3 mg per hour and higher, a health risk can occur. For other spaces (from 20 m^3 upwards) this applies at an ozone emission of 3 mg per hour and higher.

Answer to the question

What is the health risk of consumer products that generate ozone?
Ozone can cause irritation of the airways. In the event of long-term exposure, this can lead to respiratory problems, the occurrence of asthma in children and an increase in respiratory effects in asthma patients. ECHA is currently evaluating whether ozone should also be considered as a genotoxic carcinogen. The majority of air purifiers from the online market survey performed by FO result in an ozone concentration that considerably exceeds the health-based guidance value of 40 $\mu g/m^3$.

What is the maximum acceptable emission of ozone from consumer products so that this standard can be used for supervision and enforcement. This may vary according to the space in which the product is used.
For small spaces (2.4 m^3), the ozone concentration can exceed the health-based guidance value from an ozone emission of 0.3 mg per hour upwards. For other spaces (from 20 m^3) upwards, this value is 3 mg.

Advice from BuRO

To the Minister of Health, Welfare and Sport

- For the transition period in which *in situ* generated ozone in the Netherlands is exempt from the Plant Protection Products and Biocides Act, consider banning *in situ* generated ozone in applications in which there is direct exposure of consumers through inhalation.

To the Inspector-General of the Netherlands Food and Consumer Product Safety Authority

- Have a health warning applied to products on the market that generate ozone in quantities that represent a health risk. For small spaces (up to 2.4 m^3), the maximum ozone emission is 0.3 mg per hour, for other spaces the maximum ozone emission is 3 mg per hour.
- On the NVWA website, actively communicate about the risks of consumer products that emit ozone. Advise consumers to no longer use these products, or to only enter the space following a long period of ventilation.

Yours sincerely,

Director of the Office for Risk Assessment & Research
Prof. Dick T.H.M. Sijm

Substantiation

Introduction
The background to the investigation into ozone-emitting air purifiers was a report to the Dutch Food and Consumer Product Safety Authority (NVWA) about an air purifier for use around the cat litter tray. This air purifier reportedly emitted 25 mg of ozone per thirty minutes. The Enforcement Directorate of the NVWA asked the Office for Risk Assessment & Research (BuRO) whether an air purifier that emits ozone could result in a health risk for consumers. A limited search action on the Internet revealed that a number of air purifiers emitting ozone are available for purchase online. There is no legal standard available for ozone emission.

There has been more attention for ventilation and air purifiers since the outbreak of the COVID-19 pandemic in 2019. It is possible that the use of ozone-based air purifiers has increased, with the aim of reducing the transfer of the COVID-19 virus or other viruses.

Ozone has oxidating, antibacterial and antiviral properties and is used for the disinfection of bathing water, drinking water, in medical applications and also in the food industry. Ozone can be used in air purifiers for odour control and to disinfect the air.

Ozone is often generated *in situ*, because it is an unstable substance. An active substance generated *in situ* is generated in the place of use, in this case by the air purifier itself.

In 2022, a CASP project (Coordinated Activities on the Safety of Products) was launched at EU level into ozone-based air purifiers. Among the safety aspects being investigated are electrical safety, the release of a broad spectrum of noise frequencies and UV light. These safety aspects are beyond the scope of this advice.

Approach
In June 2022, BuRO asked RIVM/WFSR Front Office Food and Product Safety (FO) to conduct an assessment (FO, 2022). The following questions were asked:

1. What are the health effects of ozone and what is the health-based guidance value for the general population in the event of exposure via inhalation?
2. What is the status of ozone as a biocide? Is ozone classified under the BPR for effectiveness and safety? Are the evaluated air purifiers within the scope of the BPR?
3. What is the emission from ozone-based air purifiers available on the market? Map out this situation via an internet survey. What is the exposure to ozone for both children and adults following the placement in the home of an ozone-based air purifier? Map this out for various spaces in the home: utility room, kitchen, living room and bedroom. These ozone purifiers are also supplied for use in the car. Can an estimate be made of the exposure in this application?
4. What is the maximum ozone emission in the scenarios described above, at which no health risk occurs?

For this assessment, FO called upon the Dutch Board for the Authorisation of Plant Protection Products and Biocides (Ctgb) to assess whether *in situ* generated ozone is covered by the biocides legislation.

