Indoor air quality in primary schools

and the value of carbon dioxide as an indicator of air quality

Gezondheidsraad **President**
Health Council of the Netherlands

To the Minister of Housing, Spatial Planning and the Environment

Subject : presentation of advisory report *Indoor air quality in primary schools*
Your reference : SAS/mv2008007057
Our reference : I-103/MD/pm/828-H
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Dear Minister,

Also acting on behalf of her colleagues at the Ministry of Housing, Communities and Integration, the Ministry of Education, Culture and Science and the Ministry of Health, Welfare and Sport, your predecessor requested an advisory report on the quality of indoor air in primary schools. I hereby present the advisory report. It has been drafted by a Health Council Committee which I established especially for this purpose.

The advisory report presents current scientific knowledge of the effect of the indoor environment of primary schools on the health and cognitive performance of pupils. The advisory report is complementary to an advisory report on school buildings which was recently drafted by the chief government architect. The emphasis in the request for an advisory report was on carbon dioxide (CO_2) as a measure of ventilation and air quality. The Committee focussed on indoor air pollutants which undergo changes in concentration as a result of ventilation. At the start of the committee process various stakeholders were offered the opportunity to put forward points of interest and suggestions. The draft advisory report was assessed by members of the Health Council's Health and the Environment Standing Committee.

The Committee notes that primary school pupils may be exposed to various indoor environmental factors in their classrooms which could have adverse effects on their physical health and cognitive performance. This mainly concerns particulate matter, pathogens, allergens, high temperature and noise. The Committee takes the view that the usefulness of CO_2 as a measure of the indoor air quality is limited but considers it to be a good indicator of ventilation. For classrooms the available scientific data are limited and according to the Committee they provide no grounds for deviating from the present CO_2 concentration of 1,200 ppm, which has been adopted in the present Building Decree as the basis for ventilation requirements for new buildings.

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Given that average CO_2 concentrations of 2,000 ppm occur in classrooms, many schools ought to increase ventilation to keep CO_2 concentrations below 1,200 ppm. However, ventilation can also lead to side effects such as draught, noise nuisance or health effects as a result of dust from the ventilation system's supply air filters. The Committee therefore calls for clean ventilation air and proper ventilation facilities as well as information on how to use them properly.

In view of the major knowledge gaps, the Committee recommends commissioning scientific research into the effect of ventilation on indoor air quality in classrooms and on the health and cognitive performance of pupils. The main focus of this study should be sensitive groups, such as children with asthma, chronic headaches or learning difficulties. The Committee also takes the view that an evaluation of measures taken to improve the indoor environment in schools would be relevant.

Although the Committee's recommendations focus on primary schools they are partially also relevant for schools providing secondary education or special education. The recommendations are less relevant for day nurseries; they differ from schools too much, owing to the young age group and different purpose. Attention will have to be paid to this subject when changing the direction of policy with the aim of achieving multifunctional use of school buildings, also by young age groups.

I have also presented a copy of this report to the Minister of Housing, Communities and Integration, the Minister of Education, Culture and Science and the Minister of Health, Welfare and Sport.

Yours sincerely,
(signed)
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to:

the Minister of Housing, Spatial Planning and the Environment

the Minister of Housing, Communities and Integration

the Minister of Education, Culture and Science

the Minister of Health, Welfare and Sport

No. 2010/06E, The Hague, April 29, 2010

The Health Council of the Netherlands, established in 1902, is an independent scientific advisory body. Its remit is “to advise the government and Parliament on the current level of knowledge with respect to public health issues and health (services) research...” (Section 22, Health Act).

The Health Council receives most requests for advice from the Ministers of Health, Welfare & Sport, Housing, Spatial Planning & the Environment, Social Affairs & Employment, Agriculture, Nature & Food Quality, and Education, Culture & Science. The Council can publish advisory reports on its own initiative. It usually does this in order to ask attention for developments or trends that are thought to be relevant to government policy.

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Contents

Executive summary

In 2008 the Dutch government ascertained that the quality of the indoor environment in primary schools could be improved. The concerns were mainly related to air quality during the heating season, temperatures in classrooms during the summer and annoying noises. Also acting on behalf of her colleagues at the Ministry of Housing, Communities and Integration, the Ministry of Education, Culture and Science and the Ministry of Health, Welfare and Sport, the Minister of the Environment and Spatial Planning asked the Health Council of the Netherlands what is known about how children's health and cognitive performance are affected by the indoor environment in schools. The five questions the minister put to the Health Council are answered separately below. Following on from the government vision on the indoor environment in primary schools, this advisory report mainly focuses on pupils in primary schools.

Effects on health and cognitive performance

Question 1. What are the most important factors in the school indoor environment that may have a harmful effect on the health of children and teachers and the cognitive performance of children? At what level of exposure can these effects occur?

The Committee divided this question into two parts concerned with effects on health and cognitive performance and provided details of the latest scientific knowledge. Given the emphasis in the request for an advisory report on carbon dioxide (CO_2) as an indicator of ventilation and air quality, when considering the indoor air of primary schools the Committee focused on pollutants which undergo changes in concentration as a result of ventilation. This emphasis is also in line with the opinions of the civic organisations that were consulted. Other environmental factors which are related to ventilation, such as temperature and noise, are only discussed indirectly by the Committee.

Health effects

Chemical substances. Research abroad indicates that building and furnishing materials, such as formaldehyde, plasticisers and other volatile and semi-volatile organic substances in classrooms may lead to adverse health effects in children. This especially applies to sensitive groups such as children with asthma. The air in classrooms may also be polluted by outdoor air, when they are close to busy roads for example. This can also lead to adverse health effects.

Particulate matter. Various European studies on the air in classrooms found concentrations of particulate matter in excess of the exposure limit for outdoor air*. This mainly applied to the coarser fraction of particulate matter, which enters air through the activities of pupils. This particulate matter could plausibly exacerbate respiratory symptoms, especially in the case of the asthmatic pupils, but no research has been conducted into this.

Infectious micro-organisms. Infections can be transmitted in various ways, particularly through physical contact or through the air. Schools play a major role in spreading viral infections through the population. The likelihood of respiratory infections such as influenza being spread via schools is partly determined by the concentration of pathogens in classroom air. However, no suitable study has been conducted on the link between ventilation and the prevention of infections caused by pathogens in schools.

Other microbiological factors. Studies in other countries indicate a link between, on the one hand, indoor dampness and fungal growth and, on the other hand, inflammatory reactions in mucous membranes and respiratory symptoms. Non-infectious bacterial and fungal components that could lead to an increase in respiratory symptoms have been found in the indoor air and floor covering of classrooms. Exposure to various types of allergens also occurs in schools. In particular, exposure to cat allergens carried by classmates with pets at home can lead to respiratory symptoms caused by an allergic reaction.

* 24-hour exposure limit for particulate matter (PM_{10}): 50 µg/m^3

Perceived indoor air quality. In experiments with volunteers the CO_2 concentration in indoor air was used as a measure for the concentration of body odour substances. The experiments revealed that in the concentration range up to 1,500 ppm CO_2 a relationship between CO_2 concentration and an annoying odour was only demonstrated upon entering a room. There was no relationship when the length of time spent in the room was longer. In the case of average CO_2 concentrations (approximately 2,000 ppm), such as those detected in a random sample of Dutch classrooms in 2007, it is plausible that some pupils and teachers will experience an annoying odour upon entering the classroom.

Ventilation. Investigations at schools often use the CO_2 concentration in classrooms as a measure of ventilation. The Committee's opinion after examining the scientific literature is that in by far the majority of studies there are no indications of a relationship between health complaints and an average CO_2 concentration below 1,200 ppm*. One study conducted in Swedish schools found an indication that there had been a decrease in asthma following the installation of a new ventilation system, after which the average CO_2 concentration decreased from 1,000 to 800 ppm. The decrease in asthma cannot be explained by CO_2, as CO_2 only produces effects at concentrations of many thousands of ppm. In the classrooms concerned, the concentration of other airborne substances also decreased and this may have led to fewer asthma symptoms there.

Temperature, air movement and noise. Research into the health effects of other ventilation-related indoor environmental factors has mainly been conducted among adults. Many schools have problems with high temperatures in summertime due to heat from the sun. In 2007, 45 percent of teachers reported often being too warm in the classroom during the summer. High temperatures may not only be linked to feelings of discomfort but also to headaches or tiredness. Other frequently occurring problems associated with ventilation, such as a too low temperature in the winter, draught and too much noise can lead to ventilation facilities not being used sufficiently because they are considered to reduce the level of comfort in the room so much.

Effects on cognitive performance

Ventilation. One of the experiments studied indicated that pupils worked rather more slowly or made more mistakes when working under reduced ventilation in the classroom, associated with an increase in the CO_2 concentration from

* A maximum CO_2 concentration of 1,200 ppm was the basis of the 2003 Building Decree's minimum requirements for ventilation in new buildings .

approximately 800 to 1,600 ppm. Based on the available data the Committee is unable to define a CO_2 concentration at which cognitive phenomena of this kind start to occur, or which factors in the indoor environment are responsible. However, when occurring repeatedly, it could be possible that these effects will adversely affect cognitive development. The Committee therefore recommends conducting further studies on the effect of indoor air quality on pupils' performance, also in the long term.

Temperature and noise. High noise levels in classrooms may adversely affect the cognitive performance of pupils. The same applies to indoor temperatures higher than 25°C.

The most important indoor environmental factors in relation to health

The Committee notes that exposure to various indoor environmental factors occurs in schools and that due to their nature they may have adverse effects on the health of pupils. However, no studies are available that indicate the level of exposure in the school situation at which adverse effects start to occur. In answer to the minister's first question, the Committee concludes that it is not possible to state scientifically what the most important indoor environmental factors in schools are that result in adverse health effects. Nevertheless, the Committee is concerned about exposure to particulate matter, pathogens, allergens, and high temperature and noise levels in classrooms.

Carbon dioxide as a measure of ventilation in classrooms

Question 2. For which indoor environmental factors in schools is CO_2 a good indicator of ventilation? To what extent is CO_2 an indicator of air quality in classrooms?

The CO_2 concentration in a classroom is a good measure of the ventilation per person. To a limited degree CO_2 is also an indicator of body odours. CO_2 is less useful as an indicator of dust particles, allergens and pathogens dispersed by human beings. This is because the rate of CO_2 production is scarcely related to the rate of other substances dispersed by pupils. CO_2 is not a useful indicator of other substances and particles in indoor air, such as volatile organic compounds, plasticisers, dampness, fungi or outdoor air pollutants. CO_2 is therefore only a poor indicator of indoor air quality in classrooms. These conclusions do not affect the fact that increasing ventilation will reduce the CO_2 concentration as well as the concentration of other substances and small particles in the air.

Substantiation of the various CO_2 target values

Question 3. How do the background and reasons for choosing the CO_2 levels adopted by the Municipal Health Services relate to the CO_2 level adopted for policy purposes for the removal of pollutants from indoor air?

CO_2 target values as recommended by the Municipal Health Services. Municipal Health Services guidelines on assessing ventilation in schools recommend aiming for a CO_2 concentration of less than 800 ppm* for indoor air in schools. The Municipal Health Services in the Netherlands based this CO_2 target value on a report produced by an expert group it had established. This expert group concluded that the literature contained indications that indoor environmental factors at CO_2 concentrations even lower than 1,200 ppm led to health complaints, exacerbation of asthma, an increased risk of infection and were an impediment to school children's cognitive performance. The Committee takes the view that the evidence of the research studied is too limited to be used as a basis for determining target values.

CO_2 target value as basis for the Building Decree. The maximum CO_2 concentration of 1,200 ppm as basis for the Building Decree’s minimum ventilation requirements in new buildings was originally intended to limit odour nuisance. In 1984 the Health Council of the Netherlands deemed this value acceptable for housing. At the time, the Health Council had largely based its opinion on data from an experiment conducted in 1981 with a small number of adult volunteers. The Committee takes the view that the quality of these data was very limited.

Reconsideration of the 1,200 ppm CO_2 target value

Question 4. The 2003 Building Decree’s ventilation requirements in new buildings were aimed at avoiding odour nuisance and were based on the Health Council’s report of 1984. Are there any reasons from the health point of view for reconsidering the present CO_2 target value of 1,200 ppm?

Since the Health Council’s 1984 advisory report about twenty scientific papers have been published which contain information on the significance of air quality in schools for the health of pupils. Apart from odour nuisance upon entering a room, most of these studies did not demonstrate any adverse effects associated

* 98th percentile: the highest level, excluding the 2% highest measured levels

with increasing CO_2 concentrations. Nevertheless, there is a great deal of uncertainty about the results, which means there may have been a failure to detect an effect. In two studies the Committee found indications that health complaints arose or there was a reduction in pupils' cognitive performance at average CO_2 concentrations of about 1,200 ppm. There were more indications of adverse health effects in schools at average CO_2 concentrations exceeding 1,500 ppm, but it is unclear to what extent. Based on the available data, the Committee is of the opinion that a CO_2 target value for ventilation may be in a relatively wide range around 1,200 ppm. However, the data are inadequate for indicating a scientifically based exposure limit. The Committee therefore sees no reason to deviate from the present maximum CO_2 concentration of 1,200 ppm as the basis for the minimum ventilation requirements for new buildings as stipulated in the Building Decree. This means that some children may experience odour nuisance upon entering the classroom and that a sensitive child may experience an adverse effect.

Where the CO_2 concentration is intended as a measure of ventilation, it should actually concern the difference between the concentration in indoor air and that in outdoor air. Given a usual concentration of 400 ppm in outdoor air, a maximum CO_2 concentration of 1,200 ppm in indoor air corresponds with a concentration difference between indoor and outdoor air of no more than 800 ppm. The Committee recommends applying a concentration difference of 800 ppm as exposure limit for the extent of ventilation.

Recommended exposure limits for other indoor environmental factors in schools

Question 5: To what extent is it possible to set recommended exposure limits for ventilation-related, indoor environmental factors other than CO_2?

The Committee is of the opinion that it would be useful to develop recommended exposure limits for temperature and concentrations of particulate matter, non-infectious microbiological components and allergens in schools. However, no data on exposure-effect relationships are available for these factors.

Recommendations for a healthy indoor environment in schools

Given the finding that the average CO_2 concentration in Dutch classrooms is about 2,000 ppm, many schools ought to increase ventilation to keep CO_2 concentrations below 1,200 ppm. The Committee points out that the ventilation required for this can lead to – unnecessary – secondary effects, such as draught, noise nuisance or health effects caused by dust from the ventilation system's supply air filters, if they become contaminated due to poor maintenance. It is therefore necessary to have clean ventilation air and proper ventilation facilities as well as information on how to use them properly.

The scientific research on which the Committee has been able to base its findings is limited. Further research is therefore required into the effects of indoor air quality on the health and cognitive performance of pupils, especially those in sensitive groups, such as children with asthma, chronic headache or learning difficulties. In anticipation of the results of any such research, the Committee recommends a reduction in exposure to harmful indoor environmental factors in classrooms, as these may lead to health complaints especially in children with asthma. The government may stimulate this by establishing requirements and practical guidelines for:

- the design, installation, use and maintenance of ventilation facilities in schools, not only concerned with proper ventilation but also with minimising the emission of hazardous substances and the creation of draught and noise nuisance
- outdoor air drawn in to ventilate schools; in connection with this, ventilation systems in schools located in areas with polluted outdoor air, such as those close to busy roads, should have a suitable filtration system
- ensuring a healthy indoor climate in schools, by setting emission limits for irritating substances released by materials used in buildings, furnishings, teaching aids and equipment, and guidelines on the choice of floor covering and on classroom cleaning.

Chapter 1

Introduction

Children spend a considerable part of their time at school. It is therefore important to ensure a healthy indoor environment in schools. The physical indoor environment in schools is defined as a resultant of air quality, perceived temperature, noise and light.[1] Air quality depends on the strength of indoor and outdoor air pollution sources and on the rate of ventilation.

1.1 Indoor environment in schools is not optimal

In February 2008 the Dutch government ascertained that the quality of the indoor environment in primary schools could be improved.[2] This mainly related to air quality during the heating season, temperatures in classrooms during the summer and annoying noises. The concentration of carbon dioxide (CO_2) and especially the rate of ventilation are often used in practice as a measure of the quality of indoor air.[2] In line with an advisory report of the Health Council of the Netherlands published in 1984 a CO_2 target value* of 1,200 ppm** (0.12%) has been adopted in the Building Decree as a basic ventilation requirement for new buildings. Schools scheduled to be built or renovated must meet this requirement upon completion. These requirements were always intended to prevent odour nuisance and in 1984 the Health Council of the Netherlands deemed them acceptable for

* equilibrium concentration, which will not be exceeded during standard occupancy
** ppm: parts per million (1 ppm = 1.8 mg/m^3)

housing.[3] In 2007 the CO_2 target value of 1,200 ppm was exceeded in almost 90 percent of the samples taken in a representative random survey of 120 classrooms; the average CO_2 concentration was almost 2,000 ppm for 95 percent of the teaching period.[4]

1.2 Policy for a better indoor environment in schools

The results of various studies commissioned by the Ministry of Housing, Spatial Planning and the Environment formed the basis for designating the quality of the indoor environment in schools as one of the focal points of the National Approach to the Environment and Health 2008-2012.[5] To this end, the Ministry of Housing, Spatial Planning and the Environment, the Ministry of Education, Culture and Science, and the Ministry of Health, Welfare and Sport prepared a government vision on improving the indoor environment in schools.[2] Relevant components include the start of an 'awareness-raising programme', an incentive scheme for improving ventilation and making energy-saving alterations to school buildings* and a request for an advisory report from the Health Council of the Netherlands.

1.3 Ministers request Health Council for advisory report

As one of the action points in the government vision – and also acting on behalf of the Minister of Housing, Communities and Integration, the Minister of Education, Culture and Science and the Minister of Health, Welfare and Sport – on 8 February 2008 the Minister of the Environment and Spatial Planning requested the Health Council of the Netherlands to draft an advisory report on the effect of the indoor environment of schools on the health of pupils (see Annex A). The minister asked the following questions:

1. What are the most important factors in the school indoor environment that may have a harmful effect on the health of children and teachers and the cognitive performance of children? At what level of exposure can these effects occur?
2. For which indoor environmental factors in schools is CO_2 a good indicator of ventilation? To what extent is CO_2 an indicator of air quality in classrooms?
3. How do the background and reasons for choosing the CO_2 levels adopted by the Municipal Health Services relate to the CO_2 level adopted for policy purposes for the removal of pollutants from indoor air?

* Government provided EUR 165 million for this in 2009 and 2010.