In January 2023, BuRO asked FO to use Consexpo to calculate at what ozone emission (in mg/hour) the ozone concentration in the air can achieve the derived health-based guidance value of 40 µg ozone/m^3, in specific scenarios (FO, 2023).

BuRO itself conducted an additional literature study into ozone-based air purifiers and searched the dose-effect relationship for ozone (see appendix 1 for the search strategy). A search was also conducted for Safety Gate notifications about ozone emission. Safety Gate is the EU system for rapid warnings for hazardous non-food products. BuRO wrote this advice based on the FO assessments and literature study. The four steps of the risk assessment were followed: hazard identification, hazard characterisation, exposure estimate and risk characterisation.

Scope
Electric ozone-based purifiers can be divided into two types:

- Air purifiers that generate and emit ozone with the purpose of treating the air in the surrounding space with ozone.
- Air purifiers that use ionisers and electrostatic dust catchers are designed to electrically charge particles in the air and to ensure that these attach to surfaces in the room, such as walls or floors. Ozone is released during this process, although generally speaking these devices emit less ozone than ozone generators (California Air Resources Board, 2022).

BuRO investigated the health risk for the consumer from the use of air purifiers that intentionally emit ozone. This BuRO advice is restricted to the health risk for consumers due to exposure to ozone. Pets and plants are not considered. Physical hazards are also beyond the scope of this advice.

Hazard identification
This risk assessment focuses on *in situ* generated ozone from air purifiers for consumers. Other hazard aspects of these air purifiers are beyond the scope of this advice.

Hazard characterisation
Ozone (O_3, CAS no. 10028-15-6) is a gas at room temperature with a fairly characteristic odour. Ozone is often generated *in situ* from oxygen, for example via UV radiation. Ozone is a powerful oxidizing agent and oxidizes organic substances including microorganisms.

Smog caused by ozone occurs when large numbers of nitrogen oxides and volatile organic substances are present in the air. The pollutants are then converted into ozone by sunlight. The Smog Regulation 2010, Netherlands Government Gazette 2016, 18879, lists warning and alert thresholds for sulphur dioxide, nitrogen dioxide, particulate matter and ozone. The limit value in the event of ‘serious smog’ or ozone specifies an ozone concentration of 240 $\mu g/m^3$ and higher.

The most important exposure route for ozone from air purifiers for consumers is via the air (inhalation). Due to the low water solvability of ozone, ozone is not effectively removed from the upper airways and therefore reaches the lower airways (ECHA, 2021a). Once in the lower airways, ozone then dissolves in the thin layer of the epithelial fluid. Here it can cause oxidative stress which can lead to cell damage and changes in the cell signalling in the airways. People with respiratory diseases such as chronic bronchitis, asthma or emphysema run a greater risk of ozone-related health effects, among others as a result of a higher breathing frequency.

Annex VI of the CLP Regulation (EC) no. 1272/2008 contains no harmonised classification for ozone (European Parliament and of the Council, 2008). The abbreviation CLP stands for Classification, Labelling and Packaging. A CLH dossier has been submitted to the European Chemicals Agency (ECHA) (ECHA, 2021b) for assessment. CLH stands for Classification and Labelling Harmonisation. This CLH dossier proposes the following harmonised classification for ozone:

Ox, Gas 1	H270 May cause or intensify fire; oxidiser
Acute Tox. 1	H330 Fatal if inhaled
Carc. 2	H351 Suspected of causing cancer
Muta. 2	H341 Suspected of causing genetic defects
STOT SE 1	H370 May cause damage to nervous system following single exposure
STOT SE3	H335 May cause respiratory irritation
STOT RE1	H372 Causes damage to organs following long-term or repeated exposure
Aquatic Acute 1	H400 M-factor 100; Very toxic to aquatic life
Aquatic Chronic 1	H410 M-factor=1; Very toxic to aquatic life with long lasting effects

Short-term effects
Acute toxicity studies show that there are effects on heart, brain and airways. On the basis of a human study into irritation in the airways, a No Observed Adverse Effect Concentration (NOAEC) in humans was derived in the German Competent Authority Report (CAR) for short-term exposure of 120 µg/m^3 (ECHA, 2021a), whereby the Lowest Observed Adverse Effect Concentration (LOAEC) was 140 µg/m^3. The NOAEC is the highest tested concentration that causes no observable adverse effect. The LOAEC is the lowest tested concentration that causes an observable adverse effect. This LOAEC and NOAEC originate from a study by Adams and colleagues in which 30 people were exposed for 6.6 hours per day, in total 5 cycles (Adams, 2002).

The World Health Organization (WHO) has produced an overview of acute effects of smog on days with an average maximum exposure to ozone of 1 hour. For children and non-smoking adolescents, on the basis of observations in toxicological, clinical and epidemiological studies, an estimate was made of which acute effects occur at which ozone concentration in the air (WHO, 1992). At an ozone concentration of less than 100 µg/m^3, there are no observable effects in respect of eye, nose and throat irritation and breathing. From an ozone concentration of 200 µg/m^3 and higher, effects are observable. At an ozone concentration of 400 µg/m^3, eye, nose and throat irritation and effects on breathing such as tightness of the chest and coughing are observed in more than half of people.

In a report recently published by the United States Environmental Protection Agency (US EPA), the following effects are described under short-term effects (U.S. EPA, 2020). For the US EPA, short-term is defined as exposure with a duration between hours and 1 month. Effects on human lung function were observed from an ozone concentration of 66 µg/m^3 and higher. From an ozone concentration of 160 µg/m^3, inflammatory reactions were observed in the lungs. From an ozone concentration of 400 µg/m^3, atopic adult asthma patients demonstrated type 2 immune reactions.

Zhao and colleagues conducted a study in 10 and 15-year-old children into the effects of short-term exposure to ozone (Zhao et al., 2019). Cohorts in two different cities in Germany were monitored. The ozone concentration in these cities was measured by the Umweltbundesamt (German Environmental Agency). Blood samples were taken and analysed for biomarkers for inflammatory reactions. Zhao and colleagues concluded that a high acute exposure to ozone (≥120 µg/m^3) can promote respiratory inflammation in adolescents.

Arjomandi and colleagues conducted a study into the effect of average and high environmental levels of ozone on heart and blood vessels and inflammatory reactions (Arjomandi et al., 2015). 26 test subjects were exposed to 0, 200 and 400 μg/m^3 ozone in random order for 4 h with intermittent exercise. Variations in heartrate were measured during the test period. Blood samples were taken before and after the test, and 20 hours after the test. A bronchoscopy was conducted 20 hours following exposure. They concluded that short-term exposure has adverse effects such as inflammatory reactions and cardiac autonomous effects and that these effects are dependent on the dose. These effects were observed at an exposure to ozone concentrations of both 200 and 400 μg/m^3.

The reports published by WHO, US EPA and the studies by Zhao and Arjomandi and colleagues show that adverse health effects are observed in the event of short-term exposure to ozone (WHO, 2013; Arjomandi et al., 2015; Zhao et al., 2019; U.S. EPA, 2020). At ozone concentrations of 160 μg/m^3 and higher, inflammatory reactions are observed in the lungs as well as cardiovascular effects, including reduced heartrate and cardiac arrhythmia.

Long-term effects
Data regarding long-term exposure was in particular found in epidemiological studies (FO, 2022). The adverse health effects from ozone discovered in these epidemiological studies include respiratory mortality (death as a consequence of respiratory disease), the occurrence of asthma in children and increased respiratory effects in asthma patients (Nuvolone et al., 2018).

In a series of animal studies with mice, lung tumours were discovered following exposure to ozone. In epidemiological studies in humans, no link was found between chronic exposure to ozone and lung cancer (ECHA, 2021a). The CLH dossier submitted to the ECHA for evaluation proposes classifying ozone as a genotoxic carcinogen, on the basis of animal testing. The CLH dossier submitted to ECHA for assessment contains the proposal to classify ozone as a genotoxic carcinogen on the basis of animal testing (mutagenic category 2) (ECHA, 2021b).

The report published by US EPA provides an overview of the health effects of prolonged exposure (U.S. EPA, 2020). US EPA takes prolonged exposure to mean a period of more than 1 month, often of years. Epidemiological studies reveal an association between prolonged exposure to ozone and the development of asthma in children from an ozone concentration of 65 μg/m^3. Epidemiological research demonstrated a link between incidental COPD hospital admissions and prolonged exposure to ozone at an annual average concentration of 80 μg/m^3.