4 The 2003 Building Decree's ventilation requirements in new buildings were aimed at avoiding odour nuisance and were based on the Health Council's report of 1984. Are there any reasons from the health point of view for reconsidering the present CO_2 target value of 1,200 ppm?

5 To what extent is it possible to set recommended exposure limits for ventilation-related, indoor environmental factors other than CO_2?

1.4 Questions examined by a Committee

The President of the Health Council of the Netherlands established a Committee to answer the questions contained in the request for an advisory report. Details of the Committee's composition are provided in Annex B. The Committee met eight times in total. Various external specialists were also consulted during the advisory process.

1.4.1 Delineation of the research question

Primary schools. In line with the government vision, the advisory report mainly focuses on pupils in primary schools. Where necessary, the Committee also makes use of the results of studies conducted in other populations, such as older pupils, students, teachers or the users of other buildings, including day nurseries.

Carbon dioxide and ventilation. Given the emphasis in the request for an advisory report on carbon dioxide as an indicator of ventilation and air quality, when considering the indoor air of primary schools the Committee focussed on pollutants which undergo changes in concentration as a result of ventilation.

Other ventilation-related indoor environmental factors. Other ventilation-related environmental factors which can affect the perceived quality of the indoor environment, such as humidity, temperature, air movement and noise from outside entering through open windows or the noise produced by mechanical ventilation systems, are only discussed indirectly by the Committee.

In Annex C the Committee outlines the source-exposure-effect chain for various ventilation-related indoor environmental factors in schools.

Indoor environmental factors which cannot be affected by ventilation, such as light and other forms of electromagnetic radiation and fields, are beyond the scope of this advisory report. Likewise, the Committee does not discuss the risks of radon* or asbestos.

1.4.2 Definition of the main terms used

The main terms used in this advisory report are defined as follows.

Health: physical, mental and social well-being. The Committee's definition is based on World Health Organization (WHO) descriptions for health, disability and disease and for quality of life.[7-10] Various adverse health effects may be partially related to one another:

- Conditions, such as asthma, allergies, irritation of the mucous membrane, infections
- Physical well-being and functioning:
  - physical symptoms, such as headaches, breathing difficulties, tiredness
  - impediments to physical functioning, such as reduced lung function, a deterioration in physical condition
  - impediments to sensory perception, such as a reduction in 'speech intelligibility'
- Mental well-being and functioning:
  - psychological symptoms, such as melancholia, anxiety
  - impediments to psychological functioning, such as reduced concentration, attention, reaction time, ability to learn or other aspects of cognitive performance
- Social well-being and functioning:
  - impediments to the extent of social functioning; this may be expressed as absence from school or a reduction in the number of contacts, for example
  - impediments to the nature of social functioning, such as lack of assertiveness or cooperation.

The Committee only considers effects on physical health and cognitive performance in this advisory report. In addition, Annex D provides details of a number of studies of the effect on (unspecified**) sickness-related absence.

* Radon is a naturally occurring radioactive inert gas which is released during the radioactive decay of radium and its traces are present in the soil and rock-based building materials. Radon can accumulate in the air in indoor environments. In the Netherlands, around 800 cases of lung cancer per year are estimated to be attributable to the radioactive decay products of radon.[6]

** unspecified: cannot be traced to a specific cause

Indoor air quality. For the purposes of this advisory report the quality of indoor air is made operational as the chemical and biological composition of the indoor air.

Perceived indoor air quality. This concerns a subjective assessment of the indoor air. The indoor air quality may be perceived as stale or stuffy. Besides body odours, the humidity and temperature of the room may contribute to a negative appraisal of the air quality. The same applies to 'smells' produced by perfumes or cleaning agents.

Ventilation. Ventilation is the supply of incoming air from outside the room and the extraction of air from the room. The supply of incoming air is generally drawn in from outside the building. When concentrations in outdoor air are lower than those in indoor air, ventilation reduces the concentrations found in the indoor air. The concentration of carbon dioxide (CO_2) is often used as an indicator of the rate of ventilation.*

Ventilation-related indoor environmental factors. The Committee defines ventilation-related indoor environmental factors as all indoor environmental factors which are related to ventilation either directly (indoor air quality) or indirectly (perceived indoor environmental quality).

Ventilation-related indoor environmental factors in schools. The following physical indoor environmental factors in schools are relevant to health and exposure to them can be affected by ventilation:

- chemical indoor environmental factors, especially nitrogen oxides and ozone, formaldehyde, volatile organic compounds, persistent organic compounds, such as plasticisers and polychlorinated biphenyls, and particulate matter
- microbiological indoor environmental factors, especially infectious micro-organisms, such as viruses and bacteria, non-infectious micro-organisms and microbiological components, allergens, including those produced by mites, fungi and pets at home, and indoor dampness and fungal growth on surfaces
- physical indoor environmental factors, such as humidity, temperature, air movement and noise.

* In Chapter 4 the Committee discusses the value of carbon dioxide as an indicator of ventilation and the quality of indoor air.

1.5 Committee's method of working

1.5.1 Preparation

At the start of the committee process various stakeholders were offered the opportunity to put forward points of interest and suggestions. A summary of the responses of the stakeholders consulted is provided in Annex E. The points raised underline the need for more and better research data to enable the formation of a substantiated opinion on the suspected adverse effects of inadequate ventilation on the performance of pupils and teachers.

1.5.2 Study of scientific literature

Within the scope of the Health and the Environment Action Programme for 2002-2006, the Ministry of Housing, Spatial Planning and the Environment commissioned Delft University of Technology to conduct a literature review on the health effects of indoor environmental factors in schools and day nurseries.[1] This study focussed on reports in Dutch ('grey' literature) and only discussed a small number of 'peer-reviewed' papers. The Health Council of The Netherlands therefore requested the University of Utrecht's Institute for Risk Assessment Sciences (IRAS) to produce a supplementary overview of international, scientific literature on the main ventilation-related indoor environmental factors in schools. The scientific literature study, which also included an assessment of the quality of the scientific publications, was discussed by the Committee and was an important source of information for answering the first question in the request for an advisory report.[11] Texts and the associated references have been incorporated in various places in the present advisory report.

In particular Medline and Web of Science were used as approaches in the IRAS scientific literature overview. The search strings used were 'school and indoor', 'school and ventilation', 'school and CO_2 (carbon dioxide)'. The study, which was restricted to English and German scientific literature, was concerned with the period up to March 2008. Using the snowball method, attention was then paid to the publications that were cited. In addition, members of the Committee also presented various publications on the basis of their expertise. The emphasis was on studies which aim to establish relationships between aspects of the indoor environment in schools and health as measured. As so little is known about schools, there was also a discussion of a number of studies concerned with the indoor environment in office buildings.

1.5.3 Assessment method

The draft advisory report was reviewed by members of the Health Council's Standing Committee on Health and the Environment.

1.6 Organisation of the advisory report

Following this introductory chapter, Chapters two and three present the Committee's reply to the first question in the request for an advisory report, regarding the effect of the indoor environment in schools on pupils' physical health and cognitive performance respectively. Chapter four is concerned with questions two to four of the request regarding the value of carbon dioxide (CO_2) as a measure of ventilation and air quality in schools. In Chapter five the Committee answers the minister's final question concerning the drafting of recommended exposure limits for other agents than CO_2. Finally, Chapter six presents the Committee's recommendations for a healthy indoor environment in schools.

Chapter 2

Health effects

The minister's first question was twofold:

What are the most important factors in the school indoor environment that may have a harmful effect on the health of children and teachers and the cognitive performance of children? At what level of exposure can these effects occur?

This chapter only deals with the first part of the question concerning the effects on physical health. The Committee prefers the term adverse effects rather than harmful effects, as this avoids limiting the discussion of effects to those which are severe or irreversible. The effects on cognitive performance are discussed in Chapter 3. The present chapter discusses the effects of the physical quality of the indoor air, the perceived quality of the indoor air, ventilation and other ventilation-related indoor environmental factors. The extent of the evidence of adverse health effects of children has been examined for each category, where possible in the form of an exposure-effect relationship. The interpretation of the study results includes an appraisal of the extent to which investigators took into account possible confounding or modification of the outcomes owing to factors such as age, gender, socio-economic status, risk perception, discomfort or stress.

Summary of literature. The Committee has summarised the conclusions of the scientific literature, also in the form of a table* if considered informative** for an association with CO_2 or ventilation. The Committee has set out its interpretation in the last column of the tables and has indicated the size of the effect where possible, usually in the form of an odds ratio (OR) or correlation coefficient (r) along with the confidence interval. However, the use of the word 'effect' does not mean that CO_2 or ventilation is the direct cause. The Committee has roughly classified the probability of an effect into four categories, from 'plausible that no effect occurred', through 'no effect demonstrated' and 'indication of an effect' to 'effect demonstrated'. In practice the 'health-based recommended exposure limit' should be at a level of exposure for which it has been demonstrated that no adverse effects occur***. In the absence of data on this, the Committee is of the opinion that it is not only necessary to prevent exposure levels for which adverse effects have been demonstrated but also to prevent exposure levels for which sufficient 'indications' of an adverse effect exist. This categorisation also offers the possibility of only considering a statistically significant association as an indication, for example when there appears to be a type of bias. For a more in-depth discussion of the original studies see Annex D. This is based on the study of scientific literature which was conducted at the request of the Health Council of the Netherlands by the Institute for Risk Assessment Sciences (IRAS).[11]

2.1 Indoor air quality

This section discusses the health effects of exposure to pollutants. The quality of indoor air is determined by the chemical, physical (dust particles) and biological composition of the indoor air.

2.1.1 Chemical substances

Building and furnishing materials in schools may also emit organic compounds such as formaldehyde from particle board, volatile organic compounds from paint, or more persistent organic compounds, such as plasticisers or polychlorinated biphenyls (PCBs).[12-20] Another important source of chemical substances in

* in the case of three or more relevant studies on the association with CO_2 or ventilation in schools or experimental rooms[b]

** the studies are shown in the same order as that used in the annex (according to their evidence: from intervention studies to cross-sectional studies)

*** for the present purposes this means 'risks of a size which is socially unacceptable' classrooms is pollution entering from outdoor air, such as nitrogen oxide emissions from traffic.[21,22]

Studies abroad indicate that pupils report more asthma and other respiratory symptoms in schools in which increased concentrations of formaldehyde, volatile organic compounds or plasticisers occur owing to the building, furnishing or teaching materials*.[13,17,18] The Committee is unaware of the existence of any scientific publications concerning concentrations and possible health effects in Dutch schools or concerning the effectiveness of emission-reducing measures.

2.1.2 *Particulate matter*

As pointed out above, outdoor air pollution may also have a detrimental effect on the indoor environment of schools. In recent years attention has mainly focussed on schools close to busy roads, also as a source of particulate matter. Several hundred schools in the Netherlands are located close to busy roads**. A study conducted by Amsterdam Municipal Health Services in a primary school 100 metres away from the A10 motorway showed that not all filter systems are equally as effective in filtering particulate matter and soot particles from outside.[25] No study has been conducted of whether such filtering affects how health is experienced.

Previous Dutch publications showed that the indoor air in schools located close to motorways was polluted and that children attending those schools had more respiratory symptoms.[26-28] Significantly increased concentrations of particulate matter (PM_{10}***) were detected in two schools during – but not outside – lessons.[29] Further analysis of the dust indicated that it was probably mainly airborne dust created by pupil activities. Similar findings were made in other European countries, with daily average PM_{10} concentrations**** in classrooms of 50-100 µg/m³.[17,21,30-38] However, extremely fine dust particles (< 100 nm) occur in classrooms less extensively than in outdoor air, which reflects the fact that the sources concerned are found outside the building; this mainly concerns road traffic. The concentration of larger particles proved to be higher in the lowest age-group classes than in the highest, which may be related to pupil activities. *In vitro*

* The health-based recommended exposure limit of the Health Council of the Netherlands for volatile organic compounds in accommodation spaces (200 µg/m³) is based on sensory observations as most critical effect.[23]

** On 1 September 2007, 43 schools in the Netherlands were located within 100 metres of a motorway and 232 schools between 100 and 300 metres of a motorway and 72 schools were located within 50 metres of a provincial road.[24]

*** PM_{10}: particles (‘particulate matter’) with a median aerodynamic diameter of less than 10 µm.

**** 24-hour exposure limit for particulate matter (PM_{10}) in outdoor air: 50 µg/m³.

studies show that dust of this kind has the potential to cause inflammatory reactions in the respiratory system.[34] The effect of ventilation on PM_{10} concentrations is inconsistent.[39] On the one hand ventilation can remove particles from the air, on the other hand the air flow can cause an upswirl of settled dust.

In summary, particulate matter in the indoor air of classrooms comes not only directly from outdoor air (the finer fraction) but also from dust which enters in the air through the children's behaviour (the coarser fraction). The concentration of airborne dust, especially the coarser dust particles, is often greater indoors than outdoors owing to activities in the classroom. It is plausible that high exposure to these particles could exacerbate respiratory symptoms, especially in the case of asthmatic pupils.

2.1.3 *Infectious micro-organisms*

Various infectious diseases are transmissible through the respiratory system. Diseases such as influenza, chicken pox, measles and tuberculosis are mainly transmitted through droplets in the air (aerosols).[40] Transmission by contact through the skin and mucous membrane appears to play a more important role in the transmission of other infections, such as the Respiratory Syncytial (RS) virus, than transmission by aerosol inhalation.[41] Viral respiratory infections are most readily transmitted in schools and this is combined with an exacerbation of asthmatic symptoms, sometimes resulting in hospitalisation.[42] Schools play an important role in the spread of influenza and other viral infections in the population.[43-46] However, actually closing schools in Hong Kong had no substantial impact on the spread of influenza.[47]

The *Green Schools* report of 2006 by the American National Research Council includes an in-depth examination of the transmission of infections in schools.[48] The factors which affect the transmission of infections are varied and include direct transmission through coughing, touching contaminated surfaces, such as tables and toys, and the limited removal of infectious droplets exhaled through coughing. This explains why no clear association has been found between the rate of ventilation and the likelihood of infections. A review article in 2007 on the role of ventilation in the transmission of infectious agents described forty studies.[49] One of these studies concerned a school: in 1974 the ventilation system of a school in New York was believed to be responsible for a measles epidemic* because of the high volume of air that was recirculated in the

* The measles virus is known to be one of the most infectious viruses.[50] One case of measles can lead to hundreds of secondary cases.

school.[51,52] Other factors which played a role in the epidemic's rapid spread were exceptionally high infectiousness of the index patient and the fact that many children had not been vaccinated or had only been vaccinated in their first year of life and were consequently not completely immunised.

Table 1 shows the main findings of epidemiological studies on the association between ventilation, exposure to micro-organisms and absence through respiratory symptoms in schools.

The table shows that there is a lack of empirical data on the association between ventilation and the occurrence of infections as a result of micro-organisms in schools. There are only indications of an association between the rate of ventilation and the degree of exposure to airborne bacteria, also at CO_2 concentrations below 1,200 ppm.

Table 1 Overview of studies on exposure to micro-organisms in schools.

First author, year of publication	Type of study	Population	Exposure (micro-organisms or indicators for the degree of ventilation)	Measure of effect / outcome	Size of the effect (confidence interval / P value)	Probability of effect
Sandora, 2008[53]	RCT[a]: disinfection vs normal cleaning	Primary school pupils (grade 3-5) Ohio, US (n=285)	Presence vs absence of Norovirus and respiratory system virus on surfaces	Absence through respiratory symptoms ('blind' registration)	RR[b]:1.10 (0.97-1.24)	±
Bartlett, 2004[54]	Cross-sectional study[c]	116 classrooms in 39 primary schools, Canada	CO_2 concentration (850-1,100 ppm) and mechanical ventilation (in L/s pp[d])	Bacteria (CFU/m^3) in the air	r=0.584; p<0.001 and r= -0.322; p<0.001 respectively	+
Liu, 2000[55]	Cross-sectional study	class rooms in 2 primary schools, South Carolina, US	CO_2 concentration (600-1,600 ppm)	Bacteria (CFU/m^3) in the air	r=0.90; p<0.001	±

- plausible that no effect occurred (minimum size of effect and narrow confidence interval)
± effect not demonstrated but also not ruled out (broad confidence interval) -> non-informative study
+ indications of effect (0.05<p<0.10 or a degree of bias is plausible)
++ effect demonstrated (p<0.05 and bias unlikely)

a RCT: randomised controlled trial
b RR: relative risk
c Cross-sectional study
d L/s pp: litres per second per person

Plausibility. In accordance with the laws of physics (dilution), increasing ventilation in a classroom on a school day will result in a corresponding reduction in the concentrations of pollutants present in the air, including CO_2, small particles and aerosols. It is plausible that this could result in a decrease in the likelihood of an infection being transmitted by aerosols. However, no empirical data are available to substantiate this. The extent to which an infectious disease actually occurs also depends on various other factors, such as the amount and virulence of the micro-organisms, the humidity and temperature of the air and the sensitivity of the infected person.* In particular, when they remain in the air various types of micro-organisms undergo a reduction in pathogenicity, as a result of UV radiation, for example. There is a strong possibility of the likelihood of infection decreasing when CO_2 concentration decreases but the size of any such decrease cannot be predicted on the basis of the CO_2 reduction or the increase in ventilation. Moreover, the significance of any such decrease in the likelihood of infection is unclear because the degree to which transmission by aerosols contributes to the total is unknown.

Distribution models. Model calculations predict that an increase in ventilation in a school will result in a reduction in micro-organism concentrations in the air and therefore possibly a lower likelihood of infections.[56-59] In rooms occupied by a relatively high number of people there is an association between micro-organism concentrations in the air and CO_2.[60] This is supported by measurements made in schools.[54,55] However, calculations which only take into account the spread of infections through the air are seriously lacking because many respiratory infections are transmitted in several ways, also by coughing, sneezing or contact with infected persons or surfaces, for example.[61] Useful models of the spread of influenza in schools therefore focus on the number of contacts with other children.[43]

In summary, pathogenic micro-organisms (pathogens) and therefore infectious diseases can be transmitted through the air in schools. However, the extent to which infections which are transmissible by air are in fact transmitted by the air in schools is not known. Distribution models indicate that the risk of airborne infections is greater when there is less ventilation. However, the degree of effectiveness of ventilation in reducing the number of respiratory infections in schools in contrast to the infections which children contract through skin contact or at home is not known. It is therefore not possible to say what increase in the rate of

* Personal communication Dr N.G. Hartwig, paediatrician for infectious diseases.

ventilation would lead to a reduction in the incidence of infectious diseases and thereby the burden of disease.