Huang and colleagues conducted a study into the effects on the heart and lungs of children from exposure to ozone indoors (Huang et al., 2019). At a secondary school in Beijing (China), the ozone concentration was measured in the classroom, from Monday through to Friday, over a period of 4 months. The average ozone concentration was 17 μg/m^3. The heart and lung functions of the schoolchildren were investigated, including an ECG, blood pressure, heartrate, exhaled nitrogen oxide fraction and lung function. The conclusion of this study was that long-term prolonged exposure to low ozone concentrations in children indoors has no effect on breathing. However, there was a relationship with disturbed cardiac autonomic function and increased heartrate in children, which suggested a possible mechanism through which ozone may affect cardiovascular health in children.

Health-based guidance value
The FO assessment provides a list of available health-based guidance values for ozone for different situations and populations (FO, 2022). The identified health-based guidance values for ozone are in the same order of magnitude: the health-

based guidance values derived for employees (24-120 µg/m^3) and for the general population (40-140 µg/m^3) are close together.

For this risk assessment, FO selects as its health-based guidance value the limit value of 40 µg/m^3 as derived by Health Canada (Health Canada, 2010). This value is based on a volunteer study in which healthy people were exposed to ozone for a period of 6.6 hours per day during activity, with as its critical end point reduced lung function and subjective respiratory symptoms (expressed as pain during deep inhalation and total symptom score) (Adams, 2002). The NOAEC of this study amounted to 80 µg/m^3, which was the lowest test concentration. For intraspecies differences, an uncertainty factor of 10 was applied, resulting in a reference value of 8 µg/m^3. Studies into concentrations of ozone indoors in Canada show that the average ozone concentration during daytime is around 14 µg/m^3, with a 95th percentile of around 44 µg/m^3. For long-term exposure (8 hours a day), Health Canada therefore advises a maximum indoor ozone concentration for air of 40 µg/m^3. This value applies both to children and adults.

This limit value was selected by FO because it is the most representative for the expected exposure from the use of an ozone indoors emitting air purifier in terms of exposure time and frequency (FO, 2022). Because this limit value is based on human data, the observed adverse health effects apply to humans and therefore require no additional safety factors.

The limit value from Health Canada selected by FO does not explicitly include the possible genotoxic carcinogenicity of ozone. The CAR proposes classifying ozone as genotoxic carcinogen (ECHA, 2021a). This classification has not yet been confirmed. For ozone, no NOAECs/No Observed Adverse Effect Levels (NOAEL) could be derived from the relevant epidemiological studies for the critical effect of mortality. The NOAEL is the highest test dose at which no adverse effect is observed. A limit value for this effect could not be derived. A minimum effect level (MEL) of 25 ppb (50 µg/m^3) was proposed. MEL is the exposure level below which the risk to health is acceptable.

BuRO has adopted the limit value of 40 µg/m^3 selected by FO for the risk assessment of ozone-emitting air purifiers, because this level is a good match with a realistic exposure scenario of 8 hours per day. Moreover, this value is below the MEL for genotoxic effects.

Effectiveness against microorganisms
Ozone is a powerful oxidising agent that attacks the membrane or envelope of microorganisms and viruses through the peroxidation of phospholipids and interaction with proteins. In the opinion of the Biocidal Products Committee (BPC) on ozone generated from oxygen for product type PT2, for air disinfection of surfaces with continuous supply of ozone, a dose of 160 µg/m^3 ozone in air with a contact time of 2.5 hours is considered effective (ECHA, 2022). However, the literature study revealed that also at lower ozone concentrations and lower exposure times, ozone was already effective in tackling microorganisms and viruses.

A literature study by Grignani and colleagues into the virucidal activity of ozone revealed that even at a low level, ozone is effective in the disinfection of air and surfaces (Grignani et al., 2020). There is a relationship between the minimum concentration of ozone and the exposure time for the killing off of viruses. At an ozone concentration of 12 µg/m^3, for example, after 55 minutes, 90% of the SARS-CoV-2 virus is rendered inactive. Study by Kowalski and colleagues revealed that exposure to ozone concentrations of between 8 and 40 µg/m^3, for between 10 and 480 minutes, almost all *E.coli* bacteria were killed off (Kowalski et al., 2003). Epelle and colleagues demonstrated in a test chamber that at a concentration of 40 μg/m^3 for 4 minutes, ozone is capable of killing off microbiota (Epelle et al., 2022).

Legal aspects
Ozone is an active substance, due to its antibacterial and antiviral properties. Whether the application of ozone falls under biocide legislation depends not only on the properties of the active substance ozone, but also the intention with which it is employed. Only if the intention of the air purifier is to disinfect is ozone produced by the air purifier subject to biocide legislation. If however the intended use is to remove the smell of smoke, it is not a biocidal application but a cleaning process and is therefore not covered by the Biocidal Products Regulation. In the case of tackling odours caused by microbial activity, it is used as a biocide and as such is within the scope of the biocides legislation. Biocides legislation relates only to chemical substances; the device itself (air purifier) is beyond the scope of this legislation.

Biocides are subject to an authorisation policy: only authorised biocides may be placed on the market. At present, biocides are covered by both European and national legislation. The intention is that in the future, all biocides will be evaluated and authorised under the Biocidal Products Regulation (EU) no. 528/2012 (European Parliament and the Council, 2012). Evaluation under the Biocidal Products Regulation takes place in 2 phases. In phase one, the active substance is evaluated by ECHA for efficacy and safety. If the authorisation for an active substance is approved, in the second phase an authorisations can be applied for at national level by producers of biocides based on an active substance. In the Netherlands, these applications are evaluated by the Ctgb. In the Netherlands, biocides must comply with the Plant Protection Products and Biocides Act, Government Gazette, 2007, 386.

In 2021, the German competent authority drew up an assessment report (CAR) (ECHA, 2021a). In September 2022, ECHA also received the CAR from the Dutch competent authority. On the basis of these two reports, ozone generated from oxygen was approved as an active substance for product types 2, 4, 5 and 11, in June 2023 (European Commission, 2023). Product type 2 relates to disinfectants and algicides not intended for direct application to humans or animals, such as air purifiers based on ozone. The following special conditions apply:

- the product assessment shall pay particular attention to the exposures, the risks and the efficacy linked to any uses covered by an application for authorisation, but not addressed in the Union level risk assessment of the active substance.
- the product assessment shall pay particular attention to:
  - professional users;
  - non-professional users;
  - the secondary exposure of the general public.

At present, *in situ*-produced ozone has a special status in the Netherlands, because it is exempt according to Annex IX of the Plant Protection Products and Biocides Regulations, Government Gazette, 2007, 386. This appendix states:

‘Ozone that is generated on site using equipment intended for this purpose does not fall within the scope of this law. Only once the second phase has been concluded of placing *in situ* generated ozone under the Biocidal Products Regulation will this exemption under the Plant Protection Products and Biocides Regulations expire.’

It is estimated that the assessment of all biocides based on *in situ* generated ozone will have been concluded in around 5 years' time.

According to article 19.4 of the Biocidal Products Regulation for the authorisation of biocides, products for non-professional users may not be placed on the market if they are classified according to the CLP regulation (EC) no. 1272/2008 for acute oral toxicity in category 1, 2 or 3, for inhalation; toxicity for target organs in the event of single or repeated exposure category 1; carcinogenic, mutagenic or reprotoxic category 1A and 1B. Based on the proposed harmonised classification of ozone according to the CLH report (ECHA, 2021b), the obvious conclusion is that air purifiers that generate ozone *in situ* can then no longer be used at locations where private individuals and the general public can come into contact with ozone. However, a final decision on this will only be made when the individual ozone products are authorised.

Because *in situ* generated ozone does not currently fall under the biocides legislation in the Netherlands, the general legislation, namely the Commodities Act, Government Gazette 1935, 822, applies. According to article 18 under a of the Commodities Act, it is prohibited to trade in goods, other than food and beverages, of which the person trading in these goods knows or should reasonably suspect that they may pose special dangers to the safety or health of humans when used in view of their intended use, or if it concerns technical products, also for the safety of goods. In concrete terms this means that the intended use of an air purifier that emits ozone is not allowed to cause any health risk for consumers.

Exposure estimate

No Safety Gate notifications were found relating to ozone emissions from air purifiers in the period 2018 to the present (February 2023).