2.1.4 *Non-infectious microbiological components*

Non-infectious microbiological components are components of bacteria and fungi which can cause inflammatory reactions and/or affect the response of the immune system to allergens. Bacterial endotoxins are components of the cell wall of gram-negative bacteria. These bacterial fragments probably come from pupils' skin particles.[37] Fungal components include β 1→3 glucans.[62] A study in homes has indicated an association between exposure to β 1→3 glucans and the occurrence of respiratory symptoms.[63] The results of studies on the effect of endotoxins on symptoms of this kind are inconsistent.[62] On the one hand, exposure to high concentrations at a young age appears to provide protection against the development of allergies, whereas exposure at an older age is a risk factor for the development of respiratory symptoms.[64] On the basis of the limited amount of available scientific literature on schools, the Committee notes that little knowledge exists on the health significance of exposure to bacterial endotoxins and fungal components in schools.[37,65]

2.1.5 *Allergens*

Exposure to specific allergens can cause allergic sensitisation.[62] Allergic symptoms may occur, depending on the genetic predisposition, intensity, duration and period of exposure and the degree of sensitisation. An allergic reaction of this kind may manifest in the lungs (allergic asthma), the nose and eyes (allergic rhinitis and conjunctivitis) or in the skin (atopic eczema). Reactions in the first two categories are examples of an allergy to inhaled substances (‘inhalation allergens’) and are also known as ‘respiratory tract allergies’. Many existing inhalation allergens come from dust mites, pets, pests, pollen and fungi.

A review paper in 2005 described the results of 36 studies in which allergens from dust mites, cats, dogs or cockroaches were studied in schools.[66] The amounts of these allergens which were found were often lower than those found in homes but were not lower than those found in remediated homes or – in the case of dust mite allergens – those found in homes with no pets.

Mainly on the basis of scientific literature published in other countries it appears that children carry various allergens to school. In schoolchildren, head hair and clothing are the main sources of allergens which occur in the home, especially those from pets.[67,68] A high number of families in the Netherlands has pets, mainly dogs and cats.[69] This results in many children at school coming into contact with classmates who have pets at home. Consequently, the classroom may be a major source of exposure to cat and dog allergens. Children with asthma or an allergy can therefore be exposed to clinically relevant levels of respirable allergens and develop allergic symptoms. A great number of studies has been conducted on the presence of allergens in classrooms.[70-73] A few studies refer to the association with sensitisation, bronchial hyperreactivity or allergic symptoms.[74-76]

An intervention study following extensive remediation measures in classrooms showed no reduction in exposure to cat allergens resulting from upswirling floor dust.[77] However, there was a reduction in exposure when children at school did not wear clothing which they brought from and took back home with them.[78]

The Committee does not exclude the possibility that the rate of ventilation in classrooms may affect the incidence of allergic symptoms caused by exposure to cat allergens at school brought in by classmates with pets at home.

2.1.6 *Indoor dampness and fungal growth*

Damp spots on walls are a frequent location of fungal growth, which increases exposure to fungal products in the indoor air. There are indications of an association between, on the one hand, indoor dampness and fungal growth in schools and, on the other hand, respiratory and other symptoms among pupils and teachers.[13,79] The possibility cannot be excluded that publicity about adverse health effects of dampness or fungal products has affected the reporting of symptoms.[80] Fungal growth sometimes occurred after leaks.[81] The symptoms usually decreased after remediation.[81-84] There are also indications of inflammatory reactions in the nasal mucous membrane caused by fungi in schools.[85-89] The Committee points out that a great deal of studies is conducted in countries with a colder climate than that in the Netherlands and that the results cannot therefore simply be applied to Dutch schools. In particular, a great deal of studies in Scandinavia has been conducted into problems concerning dampness and fungal growth in schools. The sometimes extremely low winter temperatures can lead to condensation in the building and thereby lead to fungal growth. The extent to which indoor dampness and fungal growth occur in Dutch schools has not been investigated. Given the finding that fungal concentrations in schools with mechanical ventilation were higher than those with natural ventilation through windows, there is a possibility that mechanical ventilation systems may also be a source of fungi.[90-92]

2.1.7 *Pollutants from mechanical ventilation systems*

Physical symptoms with an unknown cause are frequently attributed to the building itself, often a building with mechanical ventilation or air conditioning. To this 'sick building syndrome' belong symptoms of the skin, eyes, upper respiratory tract, tiredness and headaches. Such symptoms can be caused by pollutants in the indoor air but are also affected by the perceived indoor air quality, perceived temperature, noise nuisance, stress, or facilities for ventilation according to an individual's own requirements.

Danish studies indicated that more physical symptoms occurred in schools with mechanical ventilation systems than in those with natural ventilation, despite the fact that schools with mechanical ventilation had lower concentrations of CO_2 than those with natural ventilation.[90,91] A study in Dutch offices showed that most symptoms occurred in the 'best' ventilated buildings, often those with air conditioning.[93] A possible explanation is poor quality of the supply of incoming air from contaminated ventilation systems. Other studies in offices also showed that mechanical ventilation systems are a possible source of pollutants.[94] Replacing used filters with new ones led to a reduction in symptoms of nose and eye irritation in an office building in Denmark.[95]

In summary, scientific literature on offices in particular indicates that poorly maintained mechanical ventilation systems and air conditioning systems can give rise to physical symptoms. The Committee is of the opinion that contaminated ventilation filters and supply ducts may also lead to physical symptoms in schools. Section 2.3 discusses the effect of the ventilation rate – which is usually measured on the basis of the CO_2 concentration – on the occurrence of physical symptoms.

2.2 Perceived indoor air quality

Air quality in classrooms and other indoor environments may be perceived as stale or stuffy. Body odours, as well as smells produced by perfumes or cleaning agents, for example, and the humidity and temperature of the room may contribute to a negative appraisal of the air quality. There has been a tendency in the ventilation industry to concentrate on odour nuisance for visitors to a space, also bearing in mind that occupants of a space can be considered as visitors if they leave a room for a few minutes before returning to it.

This section discusses the relationship between ventilation, CO_2 – which is odourless – and odour perception, noise, perceived air quality and health.

2.2.1 *Body odours*

Table 2 provides an overview of studies on the association between annoying body odours and the CO_2 concentration or other indicators of the ventilation rate.

The table shows that in experiments* in the concentration range up to 1,500 ppm no exposure-effect relationship was found between CO_2 and odour nuisance among adults who remained in the room ('occupants').[97,98] However, confidence intervals are not described. An experiment conducted in four computer rooms showed that after an increase in ventilation, students only perceived an improvement in air quality during the first fifteen minutes.[96] This was followed by a natural adaptation to the odour. However, an association does exist between CO_2 concentration and perceived odour nuisance in the case of 'visitors' to a room. For example, in a Danish experiment the percentage of students who experienced the body odour as 'unacceptable' upon entering a lecture hall increased from around 20 to 30 percent, in the CO_2 concentration range from 600 to 1,500 ppm.[97] In an experiment in the United States the perceived odour intensity, especially by visitors, was dependent on the ventilation rate.[98] There is an absence of experimental studies on associations of this kind in the case of schoolchildren.

2.2.2 *Other odours*

Two experiments in an office situation with a twenty-year-old carpet as the odour source confirmed that odour nuisance upon entering a room is greater than during a period spent in the room, that an odour source can have adverse effects on the perceived air quality and that those effects are reduced by ventilation.[102.103] As the outcomes were dependent on the pollution caused by the carpet, they are not significant for schools without an old carpet. Contaminated filters in the air supply ducts of mechanical ventilation systems are another source of odour in buildings.[94,95,104]

* Experiment: short-term intervention study with controlled (usually non-blinded) exposure.

Table 2 Overview of studies on the association between ventilation and annoying body odours.

First author, year of publication	Type of study	Population (number and age)	Exposure (indicators of the degree of ventilation)	Measure of effect / outcome	Size of the effect (confidence interval / P value	Probability of effect	Comments
Norbäck, 2008[96]	Experiment (reduction and increase of ventilation in 4 computer rooms)	University students aged 20-25 years, in Sweden (n= 121)	Reduction vs increase of ventilation (7 vs 10-13 L/s pp) CO_2 (ppm): 1,100-900	Perceived air quality upon entering (0 = extremely poor; 6 = extremely good)	0.1 vs 1.1; p<0.007	+	Not adjusted for number of students per classroom. Given the reported draught nuisance, not adequately 'blinded' for the rate of ventilation. Doubtful relevance for primary schools owing to large number of computers.
Berg-Munch, 1986[97]	Experiment in lecture hall	Students, Denmark (n=79 visitors; n=106 users)	CO_2 (ppm): 600->1,500	'Unacceptable' odour nuisance occupants	No effect demonstrated	±	No statistics or distribution reported.
				'Unacceptable' odour nuisance visitors	20->30%	+	No information on humidity and temperature
Cain, 1983[98]	Experiment in test room	Volunteers, United States (n=165)	Degree of ventilation (2.5->10 L/s pp)	Odour nuisance occupants	No effect demonstrated (6->6%)	±	Odour impact increased at a high temperature (> 25°C) and humidity (> 70%)
				Odour nuisance visitors	43->16%	+	
Wanner, 1982[99]	Experiment in test room	Volunteers, Switzerland (n: not reported)	CO_2 (ppm): 500-2,000	Odour nuisance test panel (visitors)	'Significant' effect for odour intensity	++	No statistical test report but a convincing distribution diagram was provided
Bouwman, 1981[100]	Experiment in test room	Volunteers, the Netherlands (15-minute average occupancy: <10)	CO_2 (ppm): 600-1,750	Odour nuisance	10% found odour at 1,200 ppm no longer acceptable	+	Small number of subjects
Versteeg, 2007[4]	Cross-sectional study	Teachers in 120 classrooms of 60 primary schools in the Netherlands	CO_2 (ppm): 1,200-2,000 Mechanical vs natural supply	Perceived air quality	Almost no effect demonstrated Lower for mech. supply	±	
Potting, 1989[101]	Cross-sectional study	Children aged 9-10 years at 7 newly built schools in Rotterdam (n=333)	CO_2 (ppm): 1,900-4,000	Odour nuisance occupants	OR: 2.86 (1.01-8.11)	++	

- plausible that no effect occurred (minimum size of effect and narrow confidence interval)
± effect not demonstrated but also not ruled out (broad confidence interval) -> non-informative study
+ indications of effect (0.05<p<0.10 or a degree of bias is plausible)
++ effect demonstrated (p<0.05 and bias unlikely)

2.3 Carbon dioxide and other indicators of ventilation

The concentration of carbon dioxide (CO_2) is often used as an indicator of the rate of ventilation and as an indirect indicator of the quality of indoor air (see 4.1). An association between the CO_2 concentration in the air of an accommodation space and the perception of body odours had been established as early as the nineteenth century.[11] It was only at CO_2 concentrations of many thousands of ppm that physiological effects were described, such as increased cerebral blood flow and disruption of breathing during sleep.[105,106]

Studies in schools. A literature review was published in 2007 by Delft University of Technology on the indoor environment and health in schools and day-care centres for children.[1] It discussed three studies conducted in the Netherlands which attempted to establish an association between ventilation (CO_2) and potential health effects.[101,107,108] Two of the studies were published in peer-reviewed journals.[101,107] Despite the high CO_2 concentrations in these two studies (more than 2,000 and 4,000 ppm* respectively) neither study demonstrated an association between CO_2 and various health indicators. However, owing to uncertainty about the validity of the questionnaire, the possibility of an association cannot be excluded. An overview of the international scientific literature published in 2003 noted that few peer-reviewed studies are available on adverse health effects of indoor air quality and ventilation in schools.[109] The results were inconsistent of the only two studies prior to this which investigated the association between CO_2 concentrations (up to around 4,000 ppm) and physical symptoms in schools, including one of the studies conducted in the Netherlands.[101,110]

Table 3 provides an overview of the studies which describe the association between the occurrence of physical symptoms among pupils and the CO_2 concentration or other indicators of the rate of ventilation in classrooms.

* A CO_2 target value of 1,200 ppm has been adopted in the Building Decree as a basic ventilation requirement for new buildings.

Table 3 Overview of studies on the association between pupil health and the CO_2 concentration or other indicators of the rate of ventilation.

First author, year of publication	Type of study	Population (number and age)	Exposure (indicators of the degree of ventilation)	Measure of effect/ outcome	Size of the effect (confidence interval / P value	Probability of effect	Comments
Norbäck, 2008[111]	Experiment (increase and reduction of ventilation in 4 computer rooms)	University students aged 20-25 years, in Sweden. Longitudinal: n= 121 Cross-sectional: n=355	Degree of ventilation: 10-13 vs 7 L/s pp CO_2 (ppm): 900 vs 1,100	Non-specific symptoms	Longitudinal: no significant effect	±	Not adjusted for number of students per computer classroom.
					Cross-sectional: significant effect for headaches: +19% per 100 ppm CO_2	+	Doubtful relevance for primary schools owing to large number of computers.
Smedje, 2000[112]	Repeated cross-sectional study (before and after fitting new ventilation system)	Schoolchildren aged 7-13 years, Sweden: 7 schools with new ventilation system (n=143); 50 schools without (n=1,333)	CO_2 (ppm) 780 vs 1,020	Formaldehyde, volatile organic compounds, particulate matter, fungi in indoor air, humidity	Reduction in indoor air factors (p<0.05)	+	Unclear to what extent concentrations of fungi and other indoor air factors correspond with those in Dutch schools.
				Asthmatic symptoms (January-March 1995 vs March-May 1993)	Reduction in incidence of asthmatic symptoms: OR:0.3 (0.1-0.8)	+	Information bias unlikely (no reduction in headaches, tiredness and reported number of respiratory infections).
Van Dijken, 2006[107]	Cross-sectional study	Schoolchildren aged 10-11 years, Eindhoven region (n=228)	CO_2 (ppm) 888-2,112	Physical symptoms	No significant effect No useful measure of effect	±	No exposure-effect relationship can be deduced, owing to 'principal component analysis'; however, a relationship between the quality of the school and home environments could be determined.
Potting, 1989[101]	Cross-sectional study	Children aged 9-10 years at 7 newly built schools in Rotterdam (n=333)	CO_2 (ppm): 1,900-4,000	Various non-specific symptoms	No significant effect	±	Validity of questionnaire unclear: poor correspondence between answers to corresponding pairs of questions.
Kim, 2005[30]	Cross-sectional study	Schoolchildren aged 5-14 years, Sweden (n=1,014)	CO_2 (ppm): 400-1,300	Respiratory and allergic symptoms	Tends towards opposite effect: OR:0.7-0.9 (n.s.)	±	Low CO_2 concentrations owing to mechanical ventilation systems.
Smedje, 1997[17]	Cross-sectional study	School children aged 13-14 years, Sweden (n=600)	CO_2 (ppm): 550-1,725	Asthma symptoms	No significant effect	±	

Myhrvold, 1996[110]	Cross-sectional study	School children aged 15-20 years, Norway (n=550)	CO_2 (ppm): 600-4,000	• Non-specific symptoms • Symptoms of irritation of upper respiratory system	r=0.22; p=0.000 r=0.10; p=0.024	+ +	Only published as conference proceedings.

- plausible that no effect occurred (minimum size of effect and narrow confidence interval)
± effect not demonstrated but also not ruled out (broad confidence interval) -> non-informative study
+ indications of effect (0.05<p<0.10 or a degree of bias is plausible)
++ effect demonstrated (p<0.05 and bias unlikely)

Seven studies at schools examined the association between the occurrence of physical symptoms among pupils and the CO_2 concentration or other indicators of the rate of ventilation in classrooms. The results of a Swedish experiment in four computer rooms were inconsistent.[111] In the cross-sectional part an increased CO_2 concentration was associated with headaches, but in the longitudinal part an increase in ventilation was not combined with a statistically significant reduction in the number of physical symptoms, including headaches. It is doubtful whether this experiment is relevant for the situation in primary schools, owing to the large number of computers in the classrooms. An earlier Swedish study in primary schools showed an improvement in ventilation and a reduction in the incidence of asthmatic symptoms after the installation of ventilation systems.[112] There was no reduction in the incidence of headaches, tiredness and the reported number of respiratory infections. The authors believed it was therefore improbable that the reported decrease in asthmatic symptoms could be explained by the fact that participants were aware that new ventilation systems had been fitted. It is unclear to what extent this reduction can be attributed to a reduction in fungi and other factors in indoor air, which may be higher in Swedish schools than in Dutch schools. Of the five observational* studies, the four which were published following a peer-review process found no association between the rate of ventilation and physical symptoms.[17,30,101,107,113] In the study results which were only published as conference proceedings the correlations between CO_2 and physical symptoms and thereby the 'explained variance' were extremely low.[110] The Committee concludes that an indication of an association between the rate of ventilation in schools and the occurrence of asthmatic symptoms was only found in one of the seven studies examined.

* observational study: study on the occurrence of health indicators in the population, without affecting the conditions (in contrast to an experiment)

Studies in offices. Far more studies have been conducted in offices than in schools into the effect of the rate of ventilation and other indoor environmental factors on non-specific symptoms. The extensive scientific literature on this subject describes relationships between CO_2 concentrations and the occurrence of physical symptoms. These studies are frequently cited in analyses of the indoor environment in schools. The Committee points out that office buildings in other countries are hardly comparable with Dutch primary schools, most of which still have no air conditioning. Another important fact is that the average occupancy rate in classrooms is almost always much higher than in offices. For the same outdoor air supply rate per person the extraction rate of pollutants not produced by humans, such as building materials, would be considerably greater in schools than in offices. Given the lower occupancy rate in office spaces, there would be a higher concentration of pollutants produced in the space for the same CO_2 concentration. For a source of the same level, the concentration would be more likely to be in a concentration range at which adverse effects occur than would be the case in schools. Therefore, in an office space, an association could be found at a certain CO_2 concentration between the rate of ventilation, 'emissions from materials' and physical symptoms, whereas such an association might not necessarily exist in a classroom. Besides differences in ventilation systems and occupancy rates, the sources of pollutants in offices, such as office supplies and equipment, may differ from those found in schools.[114] Consequently, data on quantitative relationships between CO_2 concentrations and the prevalence of symptoms in offices cannot simply be applied to schools.

2.4 Other ventilation-related indoor environmental factors

This section discusses the effect of other – mostly physical – ventilation-related indoor environmental factors, not only on health but also especially on 'thermal comfort' (perceived temperature or comfort) in the indoor space. This particularly concerns the indoor environmental factors humidity and temperature, which can also be affected by ventilation. Other important 'comfort factors', such as draughts and noise nuisance, are side effects of ventilation facilities. In recent decades the focus was more on these side effects owing to ventilation facilities being fitted at low heights and therefore being more likely to cause draughts, or owing to the installation of mechanical ventilation facilities which produce noise.