Britigan and colleagues investigated the ozone emission from 13 different air purifiers (Britigan et al., 2006). The measured ozone emission ranged between 2.2 and 220 mg of ozone per hour. The devices were subsequently tuned on in test rooms, and the ozone concentration was measured as a function of time, until a steady-state concentration level was reached. A large fan was placed in the room for better circulation of air to avoid significant ozone concentration gradients across the room volume. The lowest measured ozone concentration was 18 μg/m^3. This value was achieved by turning on an air purifier with an ozone emission of 2.2 mg per hour in an office space of 35 m^3, with a low ventilation rate. The highest measured ozone concentration in the air amounted to 1300 μg/m^3. This was caused by an air purifier with a measured ozone emission of 137 mg per hour in an office space of 27 m^3 without ventilation. In a car, an air purifier was turned on with an ozone emission of 0.5 and 0.7 mg of ozone per hour, respectively. The measured ozone concentration in the car amounted to 12 and 18 μg/m^3, respectively.

Zhang and colleagues investigated ozone emissions from various domestic appliances in the United States (Zhang & Jenkins, 2017). These were devices that generated both intentional and unintentional emissions: air purifiers, washing machines, fruit and vegetable washing machines, facial steamers, shoe sanitisers, refrigerator fresheners. These appliances were placed in various test rooms, that differed in volume, ventilation rate, furniture and upholstery. Room 1 had a volume of 14 m^3 and was furnished with a wooden table and wooden chair, vinyl tiles, aluminium interior with an inactive coating, with practically zero ventilation. Room 2 had a volume of 36 m^3 and was furnished with a wooden table and four upholstered chairs, had carpet flooring and painted wallboard throughout and a ventilation rate of 0.43 per hour. Room 3 was a small bathroom with a volume of

11 m^3, the room surfaces were comprised of ceramic tiles and painted wallboard. Room 3 had a ventilation rate of 0.4 per hour. The washing machine was tested in this room. Room 4 was a room of 72 m^3, with a ventilation rate of 0.4 per hour. This room contained a refrigerator, in which the refrigerator air purifiers were tested. The ozone concentration was measured when the refrigerator door was opened. Nine of the 17 investigated products emitted measurable quantities of ozone. Use over 1 cycle increased the ozone concentration in the room to 212 $\mu g/m^3$. Multiple user cycles by a single vegetable and fruit washing machine increased the exposure concentrations by on average 5100 $\mu g/m^3$.

In 2022, FO conducted an online market survey into ozone purifiers (FO, 2022). The purpose of this study was to gain an impression of which ozone air purifiers are available, for which application, what instructions for use are issued, and the ozone emission indicated by the manufacturer. The aim of this online market survey was not to obtain a representative picture of the market. In total, 29 products were included in this online market survey. These air purifiers were intended for use in the car, cupboards and refrigerators, cat litter trays, shoes, plug-and-play, the living room, steam appliances and the telephone. It was claimed for all of these products that they cleaned or disinfected the air, by diffusing ozone.

The inventory revealed that the information on the internet relating to use was very limited. There may be further information in the user instructions supplied. The inventory revealed that a number of forum websites focus attention on the health risks of ozone. These websites inform consumers that ozone is toxic. The majority of suppliers of ozone-based air purifiers do not report this fact. It is also rarely indicated how much time must be allowed to pass after a room has been treated, before it is once again safe to enter. Information needed for the exposure estimate was often not available, such as the ozone emission, the volume of the space in question and the duration of use. Some air purifiers are recommended on the internet site for multiple types of rooms or spaces such as cars, homes and bathrooms. Based on the information on the internet sites, the ozone emission of the products in this online market survey ranges between 0.24 and 32,000 mg/hour. The indicated period of use of these purifiers ranges from just a few minutes (plug-and-play) through to 180 minutes (car product) right through to constant operation (in the home).

FO used the Consexpo exposure model to make an estimate of the ozone concentration in the air as a result of the use of an ozone air purifier (FO, 2022). In this estimate, assumptions were made for the duration of emission, room volume and ventilation rate. Standard values for exposure parameters were adopted from the General Fact Sheet of Consexpo (Te Biesebeek et al., 2014) and the inhalation exposure to vapour-constant rate model in Consexpo. These Consexpo calculations assumed a half-life for ozone of 20 minutes, because it is a reactive substance and it is absorbed by a whole variety of surfaces. The basic scenario prepared by FO assumes a period of use of 1 hour, even though it was indicated for some air purifiers that they can be used for a longer period of time.