2.4.1 Humidity, temperature and air movement

Humidity. A laboratory experiment showed that indoor air was perceived as more stale and less acceptable in proportion to increasing relative humidity* (from around 50%).[115,116] This effect was reinforced at temperatures exceeding 20°C. At a relative humidity of 30% and lower, contact lens wearers and people with skin disorders experience physical symptoms such as dry eyes or dry skin.[116] A study conducted in a representative random selection of Dutch primary schools showed that relative humidity in the winter was generally in line with the 'target value' recommended by the Inspectorate for Housing, Spatial Planning and the Environment of at least 20% and no more than 60%.[4]

Temperature. Many schools have problems with high temperatures in summertime due to heat from the sun, unless they have proper climate control. Nuisance from body odour also increases at temperatures exceeding 25°C.[98] A high temperature may not only result in feelings of discomfort but also headaches and tiredness.[117] A study conducted in the Netherlands confirmed that the thermal indoor climate in summer is one of the main problems with the indoor environment in primary schools; 45 percent of teachers reported often being too warm in the classroom during the summer.[4] Thermal comfort could be controlled better in classrooms with mechanical facilities for air supply and extraction than in the other types of classrooms. Secondary reasons for this finding were that classrooms with mechanical facilities for air supply and extraction had generally been built more recently and consequently had facilities for controlling the temperature in summer other than by means of ventilation, such as roof insulation, less glass or more sunblinds.[4] In the winter, average minimum and maximum temperatures in practically all the classrooms investigated complied with the room temperature target value of 19 to 23°C** recommended by the Inspectorate for Housing, Spatial Planning and the Environment.

Air movement. Air movement can create draughts, a sensation of an unwanted local cooling of the skin. Ventilation can especially lead to draught problems when outdoor temperatures are low. Even a small amount of ventilation can cause draughts, especially if there is only a short distance between the ventilation

* Relative humidity indicates the percentage of water vapour found in air in relation to the maximum at a given temperature and atmospheric pressure.

** at a relative humidity of 20-60% (in winter) openings and the pupils. This is a major barrier to using some ventilation facilities. In Dutch primary schools with classrooms in which ventilation is entirely natural by means of horizontally pivoted windows or top-hung windows, 60 percent of teachers reported problems with draughts.[4] Forty percent of the respondents reported that the creation of draughts limited the use of ventilation facilities of this kind.

The Committee concludes that high humidity and especially a high temperature adversely affect the level of comfort in the indoor space. A high temperature may also lead to physical symptoms. Draughts in classrooms with entirely natural ventilation can be such a nuisance factor that teachers keep windows closed.

2.4.2 *Noise*

The noise level in a classroom is linked with the noise level outside, the sound insulation properties of the wall and the ventilation system used, the noises produced by the schoolchildren and teachers in the classroom and other noises in the building which enter the classroom. With no children and teachers present in a representative random selection of 120 classrooms in 60 Dutch primary schools, 47 percent of the classrooms proved to have a background noise level of more than 35 dB(A)* when ventilation facilities were in operation.[4] The noise level in classrooms with mechanical facilities for air supply and extraction was even higher than 35 dB(A) in 62 percent of the classrooms. Thirty percent of teachers in classrooms with mechanical ventilation reported experiencing this as a nuisance. A quarter of teachers in classrooms with a natural air supply through the wall reported noise from outside as a reason for closing the ventilation facilities.

In summary, normal noise levels in the classroom, which are also affected by the use of ventilation facilities, can be experienced as a nuisance.

2.5 Considerations

Before discussing the answer to the question regarding the most important factors in the school indoor environment which may have adverse health effects, the Committee provides a number of comments on the available studies.

* This is the maximum permissible noise level which is expected to be included as a new requirement in the Building Decree for noise produced by mechanical ventilation systems.

Quality of studies. Studies on the effect of indoor environmental factors in schools on physical health is subject to limitations. In the first place, there was often a lack of clarity about the validity of the questionnaires that were used. In addition, the interpretation of observational studies on the relationship between the indoor environment in schools and health is made difficult because health is affected by numerous factors. Moreover, the relationships between the concentrations in indoor air and the effects are rarely quantified. As far as is known, no randomised controlled trial has been published into the association between the rate of ventilation and physical health. Studies to answer specific questions which have been conducted in a similar manner are generally too scarce to enable a systematic review of scientific literature or meta-analysis.

Effect of ventilation on health. Owing to exposure to other risk factors, such as dust mite allergens or infectious micro-organisms, the results of studies on the effect of ventilation on the health of pupils are probably rather too confounded to generate reliable exposure-effect relationships. Because no information is available on the number of pupils who are exposed to relevant factors in indoor air or their exposure levels, it is not possible to estimate the burden of disease which could be avoided by more ventilation.

Health benefits of ventilation. An increase in ventilation would reduce exposure to various factors in indoor air. For some factors, such as certain pathogens and allergens, this would also reduce the likelihood of adverse health effects.

Potential adverse health effects of ventilation. Interpreting the results of studies on the association between CO_2 as a measure of ventilation and potential health effects is made difficult by differences in the type and rate of ventilation for the same CO_2 concentrations. On the one hand, in comparison with natural ventilation systems, mechanical ventilation systems generally extract more polluted air, which results in lower CO_2 concentrations, but on the other hand, if poorly maintained, they can pollute indoor air with hazardous substances from the filters or ventilation supply ducts. Ventilation with polluted outdoor air may also adversely affect health, for example in schools close to busy roads.

Exposure to various indoor environmental factors. The Committee notes that exposure to various indoor environmental factors occurs in schools and that due to their nature they may have adverse effects on the physical health of pupils and teachers. The Committee is especially concerned about exposure to particulate matter, pathogens, allergens, and high temperature and noise levels in classrooms. However, studies in the Netherlands on the influence of ventilation in classrooms on the exposure to these factors and their possible health effects have been limited. No studies are available that indicate the level of exposure in the classroom at which adverse effects start to occur.

The most important indoor environmental factors in relation to health. To answer the question concerning what the most important indoor environmental factors in schools are which may adversely affect children's health, the contribution of various indoor environmental factors to the burden of disease of primary school pupils could be expressed as population attributive risks (PAR)*. To do this requires knowing the risk per unit of exposure and the proportion of pupils with sufficiently high exposure to the factor for effects to be expected from it. However, the data needed to make calculations of this kind for the situation in the Netherlands are not available. Moreover, it would also be necessary to take into account the severity of the effects. For the following reasons the Committee is of the opinion that it is not possible to reach a substantiated conclusion on what the most important factors are which may adversely affect health in the indoor environment of Dutch schools:

- data on existing exposure levels and frequencies in the Netherlands are almost non-existent
- exposure-effect relationships of the relevant exposure level are inadequate
- the severity of the various effects is difficult to compare, and
- there is a lack of information on the size of the various sensitive groups.

In answer to the minister's first question, the Committee concludes that it is not possible to state scientifically what the most important indoor environmental factors in schools are that result in adverse health effects.

* Population attributive risk: extra likelihood of a disease or other outcome in a population as a result of exposure to a given risk factor.

Chapter **3**

Effects on cognitive performance

This chapter answers the part of the minister's first question concerning cognitive performance. The complete question was:

What are the most important factors in the school indoor environment that may have a harmful effect on the health of children and teachers and the cognitive performance of children? At what level of exposure can these effects occur?

The Committee has increased the scope of this question from 'harmful effects on cognitive performance' to 'adverse effects on cognitive performance' as this avoids limiting the discussion of effects to those which are severe or irreversible.

Developmental neuropsychology recognises three stages in the development of cognitive functions.[118,119] The following developments occur successively:
- perception and motor skills (up to approximately the age of 4 years)
- orientation, language, speech and attention (approximately from the age of 4 to 9 years) and
- more complex thinking executive functions* (approximately from the age of 9 to 23 years).

* such as perception of time, abstract understanding of language and selective attention

Relatively few studies have been conducted into the development of the aforementioned complex functions in particular. Of the various functions, attention is seen as one of the most sensitive to relatively subtle environmental influences, especially if reaction time is used as a measure of performance, instead of accuracy (or error score). The advisory report also evaluates the effects of the indoor environment in schools on perception, language and computational abilities or other cognitive functions.

The main indoor environmental factors discussed in this chapter are the physical and perceived indoor air quality, ventilation and other ventilation-related indoor environmental factors. An assessment has been made for each category of the extent to which these factors have an impact on the cognitive performance of children. In its interpretation of the results of the individual observational studies the Committee assessed the extent to which important confounding factors were taken into account, such as age, gender and socio-economic background. Other possible factors which could confound or modify the data are noise level, excessively high temperature, stress, lack of sleep, absence from school, experiences with computer games, whether or not the lesson is stimulating and the existence of learning disabilities or behavioural disturbances.

This chapter summarises the conclusions of the scientific literature which was examined, provided it was sufficiently informative[*] for an association with CO_2 or ventilation. A more extensive discussion of the original studies is provided in Annex D. This is based on the study of scientific literature which was conducted at the request of the Health Council of the Netherlands by the Institute for Risk Assessment Sciences (IRAS).[11] Annex D also includes a discussion of some results of studies on the effect of the indoor environment on (unspecified[**]) absence from school. Absence from school may be an indication of present and future problems.

3.1 Indoor air quality

The Committee is not aware of any publications on studies on the effect on cognitive performance of the physical or perceived quality of the air in schools.

* in the case of three or more relevant studies on an association with CO_2 or ventilation
** unspecified: cannot be traced to a specific cause and therefore not discussed here

An experiment in a Danish office building showed that perceived air quality can lead to reduced productivity among students.[103] Productivity increased with increasing ventilation.[102] The possibility cannot be excluded that the results were influenced by the fact that subjects were aware of the increase in ventilation and exposure to air pollution.

3.2 Carbon dioxide and other indicators of ventilation

To what extent does ventilation measured on the basis of the carbon dioxide concentration in the air affect the cognitive performance of children at primary school in the Netherlands? Few studies have been conducted on the association between the cognitive performance of children and the rate of ventilation or concentration of carbon dioxide (CO_2) in classrooms. A few observational studies examined the association between ventilation and the average result of cognitive tests in the classroom. A few experiments have also been described in which the results of one or more cognitive tests were examined following a change in the rate of ventilation.

Cognitive performance in schools. The literature review on indoor environmental factors in schools and day-care centres published in 2007 by Delft University of Technology places the emphasis on the results of reports in Dutch which were not published in scientific journals.[1] Three of these studied the association between CO_2 and cognitive tests.[120-122] The findings and limitations of these and other studies are shown in Table 4. An international review paper was published in 2005 on the effect on cognitive performance of various indoor environmental factors and the rate of ventilation.[123] Eight of the studies discussed were conducted among children in school situations. Owing to the wide range of ages, end points, settings and factors in the eight studies concerned, it is difficult to draw conclusions on associations between the results of cognitive tests and the indoor environment in schools.

Table 4 summarises seven studies which describe the association between the cognitive performance of pupils and CO_2 concentration as a measure of ventilation in classrooms.

Table 4 Overview of studies on the association between ventilation and the cognitive performance of pupils.

First author, year of publication	Type of study	Population (number and age)	Exposure (CO_2 concentration as measure of ventilation)	Measure of effect / outcome	Size of the effect (confidence interval / P value	Probability of effect	Comments
De Gids, 2007[120]	Experiment (double blind, with each child as its own control)	Primary school children year 7-8, the Netherlands (n=47)	CO_2 (ppm): 800 vs 1,600	Computational and language tests: error score	5.34 vs 5.64 errors in language test (p=0.00); 1.98 vs 2.44 errors in computational test (p=0.01)	+	Not peer reviewed. Little is known about the specific cognitive functions that were measured with the tests that were used. Not measured consistently at the same times.
Ten Boske, 1997[122]	Experiment (switching on mech. ventilation)	Primary school children (year 7) in 4 schools, the Netherlands (n=95)	CO_2 (ppm): 750 vs 2,000	Various attention tests	p=0.051	±	Not peer reviewed. Educational effect greater than weak effect of ventilation; unclear to what extent blind.
Wargocki, 2007[124,125]	Experiment (mech. ventilation: 3.0 -> 8.5 L/s pp)	Primary school children aged 10-12 years, Denmark (n=48)	CO_2 (ppm): 1,300 -> 900	Computational and language tests: speed and error score	Only a significant effect on speed in the reading comprehension test	±	Possibly influenced by parental concerns
Coley, 2007[126]	Experiment (opening windows)	Primary school children aged 10-12 years, England (n=18)	CO_2 (ppm): 750 vs 2,000	Test battery: speed and error score	Significant effect for 2 of 11 cognitive tests: up to 5% reduction in reaction time	±	Not conducted as blind study.
Van Buggenum, 2003[121]	Cross-sectional study	Primary school children (year 6) of 24 classrooms in 20 schools, the Netherlands (n=605)	CO_2 (ppm): 1,200-3,300	'Bourdon Vos Test' and 'Star Counting Test': speed and error score	No significant effect on speed and accuracy (p>>0.05)	±	Not peer reviewed. Not adjusted for possible confounding factors.
Shaughnessy, 2006[127]	Cross-sectional study	Primary school children (year 5) of 54 classrooms in 54 schools, United States (n=605)	CO_2 (ppm): > 1,400	Normal computational and reading tests (average score per classroom)	Marginal effect on computational test (p<0.10); no effect demonstrated for reading test	±	Limited adjustments for possible confounding factors. Little is known about the specific cognitive functions that were measured with the tests that were used.

Myhrvold, 1996[110]	Cross-sectional study	School children aged 15-20 years, Norway (n=550)	CO_2 (ppm): 600-4,000	Unspecified attention test	r=0.11; p=0.009	±	Only published as conference proceedings. Little is known about the specific cognitive functions that were measured with the tests that were used.

- plausible that no effect occurred (minimum size of effect and narrow confidence interval)
± effect not demonstrated but also not ruled out (broad confidence interval) -> non-informative study
+ indications of effect (0.05<p<0.10 or a degree of bias is plausible)
++ effect demonstrated (p<0.05 and bias unlikely)

In four experiments, including two conducted in the Netherlands which were not published in a peer-reviewed journal, the cognitive performance of groups of pupils was tested in classrooms which were either well ventilated or poorly ventilated.[120,122,124-126] One of the experiments provided an indication that pupils worked a little slower or made more errors when the CO_2 concentration increased from around 800 to 1,600 ppm.[120] It is not possible on the basis of the available data to define a CO_2 concentration at which cognitive effects of this kind start to occur, or which factors in the indoor environment are responsible. All experiments were limited to a few days. There is therefore very little possibility of making statements on long-term cognitive performance. Three cross-sectional studies described what were no more than marginal associations between CO_2 concentration in the indoor air of schools and the results of cognitive tests.[110,121,127] The numerous methodological limitations of the studies examined make it currently impossible for the Committee to answer the question concerning the extent to which proper ventilation in classrooms has a favourable effect on the cognitive performance of children. A recent study with an improved design is expected to provide a better answer.[128]

Cognitive performance in offices. A review paper was published in 2006 on the effect of the rate of ventilation on performance in office work.[129] The experiments discussed most concerned routine work in call centres. The conclusion was that productivity increased by 1-3 percent for an increase in the supply of fresh air of 10 litres per second (L/s) per person to a level of 15 L/s (= 54 m^3 per person per hour, which corresponds with a CO_2 concentration of approximately 800 ppm) but that above this level there was no further noteworthy association. The Committee points out that experiments of this kind always take place in rooms in which the pollution has not been qualified and quantified. For example, call centres have a high density of computers with unknown emissions of heat or pollutants. Results are difficult to interpret without any information on the pollution level or temperatures. See 2.3 for details of the limitations on using the results of studies in offices as an indication of the situation in schools.

3.3 Other ventilation-related indoor environmental factors

This section includes a discussion of the other – mainly physical – indoor environmental factors, especially humidity, temperature and noise, insofar as they are not related to the type or rate of ventilation.

3.3.1 *Humidity and temperature*

Cognitive performance in schools in relation to temperature. The authors of a Danish intervention study reported a statistically significant increase in the speed of performing two computational and language tests when the temperature decreased from 25 to 20°C in the summer months.[124] In an observational study in primary schools in Limburg, one of the two attention tests was performed less accurately as the temperature in the classroom rose to in excess of 25°C.[121] However, the study did not examine the effect of possible confounding variables.

Cognitive performance of adults in relation to temperature. A meta-analysis was published in 2007 on the effect of temperature on the cognitive performance of adults.[130] Substantial adverse effects were demonstrated, depending on the task, the duration of exposure and the temperature level. This applied to both accuracy and reaction time; in the case of effects on reaction time this applied especially at temperatures exceeding 29°C. In an experiment among employees cognitive performance decreased as the ambient temperature increased.[117] Tasks involving perception and attention were the most susceptible and were performed less well at temperatures exceeding 27°C (WBGT*). High relative humidity had an additional adverse effect.

In summary, indoor temperatures in excess of 25°C, especially when combined with high humidity, can have an adverse effect on the cognitive performance of pupils and teachers.

* WBGT: Wet Bulb Globe Temperature: a combined measurement of the ambient temperature (dry bulb), humidity and air speed (wet bulb) and radiant heat (black bulb).

3.3.2 Noise

Speech intelligibility in schools. Noise levels exceeding 35 dB(A) can lead to reduced 'speech intelligibility' in classrooms and therefore interfere with the transfer and processing of information.[131] This especially applies to sensitive groups, such as pupils and teachers with hearing problems and pupils with language difficulties, for example those with a different mother tongue. The Committee points out here that the noise produced by pupils will almost always exceed a noise level of 35 dB(A).

Cognitive performance in schools. In 1994 the Health Council of the Netherlands concluded that sufficient evidence existed for assuming that the performance of children carrying out cognitive tasks at school decreased when exposed to a high noise level from traffic (> 70 dB(A) outside the school building): they were more easily distracted and made more errors. Subsequent studies confirmed these conclusions. Exposure to environmental noise entering the classroom was shown to have adverse effects on the speed of performing cognitive tests in a randomised trial in London.[132] Studies on the effect of aircraft noise on schoolchildren before and after the relocation of an airport near Munich demonstrated that the noise level increase after the opening of the new airport had an adverse effect on speech intelligibility, long-term memory, reading and the motivation to solve difficult problems, whereas similar effects among children in the vicinity of the 'old' airport decreased.[133,134] Observational studies showed that both high noise levels from outside and the noise produced by the class were associated with a decrease in the cognitive performance of pupils.[135-137]

In summary, speech intelligibility decreases when there is an increase in environmental noise, including that produced by ventilation facilities. Environmental noise, especially road and air traffic, may also lead to a reduction in cognitive performance. The extent to which these cognitive effects also occur during exposure to noise from ventilation facilities in the school building is not known.

3.4 Considerations

As in Chapter 2, the Committee makes a number of comments on the available studies.

Quality of studies. Few good studies have been published on the effect of the various indoor environmental factors in schools on cognitive performance. Results are only available on a randomised controlled trial on the effect of noise. The relationships between concentrations and effects were rarely quantified in the studies that were examined of the effects of indoor air quality. Studies to answer specific questions which have been conducted in a similar manner are generally too scarce to enable a systematic review of scientific literature or meta-analysis.

Cognitive performance. The studies examined used a variety of cognitive tests but their validity* was often unclear or their test-retest reliability was low, especially with regard to the question they were intended to address.** Hardly any standardised instruments exist. The Committee does not exclude the possibility that many of the tests used were not sensitive enough to demonstrate subtle cognitive effects. Many of the studies of the effect of the indoor environment in schools on cognitive performance involved pupils aged 9 to 12 years. It is not possible to make generalisations about higher or lower age groups on the basis of the results of these studies, as the effect of physical environmental factors can differ sharply for the various ages. The extent to which short-term changes are significant for long-term cognitive performance is still unclear. The Committee is of the opinion that prospective cohort studies are required to obtain information on the long-term effects of chronic exposure.

Effect of ventilation on cognitive performance. Quantitative statements on the effect of the rate of ventilation on the cognitive performance of schoolchildren cannot be made on the basis of the results of available studies. The Committee deems the findings of one study to be an indication of an adverse effect on the cognitive performance of children when the CO_2 concentration was increased from approximately 800 to 1,600 ppm.[120] The Committee took the view that other studies were not sufficiently informative. The Committee is of the opinion that minor effects are also relevant, as the number of pupils concerned is so large. Assuming that reduced attention can lead to developmental disorders and poorer cognitive performance, the possible effects are a cause for concern.

* Validity: the degree to which a test measures what it is intended to measure.
** Personal communication Dr P.M. Hurks, developmental neuropsychologist.

Effect of other indoor environmental factors on cognitive performance. In the opinion of the Committee it is plausible that a high temperature in the classroom in the summer could have an adverse effect on the learning process. The Committee also takes the view that it has been proven that a high noise level can lead to reduced cognitive performance.

The Committee concludes that exposure occurs in schools to indoor environmental factors which could have adverse effects on the cognitive performance of pupils. This applies to high temperatures and noise levels and also possibly to the air quality in poorly ventilated classrooms.

Chapter 4

Carbon dioxide as a measure of ventilation in classrooms

This chapter answers the second, third and fourth questions in the request for an advisory report, all of which concern the value of carbon dioxide (CO_2) as a measure of ventilation and air quality in schools.

More attention has been paid to CO_2 and ventilation in classrooms in recent years owing to the construction of energy-efficient buildings which are more air-tight (less natural infiltration of air through gaps), have lower ceilings (less volume and therefore less dilution), more children and more active children (more CO_2 production) per m^2 and more children with asthma**.** In 2007 the CO_2 concentration of 1,200 ppm* was exceeded in 88 percent of classrooms and on average for more than 40 percent of the teaching period.[4] The Committee has no indications that CO_2 concentrations in Dutch schools are currently higher than twenty years ago, when the CO_2 concentration in the classrooms studied exceeded 1,200 ppm for 27 to 97 percent of the time.[101]

4.1 CO_2 as a measure of ventilation or air quality in classrooms?

Second question. For which indoor environmental factors in schools is CO_2 a good indicator of ventilation? To what extent is CO_2 an indicator of air quality in classrooms?

* 95th percentile: the highest value, excluding the 5% highest measured values

The CO_2 concentration is often used as an indicator of the rate of ventilation or of the quality (composition) of the indoor air. This section answers the question concerning the extent to which CO_2 is indeed a measure of this.

4.1.1 *CO_2 in indoor air*

The CO_2 concentration in the indoor air of classrooms is a function of the CO_2 produced by pupils and teachers, the rate of ventilation*, the time and the background concentration of CO_2 in the outdoor air. The CO_2 concentration C_t at time t follows from the formula below, subject to the initial condition $C_t = C_{outdoor}$ at t = 0 (see Annex F):

$$C_t = \frac{q}{a \times V} \times \left(1 - e^{-at}\right) + C_{outdoor}$$

Where C is the concentration [kg m^{-3}], q is the production rate of CO_2 [kg s^{-1}], a is the ventilation rate** [s^{-1}], V is the volume of the room [m^3] and t is the time [s]. The formula assumes complete mixing of the incoming supply air with the air in the room.

Ventilation. The rate of ventilation in a classroom can be calculated from the CO_2 concentration, if the CO_2 produced by the people in the room is known and the air in the room undergoes complete mixing. The ventilation flow is the air flow expressed as the volume per unit of time (a×V).

CO_2 equilibrium level. The CO_2 equilibrium concentration can be seen as a measure of ventilation per person. The CO_2 concentration in classrooms usually reaches an equilibrium level within 30 minutes to two hours of the start of the lesson, whereby the removal of CO_2 by ventilation equals the CO_2 production level by those present. The speed at which this level is reached increases in rooms with a smaller air volume, when there is a high rate of ventilation (see Figure 1). In the actual situation throughout the school day there will be a number of lesson breaks during which the CO_2 concentration will decrease again.

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* The CO_2 concentration is only directly related to the rate of ventilation when there is complete mixing (dilution) and not in the case of displacement ventilation, for example.

** Ventilation rate: a figure which indicates the relationship between the air flow which passes through the room per unit of time and the volume of the room.

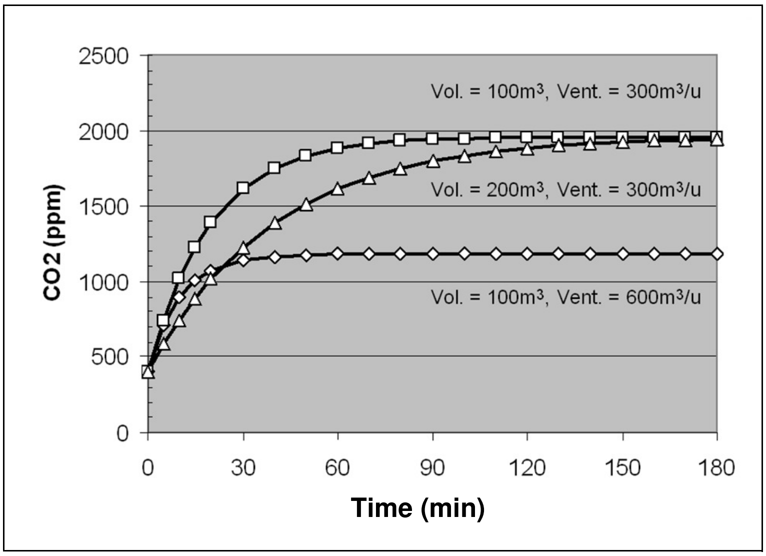

Figure 1 Change in CO_2 concentration according to the aforementioned formula:
□ small volume and little ventilation rapidly leads to a high CO_2 concentration
△ increasing the volume only delays reaching the final concentration
◇ increasing ventilation rapidly leads to a lower final concentration
The CO_2 production is at a realistic level and constant from T=0. The ventilation air contains 400 ppm CO_2.

CO_2 in exhaled air. When people breathe they take up oxygen from the surrounding air and exhale carbon dioxide, water vapour and other metabolic products into the surrounding air. Quantitatively the CO_2 produced when people exhale is the main human bio-effluent*.[138] Exhaled air contains around 4 percent CO_2 (40,000 ppm). Depending on their age, body weight and level of activity, the CO_2 people produce increases with their metabolic rate. CO_2 production in the indoor air at school therefore primarily depends on the number of pupils in the class, their age and activity. The CO_2 concentration is therefore a measure of ventilation per pupil.

CO_2 in outdoor air. The concentration of CO_2 in indoor air is affected by the concentration in outdoor air. In 1984, when it determined an acceptable CO_2 concentration in the home, the starting point of the Health Council of the Netherlands was an outdoor air concentration of 330 ppm.[3] The increase in the background

* Bio-effluent: emission product of living organisms.

concentration over the past thirty years was in the order of 40 to 50 ppm.[11] The increase since 2000 in the Netherlands and globally has been approximately 2 ppm per year.[139] Information from the Energy Research Centre of the Netherlands showed that the annual average CO_2 concentration in 2008 at the background measurement point in Cabauw, the Netherlands, was approximately 385 ppm and that considerable variations in outdoor air concentrations of CO_2 can occur. Particularly in the winter, during calm and stable weather conditions concentrations can occur of between 450 and 550 ppm. This is even more the case in urban areas and close to traffic. The CO_2 concentration can even temporarily increase to levels of 800 ppm in large cities with heavy traffic and other sources of air pollution.[33,140-142]

Delta (△)CO_2. When assessing the CO_2 concentration in indoor air as an indicator of ventilation it is necessary to take into account the difference (△: delta) between the concentration in indoor air and outdoor air.[143] When assessing the CO_2 concentration in indoor air, it is also necessary to know the concentration in the outdoor air at the same time and location, as the CO_2 concentration in outdoor air can vary in time and space. For reasons of pragmatism, in a neutral environment, in which a 'normal' outdoor air concentration of CO_2 can be expected, Municipal Health Services often assume a level of 400 ppm for the background concentration.

4.1.2 Other substances in indoor air

In theory, besides leading to a reduction in the concentration of CO_2 in indoor air, ventilation also reduces concentrations of other indoor air pollutants. Although a relationship between CO_2, as a measure of ventilation, and other gaseous pollutants, small particles and aerosols in a classroom is plausible on the grounds of the laws of physics (dilution), there is a possibility that such an association can not be demonstrated in observational studies in several classrooms or schools, owing to differences in the production of other pollutants. Moreover, the CO_2 concentration in the indoor air of classrooms is determined by various factors, especially the occupancy rate, the rate of ventilation, the type of ventilation system and the background concentration of CO_2 in the outdoor air. This could render possible associations more or less indiscernible.

Indoor air pollution of human origin. The production of body odours is an important and practically unavoidable form of indoor air pollution. Concentrations of other human-related pollutants, such as pathogens and allergens or upswirling dust particles, are mainly determined by human behaviour.[29,30,37] They are therefore avoidable in theory and more readily dealt with using a 'source-oriented' approach, such as cleaning or the type of floor covering chosen, rather than by means of ventilation.

Indoor air pollution from other sources. Other types of indoor air pollution originate in soft furnishing, materials and equipment. Emissions from these sources are mainly determined by the interior design.[13,17,18] Although these pollutants can be affected by ventilation, they are in principle avoidable and should initially be dealt with using a source-oriented approach.

4.1.3 Humidity and temperature

Humidity and temperature are two other important indoor environmental factors which may be related to the rate of ventilation. Temperature is an especially important determinant in the perception of the quality of the indoor environment.

Humidity. Relative humidity in a classroom is not only affected by the production of water vapour by the pupils and teacher but especially also by the humidity and temperature outdoors, possibilities for the formation of condensation and by ventilation. A study conducted in a representative random selection of Dutch primary schools showed that relative humidity in the winter was generally in line with the winter target value recommended by the Inspectorate for Housing, Spatial Planning and the Environment of at least 20 percent and no more than 60 percent.[4]

Temperature. The temperature in a classroom is affected from outside by heat from the sun and inside by heating. Ventilation is an important way of extracting heat from school buildings which have no thermal insulation or sunblinds. This applies to most schools. In the summer, the capacity of the ventilation facilities has a major effect on the indoor temperature. However, if the outdoor temperature is high it is almost impossible using only ventilation to keep the indoor temperature below the target value recommended for summertime by the Inspectorate for Housing, Spatial Planning and the Environment of no more than 24°C*.

* at a relative humidity of 30-70% (in the summer)

4.1.4 CO_2 as an indicator of ventilation and indoor air quality

A CO_2 equilibrium concentration has been adopted in the Building Decree as the basis for ventilation requirements in new buildings. In practice Municipal Health Services use the CO_2 concentration to determine whether ventilation is adequate.[144] CO_2 which has been readily measurable for a long time serves as an indicator for this. CO_2 has no adverse health effects in the concentrations found in classrooms*. This section therefore first discusses the extent to which CO_2 is a measure of ventilation and then discusses other health-relevant indoor environmental factors for which CO_2 can serve as an indicator and undergo changes as a result of ventilation.

CO_2 as an indicator of ventilation. Given the formula in 4.1.1, increasing ventilation reduces the CO_2 concentration, if CO_2 production in the room remains the same. The CO_2 concentration can therefore be used as a measure of ventilation.

CO_2 as an indicator of indoor air pollution of human origin. Generally speaking the (△) CO_2 concentration is a good exposure indicator for metabolic products which are exhaled by human beings in a fairly fixed ratio with CO_2. At concentrations exceeding 1,200 ppm, CO_2 is to a limited extent also an indicator of

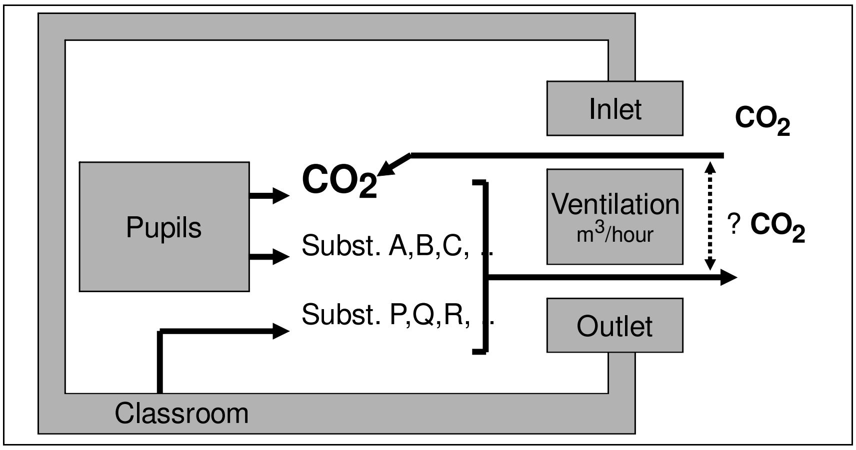

Figure 2 Relationship between CO_2, other substances in the air and the rate of ventilation in a classroom.

* P95: < 2,000 ppm[4]

other human emission products, such as body odours.[97] Increasing ventilation in the classroom reduces not only the CO_2 concentration but also concentrations of other human-related particles in the air, such as aromatic substances of perfumes, micro-organisms, dust particles and allergens (see Figure 2). However, the associations described in Chapter 2 between the CO_2 concentration in indoor air and concentrations of particulate matter and micro-organisms are probably more attributable to the presence and activities of people who remain in the room than to the rate of ventilation.[33,37,54] CO_2 is therefore less suitable as an indicator of these factors. Moreover, it is easier and better to measure dust particles directly.

CO_2 as an indicator of indoor air pollution from other sources. The CO_2 concentration cannot be used as a proper indicator of air pollution from non-human sources, such as pollutants from soft furnishings, materials, equipment or ventilation systems.[94.138] This is because of the lack of any relationship to CO_2 production.

CO_2 as an indicator of humidity and temperature. As explained in 4.1.3, the effect of ventilation on relative humidity and temperature in classrooms is highly dependent on the levels in outdoor air. Indoor relative humidity is determined more by outdoor relative humidity and temperature, while the indoor temperature is determined more by the temperature produced by pupils, the outdoor temperature, radiant heat from the sun and the degree of heating or cooling in the building. Therefore the CO_2 concentration is not useful as an indicator of humidity and temperature. It is better to measure these indoor environmental factors directly.

In summary, the ($\triangle^*$) CO_2 equilibrium concentration is a good indicator of ventilation per person, assuming that the air in classrooms is usually mixed well. Given the association between the CO_2 concentration and odour perception upon entering the room, CO_2 is to a limited extent also an indicator of body odours. CO_2 is less useful as an indicator of dust particles, allergens and pathogens. This is because the rate of CO_2 production is scarcely related to the rate of other substances dispersed by pupils. CO_2 is not useful as an indicator of other substances and particles in the indoor air of classrooms, such as volatile organic compounds, plasticisers, dampness, fungi or air pollution from traffic, because they are not related in any way to CO_2 production. CO_2 is therefore a poor indicator of air quality. These conclusions do not detract from the fact that increasing ventilation

* $\triangle$ (delta): difference between the concentration in indoor air and outdoor air

in a classroom will lead to a reduction in the concentrations of both CO_2 and other substances and small particles in the air, unless the concentrations in the incoming air supply are higher than those in the indoor air to be extracted.

4.2 Substantiation of the various CO_2 target values

Third question. How do the background and reasons for choosing the CO_2 levels adopted by the Municipal Health Services relate to the CO_2 level adopted for policy purposes for the removal of pollutants from indoor air?

4.2.1 CO_2 target values as recommended by the Municipal Health Services

Municipal Health Services guidelines published in 2006 on assessing ventilation in schools state the following 'health-related target values' for CO_2 concentrations (Table 5). These are expressed as the difference ($\triangle$: delta) between the concentration in indoor air and outdoor air and also as the concentrations in the indoor air at a background concentration of around 400 ppm. Estimates are also provided of the air flow required to achieve the CO_2 concentrations.

Based on these target values, the guidelines advise employees of Municipal Health Services to make the following recommendations to schools or municipal authorities:[143]

- $\triangle CO_2$ > 1,000 ppm: if the target value of 1,400 ppm (including background) is exceeded, take measures immediately by providing information on ventilation behaviour and by taking structural measures
- $\triangle CO_2$ = 600-1,000 ppm: provide information as soon as possible on ventilation behaviour and, if necessary, also take structural measures, if the target value of 1,000 ppm (including background) is exceeded but that of 1,400 ppm is not
- $\triangle CO_2$ = 400-600 ppm: measures are advisable if the target value of 800 ppm (including background) is exceeded but not the higher target values
- $\triangle CO_2$ < 400 ppm: consider optimisation; the objective is to avoid exceeding the target value of 800 ppm (including background) or an even lower value.

Table 5 Municipal Health Services assessment of CO_2 concentration (P98[a]) and ventilation per person in a classroom.[143]

$\triangle CO_2$ concentration in ppm (indoor/outdoor)	CO_2 concentration in ppm, including background	Fresh air flow per person in litres/second	Fresh air flow per person in m^3 per hour	Municipal Health Services Assessment
< 400	< 800	> 15	> 54	Good
400-600	800-1,000	10-15	36-54	Moderate
600-1,000	1,000-1,400	6-10	22-36	Inadequate
> 1,000	> 1,400	< 6	< 22	Poor

a 98th percentile: the highest value, excluding the 2% highest measured values.