For a number of basic scenarios, using Consexpo, FO calculated the resultant ozone concentration in a space, based on the assumptions and parameters referred to above. The calculation was carried out for each category/space for a low and a high scenario in order to estimate the range of the determined ozone concentration as a result of using an air purifier. A low scenario assumes the lowest reported ozone emission in this category and the highest ventilation rate. A high scenario assumes the highest identified ozone emission in this category and the lowest ventilation rate. The average ozone concentration over a 60-minute period is calculated using Consexpo. The results appear in the FO assessment (FO, 2022) and have been copied in Table 1.

In the calculation using the Consexpo model, the intended effect of ozone, the reaction with dirt or bacteria, is taken into account. A half-life of 20 minutes results in an additional reduction by a factor 3. The presented concentration of ozone after one hour operation are based on ventilation multiplied by a factor 3.

Table 1: Ozone concentration per scenario shown as an average over a period of 1 hour. Ventilation rate is multiplied by a factor of 3 based on a half-life of ozone of 20 minutes.

Category and space	**Indicated emission (mg/hour)**	**Ventilation rate (per hour)**	**Low scenario (µg/m³)**	**High scenario (µg/m³)**
Car	0.24	2.5	12	
Car	32,000	0.6		4000000
Home/toilet	50	2.5	2300	
Home/toilet	2400	0.6		290,000
Home/living room	50	2.5	100	
Home/living room	2400	0.6		12,000
Plug-and-play/toilet	100	2.5	4600	
Plug-and-play/toilet	100	0.6		12,000
Plug-and-play/living room	100	2.5	200	
Plug-and-play/living room	100	0.6		510
Cat litter tray / non-specific room	100	2.5	580	
Cat litter tray / non-specific room	100	0.6		1,500

The ozone concentration calculated by FO for a specified emission of 100 mg per hour in a living room (200-510 µg/m³), is in the same order of magnitude as the measured ozone concentration achieved for an air purifier with an ozone emission of 137 mg per hour (580-1300 µg/m³) (Britigan et al., 2006). The ozone concentrations calculated by FO are therefore realistic values that can be achieved in practice. In the online market survey conducted by FO, air purifiers were identified with a far higher claimed ozone emission than 137 mg per hour, consequently the maximum calculated ozone concentrations in certain scenarios in Table 1 are far higher.

The ozone concentration in the air is determined by many variables. In addition to the space (volume) and emission duration, the ozone concentration also depends on the ventilation and the half-life of ozone in the space. This latter element relates to the absorption of ozone by materials and the net effect of the reaction of ozone with dirt and, among others, viruses. Due to these uncertainties in the different assumptions, and the combinations of assumptions, the FO was unable to derive a generic maximum safe emission (FO, 2022).

BuRO subsequently asked FO, using the Consexpo model, to calculate for the following specific described scenarios at what level of ozone emission (in mg/hour), the ozone concentration in the air can reach the derived health-based guidance value of 40 µg ozone/m³ (FO, 2023). These scenarios are an active source of ozone in a:

- small space (2.4 m^3)
- non-specific space (20 m^3)
- large space (58 m^3)

For each of these spaces, a calculation was carried out on the basis of a high ventilation rate (2.5 per hour) and a low ventilation rate (0.6 per hour). In making the calculations, the following assumptions were made:

- period of use of 1 hour per day
- half-life of ozone indoors of 20 minutes
- no other active ozone sources in the space

The results of these calculations appear in Table 2. For more details of the Consexpo calculations, see the FO assessment (FO, 2023).