The report of an expert group set up by Municipal Health Services in the Netherlands is cited as substantiation of the proposed target values stated in the guidelines of the Municipal Health Services.[145] The report came about following various experiences from the field that inadequate ventilation was suspected of having adverse effects on the performance of pupils and teachers. The expert group concluded from the findings of a number of studies that the likelihood of adverse effects increases with the CO_2 concentration, without it being possible to establish an unambiguous exposure level below which no effects occur. Some effects could supposedly occur at CO_2 concentrations which only just exceeded the CO_2 concentration in the outdoor air. To arrive at quantitative target values, the group referred to existing standards, especially the European standard EN 13779 for the classification of ventilation systems in non-residential buildings, including schools.

The limitations of the various studies cited by the expert group were discussed by the Committee in Chapters 2 and 3 and the associated appendices. To summarise, the Committee has ascertained that although ventilation may have an effect on the number of micro-organisms in the air, its effect on the transmission of respiratory infections is unclear.[55,60] With regard to statements on the occurrence of adverse health effects, the Committee takes the view that there is hardly any comparison between the situation in office buildings in the United States and that in Dutch primary schools.[114] The cited study that was conducted into the cognitive performance of pupils attending Dutch primary schools did not appear as a peer-reviewed publication.[121.122] Finally, the Committee points out that the classification in the European standard has not been scientifically substantiated. For the aforementioned reasons the Committee is of the opinion that the evidence for the studies cited by the Municipal Health Services is too insufficient to determine target values.

4.2.2 CO_2 target value as basis for Building Decree

The minimum ventilation capacity stipulated in the 2003 Building Decree for new buildings was 25 m^3 per hour (or 7 litres per second) per person*. This 'ventilation requirement' is based on a 1995 report by TNO (Dutch organisation for Applied Scientific Research), which in turn was based on the 1974 Dutch standard** 'NEN 1087' for ventilation for residential buildings.[146] Such a ventilation capacity enables an equilibrium concentration below 1,200 ppm CO_2 to be achieved for a CO_2 concentration in the outdoor air of 330 ppm ($\triangle CO_2$: 870 ppm). This ventilation requirement was originally intended to prevent a brief sensation of an unpleasant body odour being experienced by visitors to a room and by re-entering occupants. In 1984 this starting point had the support of a Committee established by the Health Council of the Netherlands and was deemed acceptable for housing.[3] The Health Council's decision at the time was mainly based on a study on the minimum permissible supply of fresh air per person in buildings, which was conducted in 1981 by TNO and supported an acceptable CO_2 concentration not exceeding 1,000 to 1,500 ppm.[100] It estimated that 1,200 ppm CO_2 corresponded with a situation in which ten percent of the adult occupants of the rooms investigated considered the smell to be 'no longer acceptable'***. The study also included situations in which the occupants stated their opinion after they had been out of the room for several minutes. The numbers of subjects were so small that it is not possible to attach much significance to the relationship between the CO_2 concentration and odour nuisance.

The Committee takes the view that the substantiation of the CO_2 target value of 1,200 ppm, as basis for the ventilation requirements stipulated in the Building Decree, was extremely limited at the time and provides an answer in the next section to the question whether it is now possible to provide better substantiation for the situation in schools.

* The Committee refers to Annex G for other relevant stipulations on the indoor school environment which are included in the Housing Act Building Decree and other legislation.

** Dutch standard (NEN-norm): a standard issued by the NEN (Netherlands Standardisation Institute/Nederlands Normalisatie-Instituut); NEN standards which are not referred to in the Building Decree or other statutory regulations have no legal status but are private agreements concluded between the parties concerned.

*** However, the author deemed such a percentage of odour nuisance complaints unjustifiable for offices and similar buildings. For a minimum fresh air supply of 35 and 50 m^3 per hour and per person respectively the percentage was five and one respectively.

4.3 Reconsideration of the 1,200 ppm CO_2 target value

Fourth question. The 2003 Building Decree's ventilation requirements in new buildings were aimed at avoiding odour nuisance and were based on the Health Council's report of 1984. Are there any reasons from the health point of view for reconsidering the present CO_2 target value of 1,200 ppm?

4.3.1 *Starting points of the Health Council of the Netherlands in 1984*

Air quality in the home. The starting point in the Health Council's advisory report of 1984 on the climate in Dutch homes was that the quality of the indoor air should be such that no discomfort or adverse health effect would occur even in the long term and for sensitive groups.[3]

Odour nuisance for visitors. The starting point was more the well-being of visitors rather than that of occupants, who adapt naturally to odours.

Sensitive groups. The Health Council was of the opinion that special conditions should be stipulated for the quality of the climate in the homes of people in particularly sensitive groups, such as patients with asthma. The homes of people in these groups should be individually 'remediated'.

Unavoidable sources. The Health Council's opinion at the time was that only unavoidable sources of indoor air pollution should be taken into account when determining the minimum ventilation capacity for homes, namely the CO_2 and aromatic substances produced by human beings.

Avoidable sources. The Health Council took the view that the indoor air quality polluted by avoidable sources should not be improved by increasing the general 'ventilation requirements' but by taking measures to limit the 'source level', by stipulating emission requirements for building and furnishing materials, for example.

4.3.2 *Starting points of the present Committee*

Air quality in schools. By analogy with the Health Council's starting points in 1984, which were concerned with the indoor environment in the home, the present Committee is of the opinion that the indoor environment in schools should be such that it has no adverse effects on the physical, mental and social well-being and functioning of pupils, also in the longer term.

Odour nuisance for pupils and teachers. The Committee is of the opinion that odour nuisance detracts from a feeling of well-being and that it should be limited as far as possible, even upon entering the classroom. The Committee assumes that studies generally showed that a few percent of those questioned also reported experiencing annoyance during extremely low levels of exposure.

Sensitive groups. The Committee takes the view that the indoor environment in schools should be suitable for the majority of pupils with asthma, who are more sensitive than others to indoor air pollution. An additional problem is that it is not possible to indicate an exposure level below which asthmatic children do not develop respiratory symptoms. Four to seven percent of primary school pupils in the Netherlands have asthma, defined as symptoms of recurring coughs, wheezing or shortness of breath.[62] The Committee also considers children with chronic headaches and children with learning difficulties as possibly being more sensitive to environmental factors. Depending on their age, two to five percent of children have chronic headaches.[147] The number of children with learning difficulties is not known precisely, mainly because of the lack of an unambiguous definition.

Unavoidable sources. As with the Health Council's advisory report in 1984, the Committee states that only unavoidable indoor environmental pollution, especially pupil-related sources, should be taken into account when determining a recommended exposure limit or target value for ($\triangle$) CO_2 in classrooms. This mainly concerns body odour.

Avoidable sources. The Committee takes the view that additional ventilation should not be the primary means of dealing with avoidable sources of indoor air pollution which are not of direct human origin but which may adversely affect health, and that they should be dealt with at the source in the schools, where possible.

4.3.3 Reconsideration of the CO_2 target value

To enable an assessment of whether there is a reason to change the CO_2 target value from 1,200 ppm as basis for the Building Decree's ventilation requirements, the Committee provides a summary in this section of the current knowledge described in the preceding chapters on the association between CO_2 concentrations and health effects. As mentioned, CO_2 is seen here as an indicator of ventilation and as an indirect indicator of indoor air quality.

Evidence of exposure-effect relationships at indoor air CO_2 concentrations. The Committee has ordered the evidence of the examined studies conducted in schools according to the type of effect, in relation to the indoor air CO_2 concentrations detected. To this end the Committee has assessed the probability of an effect on the basis of the size of the effect in combination with the confidence interval, the evidential value of the study design and the quality of its execution (see Tables 1 to 4).

Note that some studies concern more than one CO_2 category: Norbäck (900-1,100), Berg-Munch (600-1,500), Wanner (500-2,000) and De Gids (800-1,600). If their outcome is statistically significant, this is indicated for the higher category, as the significance applies in respect of the exposure in the lower category.

Table 6 Probability of adverse health effects for CO_2 concentrations in indoor air in schools.

Adverse health effect	<1,000 ppm	1,000-1,500 ppm	>1,500 ppm
Odour nuisance for ‘visitors’	Norbäck, 2008[96]: + Berg-Munch, 1986[97]: ±	Berg-Munch, 1986[97]: + Wanner, 1982[99]: +	Wanner, 1982[99]: ++
Committee’s opinion	+	+	++
Odour nuisance ‘users’ (teachers and pupils)		Berg-Munch, 1986[97]: ±	Versteeg, 2007[4]: ± Potting, 1989[101]: ++
Committee’s opinion	?	±	+(+)
Physical symptoms	Smedje, 2000[112]: + Kim, 2005[30]: ±	Norbäck, 2008[111]: ± Smedje, 1997[17]: ±	Potting, 1989[101]: ± Myhrvold, 1996[110]: +
Committee’s opinion	±	±	+
Infections			
Committee’s opinion	?[a]	?	?
Cognitive effects		De Gids, 2007[120]: + Ten Boske, 1997[122]: ± Wargocki, 2007:[125] ± V Buggenum, 2003[121]: ±	Coley, 2007[126]: ± Shaughnessy, 2006[127]: ± Myhrvold, 1996[110]: ±
Committee’s opinion	?	±	±

[a] The likelihood probably decreases in relation to a decrease in the CO_2 concentration.
- plausible that no effect occurred (minimum size of effect and narrow confidence interval)
± effect not demonstrated but also not ruled out (broad confidence interval) -> non-informative study
+ indications of effect (0.05<p<0.10 or a degree of bias is plausible)
++ effect demonstrated (p<0.05 and bias unlikely)
? no statement possible (lack of empirical data)

Exposure-effect relationship CO_2 and odour nuisance. It emerged from the scientific literature studied that a relationship between CO_2 concentration and odour nuisance has only been demonstrated for persons entering a room ('visitors'). No such relationship was found at levels below 1,500 ppm for people who remain in the room ('occupants'). The Committee draws this conclusion mainly on the basis of a Danish experiment in a lecture hall.[97] The percentage of students who experienced the body odour as 'unacceptable' upon entering the lecture hall increased from around 20 to 30 percent, for an increase in CO_2 concentration from 600 to 1,500 ppm. There was no relationship for those who remained in the room. In an experiment conducted in Switzerland body odours were only shown to be experienced as a nuisance in excess of an indoor air CO_2 concentration of 1,500 ppm.[99] These studies, which are summarised in Table 2, provide a better description of the relationship between CO_2 and the extent to which adult occupants and visitors perceive odour nuisance than that provided by the TNO study of 1981, which formed the basis for the Health Council's advisory report in 1984.

Exposure-effect relationship CO_2 and physical symptoms. The Committee only found an indication in one Swedish study of an association between the rate of ventilation in schools and the incidence of asthmatic symptoms among pupils.[112] These symptoms decreased after the installation of a new ventilation system, after which the CO_2 concentration at the end of the lesson decreased from 1,000 to 800 ppm. They cannot be explained by CO_2. It is unclear to what extent this reduction can be attributed to a reduction in fungi and other factors in indoor air, which may be higher in Swedish schools than in Dutch schools. On the basis of the scientific literature studied, the Committee's conclusion is that there is insufficient knowledge to indicate a CO_2 concentration above which adverse health effects begin to occur in classrooms.

Exposure-effect relationship CO_2 and infections. Hardly any empirical study has been conducted on the association with infections. In the opinion of the Committee it is plausible that an increase in ventilation in schools could reduce exposure to pathogens and thereby the likelihood of infections. However, it is not possible to say how strong this relationship would be.

Exposure-effect relationship CO_2 and cognitive performance. In a single non-peer-reviewed Dutch study indications were found of an adverse effect on the cognitive performance of children when the CO_2 concentration increased from around 800 to 1,600 ppm, although here too, the CO_2 concentration itself could not have been responsible.[120] The Committee deemed the informative content of other studies to be insufficient.

In summary, on the basis of the available data, the Committee is of the opinion that a CO_2 target value for ventilation in classrooms can be in a fairly wide range around 1,200 ppm. However, the data are inadequate for indicating a scientifically based exposure level below which no adverse effects are expected. The Committee therefore sees no reason to deviate from the present maximum CO_2 concentration of 1,200 ppm as the basis for the Building Decree. The Committee recommends that this should henceforth be expressed as the difference (delta: △) between the concentration in indoor air and outdoor air. At a normal concentration in outdoor air of 400 ppm a CO_2 concentration of 1,200 ppm in indoor air corresponds with a concentration difference of 800 ppm. The Committee recommends adopting a concentration difference of 800 ppm as the target value for the rate of ventilation. In the case of concentrations in excess of this, measures will be required to improve ventilation (see Chapter 6).

4.4 Considerations

For the determination of a new target value for CO_2 in primary schools as an indicator of ventilation and also as an indirect indicator of indoor air quality, the Committee opts for an approach intended to show that it is plausible that no adverse health effects occur at and below a given CO_2 concentration. If no data are available on this, the Committee is of the opinion that it is not only necessary to avoid exposure levels for which adverse effects have been demonstrated but also to avoid exposure levels for which sufficient indications of an adverse effect exist.

Evidence of the studies examined. Since the Health Council's 1984 advisory report around twenty scientific papers have been published which contain information on the relevance of indoor air in schools for the health of pupils. Most of these studies did not demonstrate any adverse effects. Nevertheless, there is a great deal of uncertainty about the results, which means there may have been a failure to detect an effect. The uncertainty is mainly accounted for by the fact that:

- CO_2 is only a poor indicator of indoor air quality
- often relatively small differences in CO_2 concentrations were investigated, so an effect or stronger effect is conceivable in the case of larger differences

- the concentration or concentration difference at which the effect begins to occur is unclear
- pupils or parents may be influenced by the fact that they are aware of the change being studied
- the quality of the indoor environment in schools is related to living conditions at home, so there is little, if any, possibility of separating the school's individual effect on health.

These interpretation problems mean that there is insufficient evidence to establish an unambiguous recommended exposure limit for CO_2. Three of the studies examined provide some indication that relatively low CO_2 concentrations have an adverse effect, namely asthmatic symptoms (1,000 versus 800 ppm), headaches (1,100 versus 900 ppm) and cognitive effects (1,600 versus 800 ppm).[111,112,120] The aforementioned interpretation problems also apply to these studies to some degree and make their evidence limited. There are more indications of adverse health effects occurring at CO_2 concentrations in classrooms in excess of 1,500 ppm but the extent to which they occur is unclear.

CO_2 target value. The Committee concludes that in by far most of the studies no adverse effects on health and cognitive performance have been demonstrated in the concentration range below 1,200 ppm CO_2* . The Committee is unable to indicate a well-substantiated target value, as the adequacy of the studies is limited. It therefore sees no reason to deviate from the present maximum CO_2 concentration of 1,200 ppm as the basis for the minimum ventilation requirements for new buildings as stipulated in the Building Decree. This means that some children may experience odour nuisance upon entering the classroom and that a sensitive child may experience an adverse effect.

Proposal concerning $\triangle CO_2$ target value. The Committee points out that a CO_2 target value of 1,200 ppm in the indoor air does not take into account CO_2 variations in the outdoor air. Strictly speaking, given these variations, a new target value should be defined as the difference (delta: $\triangle$) between the concentration in the indoor air and that in the outdoor air. The Committee is therefore of the opinion that it would be highly advisable to use this concentration difference as the target value for the rate of ventilation. This difference was rarely mentioned in the scientific literature considered but it has been assumed that the concentration in outdoor air was roughly 350-400 ppm. Given the results of the studies into the

* mostly represented as the schoolday average and sometimes as a percentile rate

relationship between CO_2, health and cognitive performance do not permit a level of accuracy greater than 100 ppm in smaller classes, the Committee takes the view that a $\triangle CO_2$ concentration not exceeding 800 ppm is acceptable in classrooms.

CO_2-target value exceedances. As the scientific literature is generally based on school-day average CO_2 concentrations, the possibility could also be considered of using an average as the target value. As a precaution, the Committee recommends that the CO_2 concentration during lessons should not exceed 1,200 ppm ($\triangle CO_2$: 800 ppm). However, brief fluctuations are unavoidable in practice and are also almost certainly not relevant from the health point of view.

Potential adverse side effects of reducing the CO_2 concentration. CO_2 concentrations of 1,200 ppm in the indoor air of classrooms ($\triangle CO_2$: < 800 ppm) can often only be achieved using enhanced ventilation*. Enhancing ventilation proves not to be readily possible in practice using only natural ventilation facilities, especially because this leads to complaints of draughts and cold temperatures.[148.149] However, mechanical ventilation systems can also be a source of problems owing to possibly noise nuisance and the contamination of filters or supply ducts.[90,91,93,94] This is often the result of design faults, incorrect installation and adjustment or inadequate maintenance and is consequently avoidable.

Other aspects of the indoor environment. The Committee stresses that focusing attention on the CO_2 concentration and the rate of ventilation ignores other aspects of the indoor environment which affect health. This applies to unpleasant high temperatures, air movements and noise levels. The Committee makes several recommendations on this in Chapter 6.

* Low CO_2 concentrations in fact require different ventilation techniques from ventilation systems based on complete dilution. For example, ventilation systems based on displacement achieve the same result with less air.

Chapter 5

Recommended exposure limits for the indoor environment in schools

In this chapter the Committee discusses the ventilation-related indoor environmental factors other than CO_2 for which recommended exposure limits might be advisable.

Fifth question. To what extent is it possible to set recommended values for ventilation-related, indoor environmental factors other than CO_2?

In 2004 the National Institute for Public Health and the Environment (RIVM) defined 'health-based recommended exposure limits for the indoor environment' for a large number of chemical substances and for noise.[144] They were updated in 2007, also in response to the updating of the WHO Air Quality Guidelines.[150] According to RIVM, the recommended values are mainly concerned with dwellings but could also be applied to other locations where people spend considerable time, such as schools (see Annex H). The Committee on Occupational Exposure Safety, a committee of the Health Council of the Netherlands, advised the Minister for Social Affairs and Employment on new health-based recommended occupational exposure limits, firstly for heat stress in the workplace.[117]

In addition to the aforementioned recommended exposure limits, the Committee finds it advisable for recommended exposure limits to be provided specifically for schools for the health-relevant and ventilation-related indoor environmental factors for which CO_2 is not a reliable indicator, namely:

- chemical substances from building and furnishing materials
- upswirling particulate matter: PM_{10}
- ultra-fine particulate matter (< 100 nm) and soot particles from outside
- non-infectious microbiological components
- allergens, from mites, fungi and pets
- temperature (maximum as well as minimum).*

However, in view of the lack of relevant data in scientific literature on these agents in schools and their effects on health, it will first be necessary to conduct studies on effects, exposure-effect relationships and the factors which affect them. Until recommended exposure limits have been determined on the basis of data obtained from research of this kind**, the Committee takes the view that it would not be advisable to recommend measuring the aforementioned indoor environmental factors in classrooms. Nevertheless, Chapter 6 does include recommendations on avoiding exposure to hazardous factors as far as possible by dealing with them at source.

In summary, the Committee is of the opinion that it would be advisable for health-based recommended exposure limits to be provided specifically for schools in respect of chemical substances from building and furnishing materials, particulate matter, allergens and temperature. However, there is currently a lack of knowledge of the adverse effects of the school indoor environment to determine properly substantiated recommended exposure limits. To enable this, the Committee is of the opinion that more studies should be conducted on the effect of the indoor environment in classrooms on the health of pupils and teachers.

* An ISO standard is available for thermal comfort.
** Various WHO guidelines are currently being drafted on indoor environmental quality.[151]

Chapter 6

Recommendations for a healthy indoor environment in schools

In this chapter the Committee makes recommendations for protecting the health of pupils and teachers. The recommendations focus on pupils in primary schools but they are also partially relevant for schools providing secondary education or special education. They are less suitable for day nurseries; they differ from schools too much, owing to the young age group and different purpose.

6.1 Further research and evaluation

As described in preceding chapters, the scientific literature which the Committee was able to use as a basis for its task was limited. The Committee therefore recommends further research into the effect of ventilation on the indoor air quality in classrooms and on the health and cognitive performance of pupils. The main focus of this study should be sensitive groups, such as children with asthma, chronic headaches or learning difficulties. The Committee also recommends research into the effectiveness of technical measures for reducing exposure to hazardous indoor environmental factors in schools and into their effects on health.

In anticipation of the results of further research, the Committee recommends to stimulate measures and the development of practical guidelines, also for child health care, to reduce exposure to hazardous indoor environmental factors in classrooms. However, there are still major gaps in the knowledge required for quantifying these recommendations.

6.2 Requirements for ventilation facilities

A representative random selection of 120 classrooms in 2007 showed that the average CO_2 concentration, as a measure of ventilation, during lessons was almost 2,000 ppm. Ventilation should therefore be enhanced in many schools to keep the CO_2 concentration below the target value of 1,200 ppm, which has been adopted as the basis in the 2003 Building Decree for ventilation requirements in new buildings. The Committee points out that the ventilation required for this may lead to unnecessary side effects, such as draughts or noise nuisance. It is therefore necessary to have proper ventilation facilities as well as information on how to use them properly. Preventing the side effects of enhanced ventilation will require measures to be drafted for the design, installation and maintenance of school ventilation facilities. The requirements must not only guarantee adequate ventilation and thermal comfort but must also prevent the emission of hazardous substances into the indoor air, and the creation of draughts and noise nuisance.

Indoor air. Given the increasing use of ventilation facilities in schools in aid of energy saving, ventilation or soundproofing, the Committee is of the opinion that it would be relevant to set requirements for the design and maintenance of ventilation systems. The dust in the air supply filters and ducts of inadequately maintained ventilation systems can lead to adverse health effects. Ventilation ducts should be regularly cleaned and filters should be timely replaced to ensure the quality of the air in schools.

Clean outdoor air. Maintaining a healthy indoor environment also entails ensuring that the ventilation air itself is of a high quality. To this end, the Committee recommends drafting requirements for the outdoor air which is drawn in for school ventilation. In schools in areas with polluted outdoor air, using a ventilation system fitted with a suitable filter system can improve the quality of the indoor air in classrooms and thereby reduce the risk of respiratory symptoms, especially in children with asthma.

Air movement and noise. The draughts produced by facilities for natural ventilation often lead to insufficient use of the ventilation facilities.[4] The use made of mechanical ventilation systems may be limited because of the noise nuisance they sometimes produce. The Committee therefore concurs with the proposed policy to limit the maximum noise level produced by ventilation systems in classrooms to 35 dB(A). This is the level above which reduced ‘speech intelligibility’ occurs in classrooms. To this end, it is important to pay attention to the design of ventilation systems and to limiting draughts and noise nuisance.

6.3 Other measures for a healthy indoor environment

The Committee stresses that besides focusing on the CO_2 concentration as an indicator of ventilation, it is also necessary to take into account other indoor environmental factors which can adversely affect health, for which CO_2 is not a useful indicator. This applies for example to chemical substances from building and furnishing materials, dust particles, pathogens, allergens, temperature and noise. This type of ‘avoidable’ exposure should be dealt with using a specific source-oriented approach, such as the choice of interior design and proper classroom cleaning.

Emissions from building and furnishing materials. Health-relevant emissions such as those from soft furnishings, fixtures, fittings and teaching materials or equipment are mainly determined by the interior design of the room. The Committee is not aware of any scientific publications concerning concentrations in Dutch schools and their possible health effects on pupils or concerning the effectiveness of emission-reducing measures. As a precaution, the Committee calls for the minimisation of the use of materials which emit irritating substances, such as formaldehyde, volatile organic compounds and plasticisers, as they may lead to symptoms in sensitive groups, such as children with asthma. Until such measures have been taken, ventilation may help limit the level of exposure to irritating substances.

Dust particles, pathogens and allergens. The levels of exposure to concentrations of pupil-related pollutants, such as dust particles, pathogens and allergens, are also determined by the children's behaviour. They can also be partially dealt with at source, by means of classroom cleaning or the type of floor covering chosen. In addition, ventilation can reduce exposure levels. This will reduce the likelihood of adverse health effects.

Temperature and noise. Finally, the Committee is of the opinion that it is important to endeavour to achieve optimal thermal and acoustic conditions in classrooms.

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A Request for advice

B The Committee

C Source-exposure-effect chain indoor environmental factors in schools

D Review of scientific literature on indoor school environment and health

E Consulted stakeholders

F Model for calculating changes in CO_2 concentration

G Legislation and regulations on indoor environment in schools

H Health-based recommended exposure limits

Annexes

Annex **A**

Request for advice

On 8 February 2008 the Chairman of the Health Council of the Netherlands received the following letter from the Minister of the Environment and Spatial Planning.

Dear Mr Knottnerus,

Achieving a healthy and safe living environment for children is one of this government's focal points. A healthy indoor environment in schools is one of the aspects which has a positive effect on the quality of the living environment of children and teachers. This has been taken up by the government as part of the 'National Approach to the Environment and Health 2008-2012'.

The many aspects of the indoor environment include air quality, noise, temperature and humidity. Improving the indoor environment in schools is a subject worthy of attention. Children spend a considerable part of their childhood in and around school buildings and it is therefore advisable to guarantee the quality of the indoor environment.

At my request and on behalf of my colleagues at the Ministry of Education, Culture and Science, the Ministry of Transport, Public Works and Water Management and the Ministry of Housing, Communities and Integration, various studies have been commissioned in recent years to obtain information on the actual situation in relation to the indoor environment in schools. Various municipal authorities and school boards have also taken steps to improve the indoor environment where necessary. The findings of the studies and input from the field form the basis of the government vision on the indoor environment in primary schools which the government will present to the Lower House in early 2008.

The aforementioned government vision will present the future policy lines, with regard to which it is clear that some gaps still exist in what is known about the indoor environment. Against this background, I request you, also on behalf of my colleagues at the Ministry of Education, Culture and Science, the Ministry of Transport, Public Works and Water Management and the Ministry of Housing, Communities and Integration, to inform me what the Council's standpoint is on the following questions.

1 What are the most important factors in the school indoor environment that may have a harmful effect on the health of children and teachers and the cognitive performance of children? At what level of exposure can these effects occur?
2 For which indoor environmental factors in schools is CO_2 a good indicator of ventilation? To what extent is CO_2 an indicator of air quality in classrooms?
3 How do the background and reasons for choosing the CO_2 levels adopted by the Municipal Health Services relate to the CO_2 level adopted for policy purposes for the removal of pollutants from indoor air?
4 The 2003 Building Decree’s ventilation requirements in new buildings were aimed at avoiding odour nuisance and were based on the Health Council’s report of 1984. Are there any reasons from the health point of view for reconsidering the present CO_2 target value of 1,200 ppm?
5 To what extent is it possible to set recommended exposure limits for ventilation-related, indoor environmental factors other than CO_2?

Please include relevant aspects of the above subjects in the advisory report you draft. In view of the importance of the subject, I request you, also on behalf of my colleagues, to present your advisory report on this at the end of 2008.

Yours sincerely,
the Minister of the Environment and Spatial Planning,
(signed)
Dr Jacqueline Cramer

Annex **B**

The Committee

- Professor J.C. de Jongste, *Chairman*
  professor of paediatric respiratory medicine , Erasmus University, Rotterdam
- M. van Bruggen, *adviser*
  medical consultant in environmental health, Centre for Health and the Environment, National Institute for Public Health and the Environment (RIVM), Bilthoven
- Professor B. Brunekreef
  professor of environmental epidemiology, Institute for Risk Assessment Sciences, University of Utrecht
- Professor J.J.M. Cauberg*, adviser*
  professor of climate design and sustainability, Delft University of Technology
- F. Duijm,
  medical consultant in environmental health, Municipal Health Service Groningen and environs
- W.F. de Gids, *adviser*
  ventilation specialist, Netherlands Organization for Applied Scientific Research (TNO) Building and Construction Research, Delft
- Professor Dr R. Hirasing
  professor of child health care, VU University Medical Centre, Amsterdam
- Professor Dr J. Passchier
  professor of medical psychology, Erasmus University Rotterdam, and

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- Dr M.M. Verberk
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- Dr P.M. Hurks, developmental neuropsychologist, Maastricht University*
- Professor W.F. Passchier, physical chemist, Maastricht University
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The Health Council and interests

Members of Health Council Committees – which also include the members of the Advisory Council on Health Research (RGO) since 1 February 2008 – are appointed in a personal capacity because of their special expertise in the matters to be addressed. Nonetheless, it is precisely because of this expertise that they may also have interests. This in itself does not necessarily present an obstacle for membership of a Health Council Committee. Transparency regarding possible conflicts of interest is nonetheless important, both for the President and members of a Committee and for the President of the Health Council. On being invited to join a Committee, members are asked to submit a form detailing the functions they hold and any other material and immaterial interests which could be relevant for the Committee's work. It is the responsibility of the President of the Health Council to assess whether the interests indicated constitute grounds for

* In aid of the advisory reports preparation, Dr P.M. Hurks, developmental neuropsychologist at Maastricht University, provided a presentation at the second Committee meeting on the validity and predictive value of the cognitive tests used on children in the indoor environment publications which were studied.

non-appointment. An advisorship will then sometimes make it possible to exploit the expertise of the specialist involved. During the establishment meeting the declarations issued are discussed, so that all members of the Committee are aware of each other's possible interests.

Annex **C**

Source-exposure-effect chain indoor environmental factors in schools

Outline Source-exposure-effect chain of ventilation-related indoor environmental factors in schools.

Source ↓	• Children, teachers, pets if present • Building materials (particle board), furnishing materials (floor covering) and teaching materials (chalk) • Outdoor air and 'dust in outdoor air' (blown/carried indoors) • Poorly maintained mechanical ventilation systems
Emissions ↓	• Emissions from humans and animals: CO_2, water vapour, odour, skin particles, allergens, pathogens and other microbiological factors • Emissions from materials used for building, furnishings and teaching • Impact of environment (humidity, temperature) on emissions • Pollutants resulting from human activity (such as cleaning agents)
Dispersal ↓	• Degree of ventilation (CO_2, ventilation rate), cleaning, activities of children
Exposure ↓	• Aromatic substances, allergens, pathogens and other microbiological factors • Formaldehyde, volatile organic compounds, particulate matter, upswirling dust, persistent compounds, such as plasticisers, polychlorinated biphenyls and other substances which disrupt the hormone balance • Humidity, temperature, air movement (comfort) • Noise
Effects	• Effects on health and cognitive performance Sensitive groups: • general: children (developing)[152] • specific: child with asthma, allergy, chronic headache or learning difficulties; teacher with asthma or allergy

Each level in this source-exposure-effect chain can serve as a point of action for possible interventions to prevent effects, in the form of standardisation, measures or the provision of information:

- source: e.g. fewer children in the classroom, not building close to environmentally impacted locations
- emission: e.g. emission requirements
- distribution: e.g. ventilation or CO_2 standard, ventilation capacity and behaviour
- exposure: e.g. recommended exposure limits.

Annex

D

Review of scientific literature on indoor school environment and health

This annex describes the original studies examined by the Committee in order to answer the first question in the request for an advisory report. This was done using a review of scientific literature conducted by the Institute for Risk Assessment Sciences (IRAS).[11] The Committee discusses the studies in the following order, whereby the last source referred to is discussed insofar as it supplements the first:

- from intervention studies to cross-sectional studies
- from Dutch studies to studies conducted abroad (insofar as representative)
- from peer-reviewed to 'grey' literature
- from most recent to older studies
- from pupils to teachers
- from schools to offices and homes.

D.1 Health effects

Indoor air quality

Chemical substances

Nitrogen oxides and ozone. It emerged in 2008 from a French study that the concentrations of nitrogen oxides (NO_x) at eight schools, two of which had mechanical ventilation, were practically identical in indoor and outdoor air; the ozone level indoors was much lower than that outdoors.[21] In the context of the proven harmful effects of ozone, the authors commented that it could be recommended to reduce ventilation during periods of summer smog. In 2006, in Shanghai, the respiratory symptoms of schoolchildren aged 13 and 14 years were examined in relation to a series of indoor-environment parameters.[22] The average concentration of carbon dioxide (CO_2) during a lesson varied between 530 and 1,910 ppm. Only the relationship between traffic-related nitrogen dioxide (NO_2) and respiratory symptoms was statistically significant: 50 percent more symptoms per 10 $\mu g/m^3$ increase in the NO_2 concentration.

Formaldehyde. A large amount of particle board has been used in the roofs, floors and partitioning walls of schools since the nineteen-sixties.[12] In a number of cases it emerged that the use of particle board can result in increased levels of formaldehyde in the indoor air. A Swedish cohort study among 1,347 pupils aged 7 to 13 years found a positive association between the incidence of asthma and – relatively low – concentrations of formaldehyde in the air (an average of 8 $\mu g/m^3$) of 100 classrooms.[13]

Volatile organic compounds. The concentrations of volatile organic compounds (VOC*) in schools have been investigated in the United States.[14] There was limited ventilation in many classrooms, given the high CO_2 concentrations (sometimes up to 3,000 ppm). The VOC concentrations were related to CO_2 but were generally low (an average of 58 $\mu g/m^3$) in comparison with the usual levels in offices. Art rooms and rooms used for practical training were the main source of VOC. No studies on health effects were conducted. A study in California examined the concentration of volatile hydrocarbons in temporary classrooms and normal classrooms.[15] Concentrations were generally lower, although sometimes slightly higher in the temporary classrooms. In two schools in Minneapolis, Minnesota, the concentrations of various volatile organic hydrocarbons were low in comparison with concentrations in personal-exposure samples and in homes and almost equal or lower than concentrations in outdoor air.[16] A Swedish cross-sectional study demonstrated an association between concentration of volatile organic compounds in the air (an average of 23 $\mu g/m^3$**) and the incidence of asthmatic symptoms in children aged 13 and 14 years (odds ratio: 1.3: 1.1-1.5 for an increase of 10 $\mu g/m^3$; $p<0.001$).[17]

* VOC: volatile organic compounds
** health-based recommended exposure limit: 200 $\mu g/m^3$

Plasticisers. A Swedish observational study took measurements in the indoor air of schools to determine the concentrations of volatile hydrocarbons from micro-organisms (MVOC*) and from a number of plasticisers and their degradation products.[18] Statistically significant positive associations were found between the total MVOC concentration, nocturnal shortness of breath and doctor-diagnosed asthma. The schools investigated had no problems with dampness or fungi. However, there was a relationship between the concentrations of a number of plasticisers and respiratory symptoms.

Polychlorinated biphenyls (PCBs). A German study investigated the presence of PCBs** in the air in a school polluted by PCBs and a control school.[19] PCBs found in pupils' blood samples were also analysed. The lower congeners*** were found in higher concentrations in the polluted building than in the control building, both in indoor air and in blood. The total external PCB level was the same and was dominated by that taken in through ingestion. There was also no difference between the two populations in reported physical symptoms. Another German study also measured PCB concentrations in the air and in the blood of teachers at a polluted school and at a control school.[20] Here too, some specific congeners were found in increased concentrations in the air as well as in the blood of teachers at the polluted school but the total PCB level of the persons examined did not differ from that of a control group.

Particulate matter

Investigators in Athens conducted studies in a number of schools to determine the concentrations of PM_{10}, $PM_{2.5}$**** and ultrafine dust particles (< 100 nm) in indoor and outdoor air.[31.32] PM_{10} and to a lesser extent $PM_{2.5}$ were usually higher in indoor air than in outdoor air. Ultrafine dust particles were in fact found in lower levels in the classrooms than in the outdoor air. A French study also investigated the numbers of particles of different sizes in indoor and outdoor air at eight schools.[21] Here too, the concentrations of larger dust particles (> a few µm) were higher on account of upswirling dust as a result of the children's activities.

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* MVOC: microbial volatile organic compounds

** PCBs: polychlorinated biphenyls

*** congeners: variants of given substances with a similar chemical structure and usually similar properties but sometimes with major differences in toxicity.

**** $PM_{2,5}$: small particles ('particulate matter') with a median aerodynamic diameter of less than 2.5 µm, as an indicator of anthropogenic dust particles in the outdoor air, caused by combustion processes.

A large study in Munich and environs measured concentrations of particulate matter and CO_2 in 167 classrooms.[33] Concentrations of CO_2 during lessons in the winter were high (an average of 1,759 ppm), whereas they were lower in the summer (an average of 890 ppm). Average PM_{10} concentrations in the winter were 92 $\mu g/m^3$ and in the summer they were 65 $\mu g/m^3$. The average $PM_{2.5}$ concentration in classrooms was 37 $\mu g/m^3$ in the winter and 20 $\mu g/m^3$ in the summer. Unlike the PM_{10} concentration, the $PM_{2.5}$ concentration in classrooms in the winter was not related to the CO_2 concentration. The PM_{10} and $PM_{2.5}$ concentrations in the higher age-group classrooms were statistically significant lower than those in the classrooms of the lowest four age groups. The authors attributed this to the much higher level of physical activity in the lower age-group classes. The dust concentrations proved not to be dependent on the type of floor covering (smooth or carpet). The authors assumed that a low cleaning frequency was a possible cause of the increased upswirling of settled dust in the classrooms.

A study in Sweden investigated the relationship of PM_{10} to respiratory symptoms. A once only measurement of PM_{10} was taken in the classrooms during lessons.[30] The concentrations were high (an average of 94 $\mu g/m^3$) with a large distribution from 12 to 544 $\mu g/m^3$. No association with reported respiratory symptoms was demonstrated. However, another Swedish study found an association between asthmatic symptoms among children aged 13 and 14 years and the potential exposure to dust measured along the length of open book shelves in the classrooms (*shelf factor*).[17] Adjustments were also made for other risk factors.