Table 2: Maximum ozone emission (mg/hour) for air purifiers in different spaces whereby the ozone concentration does not exceed 40 μg/m^3

Space	Maximum ozone emission at low ventilation rate (mg/hour)	Maximum ozone emission at high ventilation rate (mg/hour)
small space (2.4 m3)	0.32	0.83
non-specific space (20 m3)	2.7	6.9
large space (58 m3)	7.8	20

Risk characterisation
The online market survey conducted by FO reveals that ozone-emitting air purifiers are offered for different rooms and applications. The calculated ozone concentrations achieved by using these air purifiers range from 12 to 4,000,000 μg/m^3. Only the air purifier intended for use in a car with an ozone emission of 0.24 mg/hour does not exceed the health-based guidance value of 40 μg/m^3. According to the Consexpo calculation, the other air purifiers from the online market survey can result in an ozone concentration that considerably exceeds this health-based guidance value. As a result there is a risk to health for the consumer. According to the US EPA, from an ozone concentration of 160 μg/m^3 upwards, there are adverse health effects in the event of short-term exposure, namely inflammatory reactions in the lungs (U.S. EPA, 2020). According to the Consexpo calculations, the majority of the products from the internet survey generate a higher ozone concentration.

Table 2 shows that the maximum ozone emission as calculated for various types of spaces and ventilation rates, ranges between 0.32 and 20 mg/hour. BuRO has selected a scenario that is protective for all intended uses. This means that the consumer operates an air purifier for a period of 1 hour per day at low ventilation. In respect of the volume of the space, a small space has been chosen (toilet, car) of 2.4 m^3, and a non-specific space of 20 m^3. The calculated value for a non-specific space is also protective for a larger space. For small spaces up to 2.4 m^3, the maximum ozone emission is 0.3 mg/hour; for other non-specific spaces the maximum ozone emission is 3 mg/hour.

Conclusions
- At present, *in situ* generated ozone is not subject to Dutch biocides legislation. It is expected to be a further 5 years before the process of assessment and authorisation is completed, at national level. It is to be expected that air

purifiers based on *in situ* generated ozone will no longer be permitted for consumers or in publicly accessible areas, after that time.

- The selected health-based guidance value for ozone is 40 µg/m^3, based on a human study with as critical end point reduced lung function and subjective respiratory symptoms. At this ozone concentration and with an exposure time of one hour or less, ozone is effective at tackling microorganisms and viruses.
- According to the Commodities Act, ozone-based air purifiers are not allowed to cause a health risk for the consumer if used as intended. On the basis of this risk assessment, it emerges that the majority of air purifiers from the online market survey claim such a level of ozone emission that the health-based guidance value is considerably exceeded.
- At an ozone emission in a small space of 0.3 mg per hour, an ozone concentration in the air can be achieved that exceeds the health-based guidance value. For general non-specific spaces, an ozone concentration can occur which is higher than the health-based guidance value at an ozone emission of 3 mg per hour or higher.

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Appendix 1: Literature study and Safety Gate notifications

Literature study

On 17 February 2023, a search was conducted in PubMed using the search terms 'ozone' AND 'air purifier'. This delivered 48 results. Publications relating to the effectiveness, the removal of ozone or toxicity studies were filtered out. This resulted eventually in 3 relevant publications.

With regard to toxicity, the German CAR conducted an extensive literature study (ECHA, 2021a). An additional search was conducted into reports by WHO and US EPA about ozone. These reports contain data about the dose-effect relationship of ozone. In PubMed, a search was conducted using the terms 'dose' AND 'response' AND 'ozone'. Initially this search delivered 149 results. Publications on effectiveness in respect of viruses and microorganisms were filtered out. Medical treatments were also filtered out. A number of publications concerned the effects of polluted air, whereby ozone was one of the parameters, and the effects related not only exposure to ozone. A selection was made based on human health effects. This resulted in 3 relevant publications.

On 17 August 2023, a search was conducted in PubMed into the effectiveness of ozone in tackling microorganisms and viruses. The search terms 'ozone' and 'air disinfection' were used. This delivered 104 results. Publications relating to (drinking) water, food, personal protective equipment and medical equipment were removed. This resulted in 3 relevant publications.

Safety Gate notifications

On 17 February 2023, a search was conducted in the Safety Gate system (EU rapid alert system for dangerous non-food products) for notifications based on the search term 'ozone' for the period between 1 January 2018 and 17 February 2023. In total, 5 notifications were found: 4 air purifiers and 1 helmet (brand name Ozone). The air purifiers came with the notice that they did not comply with the Low Voltage Directive 2014/35/EU (European Parliament and the Council, 2014) and/or the EN 62471 standard. No mention is made of ozone emission.