A large study of ‘building-related’ symptoms in relation to settled dust was conducted in Copenhagen at 75 schools among pupils aged over thirteen and staff.[34] The symptoms examined were eye irritation, nose irritation, blocked nose, throat irritations, itching or a warm sensation in the face, headaches, tiredness and concentration problems. Settled dust was collected at ten schools with a low prevalence of symptoms and ten schools with a high prevalence, and was then analysed *in vitro* for the potential to promote inflammatory reactions in epithelial alveolar cells. The floor dust from the schools where symptoms were most prevalent proved to be almost twice as reactive (per mg of dust) as the dust from schools where few symptoms were reported. The investigators were unable to indicate which factors or components in the dust might have been responsible for the observed differences.

Investigators in the United States studied the dust concentration in schools. At three schools in Ohio the relationship was investigated between $PM_{2.5}$ concentrations in indoor air and outdoor air.[35] During lessons $PM_{2.5}$ concentrations in the classrooms proved to be two to three times higher than in the outdoor air, which was also attributed to the activities of children causing an upswirl of previously settled dust particles. It was established in Illinois that the indoor air of classrooms had a higher concentration of dust and especially larger dust particles than the level found in the outdoor air.[36] Total dust concentrations of more than 100 μg/m³ were observed at various places in the school. In South Carolina, when classrooms were in use, the concentration of dust particles larger than 0.8 μm rose, the sharpest rise being in the classrooms with least ventilation.[37] Throughout the school day concentrations could rise to several hundred μg/m³. This occurred at times when the CO_2 concentration rose to more than 2,000 ppm. Particles of different sizes were also counted in classroom air and outdoor air in Colorado.[38] Particles smaller than 1 μm were present in lower concentrations in classrooms than outdoors, whereas particles larger than 1 μm were often found in considerably greater numbers indoors than outdoors. The effect of ventilation on PM_{10} concentrations is inconsistent.[39] On the one hand ventilation can remove particles in the air, on the other hand the air flow can cause an upswirl of settled dust.

Infectious micro-organisms

Intervention study. In a randomised controlled trial of 285 primary school pupils in Ohio, the United States, a weak association was shown between disinfecting hands and surfaces and the incidence of absence through gastrointestinal symptoms[53]. No association was demonstrated to absence through respiratory symptoms. No respiratory viruses were found on any surfaces either; only norovirus was found. This is an indication that skin contact with surfaces plays a major role in the transmission of viral respiratory infections.

Observational study. Investigators in Canada in 2004 studied the presence of bacteria in the air of 39 schools (116 classrooms).[54] In 62 mechanically ventilated classrooms the school-day average CO_2 concentration was 845 ppm, determined during the six hours that the classrooms were occupied. The average CO_2 concentration in the 54 classrooms with natural ventilation was 1,079 ppm. The concentration of bacteria in the air was always higher in the indoor air than in the outdoor air. The average concentration in classrooms with natural ventilation was twice as high as that in mechanically ventilated classrooms. These levels are lower than those found in day nurseries and homes and higher than those found in offices. There was a strong association between concentrations of bacteria in the air and the concentration of CO_2. The authors saw this as an indication that the children were acting as a source of bacteria. Moreover, the measured concentrations were affected by the age of the building, the presence of damp spots, the relative humidity and pupil activity. No examination was conducted of the effect of socio-economic status or the associations with disease symptoms.

Non-infectious microbiological components

One of the few studies in this field was an observational study conducted in South Carolina, the United States. The presence of bacterial components was examined in three schools in a small number of classrooms which were in use and in classrooms which were temporarily not being used.[37] Floor dust in the classrooms which were in use contained more endotoxin and muramin acid, indicators of the presence of gram-negative or gram-positive bacteria respectively. Concentrations in the indoor air while the classroom was in use were higher than when it was not in use; however, endotoxin concentrations were not higher than those found in the outdoor air. The investigators assumed that skin particles of pupils were a possible source of the gram-positive bacterial fragments. Ventilation had hardly any effect on the concentrations in the indoor air. Other investigators in North Carolina had studied endotoxins and fungi in the floor dust and indoor air of classrooms with hard floors and carpeted floors.[65] Statistically significant higher concentrations of endotoxins and β 1$\longrightarrow$3 glucans were found on carpeted floors per m^2. Airborne concentrations of endotoxin, fungal spores and β 1$\longrightarrow$3 glucans were greater in the school with a hard floor covering.

Allergens

Intervention study. A study in Swedish schools found that various preventive measures, such as more intensive cleaning, removing soft furnishings and plants and replacing open book shelves with closed cupboards, had no effect on the level of exposure to cat allergens.[77] The authors considered it plausible that this would likewise apply to the health of allergic children.

Observational studies. Attention in the Netherlands has thus far only focussed on dust mite allergens in classrooms. A study was conducted in the city of Rotterdam and the province of Gelderland into the presence of dust mite allergens on floors in primary schools.[70] The concentration was higher on carpeted floors than on smooth floors. The concentrations were considerably lower than those found in floor dust collected in homes with floor covering of a similar type.

A study in Sweden found much higher concentrations of cat allergens in the air of classrooms in which a large number of pupils had a cat at home than the concentrations found in the air of classrooms in which a small number of children had a cat at home.[68] The air at school often contained a higher concentration of cat allergens than that found in the homes without a cat. Mattresses in houses without cats also contained higher concentrations of cat allergens if the child was in a class at school in which relatively many pupils had a cat at home. This was assumed to be attributable to allergens being transported in clothing and head hair.[67] The same investigators showed that children with asthma had more symptoms if they were in a class in which relatively many children had a cat at home.[76] Other Swedish investigators found statistically significant associations between respiratory symptoms and dog and horse allergens in floor dust in classrooms.[30] The same research group also found an association between asthmatic symptoms in children aged 13 and 14 years and cat allergens in floor dust at school.[17] A prospective study conducted among pupils aged 7 to 13 years found that the incidence of 'doctor diagnosed asthma' was higher over a period of four years in schools with higher concentrations of cat allergens in floor dust.[13] Other Swedish investigators found that children with mild asthma and sensitisation to cats and dogs displayed higher bronchial reactivity after a week at school than they had at the start of the week.[75] Concentrations of cat and dog allergens in dust at school were higher than those found in house dust.

In Norway it was also established that concentrations of domestic pet allergens (cats and dogs) in floor dust in classrooms were related to the number of pupils with cats or dogs at home.[71] German investigators found that children who were not regularly exposed to cats at home but who were in a class in which many of their classmates had cats at home were twice as likely to become sensitised to cat allergens than if they were in a class in which few of their classmates had cats at home.[74]

In the United States, besides dust mite and cat allergens, sometimes considerable concentrations of mouse and cockroach allergens are found in floor dust in schools.[72,73]

Indoor dampness and fungal growth

Intervention studies. A school in Finland with problems caused by dampness and fungal growth was studied for five years, before, during and after renovation.[83] A control school was also studied. The 'problem school' originally had higher rates for physical symptoms and exposure to fungi; however, after renovation, both rates fell to those at the control school. A study at a Finnish school with problems caused by dampness and fungal growth showed that symptoms among staff decreased following a remediation operation.[84]

Another intervention study was conducted at a school with dampness problems in a suburb of Stockholm.[81] Leaks at the school had caused 'microbial' pollution. Pupils and staff consequently developed skin symptoms, eye symptoms, tiredness and headaches. Most of the symptoms decreased once the pollution had been removed. The study was conducted simultaneously at a control school with no known problems and no intervention was performed. There was no change in reported physical symptoms at this school.

Observational studies. In the United States, at two primary schools with problems caused by dampness and fungal growth, staff reported more work-related symptoms in the respiratory system, throat and eyes than respondents in a large national questionnaire survey, who were used as a control group.[79] In parts of the school with problems caused by dampness and fungal growth, staff had more respiratory symptoms than their colleagues.

A study conducted in the spring at eight schools in Sweden investigated the association between respiratory symptoms and the presence of fungi and bacteria in indoor air.[18] Bacterial concentrations in indoor air were approximately the same as those in outdoor air, whereas fungal concentrations were markedly higher in outdoor air. For higher concentrations of fungi and bacteria in indoor air, consistently lower levels of respiratory symptoms were found, and some associations were statistically significant. In a prospective study among children without a medical history of allergies the same research group found a positive association between fungal concentrations in classroom air and the incidence of 'doctor-diagnosed asthma' (odds ratio: 4.7: 1.2-18.4; $p<0.05$).[13] This association may have been somewhat overestimated because the analysis failed to take into account the clustering of classrooms per school. In an earlier study the same research group investigated inflammatory reactions in nasal mucous membrane among staff at twelve schools.[86,87,89] The results presented an inconsistent picture: more inflammatory reactions in mechanically ventilated schools, fewer at higher ventilation rates, little if any relationship to CO_2, more inflammatory reactions at increased concentrations of fungi, dust, NO_2 and formaldehyde in the indoor air.

A study in Denmark involving more than a thousand adolescents at eight 'damp' schools and seven 'dry' schools demonstrated a relationship between the concentration of colony-forming units of fungi in classroom floor dust and the reporting of irritated eyes and throats, headaches and dizziness.[90,91] Fungal concentrations in floor dust were higher in schools with mechanical ventilation than in schools with natural ventilation. This may mean that ventilation systems can also be a source of fungi. Fungal concentrations were also higher in schools with the lowest CO_2 concentrations. The relationship between mechanical ventilation and the CO_2 concentration was not investigated in this study.

Canadian investigators studied in 2004 the presence of fungi in the air in 116 classrooms at 39 schools.[92] In 62 mechanically ventilated classrooms the average CO_2 concentration was 845 ppm. The average CO_2 concentration in the 54 classrooms with natural ventilation was 1,079 ppm. A positive association was found between the CO_2 concentration in the classroom and fungal concentrations in the indoor air, which were almost always lower than the concentrations in the outdoor air. This suggests that the fungal spores in the outdoor air were probably being filtered out by air conditioning systems.

In Texas the reporting of symptoms was investigated at two schools, one with problems caused by fungi and one without. Prior to the problems with fungi receiving any publicity, the school doctor observed a statistically significant higher prevalence of three of the eight symptoms at the 'problem school'.[80] Following publicity, this applied to seven of the eight symptoms. This showed that the perception of symptoms related to fungi in a school can be influenced by publicity about the problem. At a Finnish school with problems caused by dampness and fungal growth, a study among staff showed not only that the incidence of symptoms at the 'problem school' was higher than that at the control school but also that more inflammation indicators were found in nasal lavages.[85,88] This showed that in addition to perception there are also objective differences between problem schools and control schools.

Perceived indoor air quality

An experiment conducted in four computer rooms showed that an increase in ventilation improved the perceived air quality during the first fifteen minutes.[96] Given the reported nuisance from draughts, this study was not completely 'blinded' for the rate of ventilation. It was especially remarkbable that a reduction in ventilation had no effect on the perceived air quality, whereas an increase did have an effect. It was not a cross-over design: one group was only given a reduction in ventilation and the other group was given an increase in ventilation. Consequently, it was not possible to ascertain whether the effect had been confounded by the group, classroom or the sequence of the effect.

Body odours

Intervention study in lecture hall. In the CO_2 concentration range of 600 to 1,500 ppm ($\triangle CO_2^*$: 250-1,150 ppm), as relevant for practice, a Danish experiment involving people who remained in a lecture hall ('occupants') found almost no association between the CO_2 concentration and the percentage of people experiencing odour nuisance.[97] However, there were indications of an association for people entering the room ('visitors'); the percentage of people who experienced odour nuisance as unacceptable increased from 20 to 30 percent in the CO_2 range from 600 to 1,500 ppm.

Intervention studies under different test conditions. In a test room in the United States an extensive experiment was conducted to examine the perception of body odours.[98] The results showed that the percentage of occupants who experienced body odours as 'unacceptable' was well below 10 percent, even when ventilation was at the lowest setting (2.5 L/s per person). In the case of visitors, the percentage was markedly higher and there was a statistically significant association to the rate of ventilation. This experiment showed that the supply of fresh air per person – and thereby the CO_2 concentration in the room – could be varied within a wide range without any substantial effect on the extent to which visitors perceived body odours to be a nuisance. However, the odour impact increased substantially in combination with a high temperature (> 25°C) and high humidity (> 70%). A briefly described experiment conducted in 1982 at a test laboratory in Switzerland showed that an association could be demonstrated between the CO_2 concentration and odour intensity in the CO_2 concentration range between 500 and 2,000 ppm.[99] At a CO_2 concentration of 1,500 ppm the odour impact was characterised as a minor nuisance. This corresponded with a minimum fresh air supply per person of 12-15 m^3 per hour (3.3-4.2 L/s). The small increase in odour nuisance, which displayed a large variance, for a fairly large increase in the CO_2 concentration indicates limited precision in statements on a CO_2 concentration at which a predetermined nuisance percentage occurs.

Observational study in schools. The Ministry of Housing, Spatial Planning and the Environment in the Netherlands commissioned a study conducted in primary schools.[4] In the winter of 2007, measurements were made at more or less the same time in 120 classrooms, divided into four types of ventilation systems:

* $\triangle CO_2$: the difference between the CO_2 concentration in indoor and outdoor air

Table 7 CO_2 concentrations and perceived indoor air quality during lessons in classrooms.[4]

	Classroom type 1: windows (n=45)	Classroom type 2: windows and grilles (n=25)	Classroom type 3: mechanical extraction (n=32)	Classroom type 4: mechanical facilities for air supply and extraction (n=18)
CO_2 in ppm (P95)[a]	1,906	1,983	1,889	1,164
Report mark for indoor air quality (1-10)	6.4	5.9	5.9	5.6
Air quality often perceived as stale and stuffy	20%	24%	47%	25%
Air quality never perceived as stale and stuffy	36%	20%	22%	50%

a Average percentile per type of classroom.

1) natural air supply and discharge through windows; 2) natural air supply and discharge through windows and ventilation grilles; 3) natural air supply through ventilation grilles, mechanical extraction; 4) mechanical facilities for air supply and extraction ('balanced ventilation'). The CO_2 concentrations* during lessons are shown in Table 7.

In the first three types of classrooms the CO_2 concentrations during lessons were 'plateau values' around 2,000 ppm. The concentrations were markedly lower in the fourth type of classroom (entirely mechanically ventilated). Teachers were asked to assess classroom air quality during lessons. The air quality in classrooms that were entirely mechanically ventilated and which had the lowest CO_2 concentration received the lowest rating in the assessment. Teachers rated the air in classrooms with mechanical extraction most frequently as 'stuffy', whereas the air in classrooms with balanced ventilation was most frequently rated as 'never' stuffy. Further analysis of the relationship between the CO_2 concentration and perceived air quality showed practically no association. The investigators concluded that in the observed concentration range up to around 2,000 ppm CO_2 there was almost no association between CO_2 and the air quality perceived by teachers.

* 95th percentile: the highest value, excluding the 5% highest measured values.

Other odours

Intervention studies in offices. At an office building in Denmark a randomised experiment which was 'blinded' for the subjects was conducted to investigate the effect of exposure to the air of a twenty-year-old carpet on students' non-specific symptoms.[103] Especially subjects who considered themselves to be extremely sensitive reported more symptoms during exposure to the air of the old carpet. In another experiment with largely the same group of subjects and the same source of pollution, the ventilation rate was manipulated, without the subjects' knowledge.[102] Non-specific symptoms decreased with increasing ventilation. The highest selected ventilation capacity of 30 L/s per person was much higher than the level normally used in offices (and schools).

Intervention studies under different test conditions. Chemical reactions with filter materials or with dust on filters in air supply ducts can lead to complex, olfactorily perceivable, chemical compounds in the indoor air.[104] This is preventable with the right choice of filter materials and the use of activated carbon filters. In a Danish experiment with air supplied through new filters and filters that had been in use for six months, the quality of the air supplied through the used filters was rated as poorer and as even poorer when the volume of air supplied through the used filters was increased.[95]

Observational study in offices. It has long been recognised that buildings produce their own 'odour'. In a study conducted in fifteen offices, Danish investigators found that 'odour' production by the building itself was six to seven times higher than the production of body odours by the staff.[94] This was attributable to the materials used, the presence of smokers and especially to 'olfactorily perceivable' pollutants from mechanical ventilation systems.

Carbon dioxide and other indicators of ventilation

'Intervention' study in schools. The results of a Swedish experiment in four computer rooms were inconsistent.[111] In the cross-sectional part an increased CO_2 concentration was associated with the occurrence of headaches but in the longitudinal part an increase in ventilation was not associated with a statistically significant reduction in the number of physical symptoms. Owing to the large number of computers it is doubtful whether this experiment is relevant for the situation in primary schools. In 1993 (March-May) and 1995 (January-March) the same research group conducted a repeated cross-sectional study into the pos-

sible effect of improved school ventilation on exposure to various indoor environmental factors and on health.[112] In the interim a new ventilation system had been installed in twelve percent of the classrooms. In the schools where this was done there was a statistically significant decrease in humidity and concentrations of CO_2, formaldehyde, particulate matter and fungi in the indoor air. The incidence* of asthmatic symptoms in those schools was also lower than that in schools where the ventilation system had not been changed. However, the number of children in schools with a new ventilation system (n=143) and the number of incident cases (< 10) were small. As there was no reduction in the incidence of headaches, tiredness and the reported number of respiratory infections, it is improbable that the reported reduction in asthmatic symptoms can be explained by the fact that participants were aware that new ventilation systems had been fitted. The Committee views this as an indication that the decrease in asthmatic symptoms was actually the result of the ventilation system's replacement.

Observational studies in schools. Two Dutch cross-sectional studies were unable to find any relationship between the CO_2 concentration and physical symptoms. Results were published in 2006 of measurements of CO_2 and other indoor environmental parameters in eleven classrooms at eleven schools.[107] The average CO_2 concentration during school hours varied from 888 to 2,112 ppm with a median of 1,524 ppm. Parents of 228 pupils aged 10 and 11 years reported symptoms. No association was found between physical symptoms and the ventilation system or CO_2 concentration. However, a relationship was demonstrated in the 'principal components analysis' between the quality of the environment at school and in the home. A previous Dutch study involving 333 children at seven newly built schools in Rotterdam also failed to find a statistically significant association between reported 'non-specific'** symptoms and the CO_2 concentration in classrooms.[101] Nevertheless, a statistically significant higher number of children experienced the 'smell' as more intense in the classrooms with CO_2 concentrations exceeding 1,200 ppm for more than 90 percent of the teaching period than was the case in classrooms in which this occurred for less than 50 percent of the teaching period. However, in view of the poor correspondence between answers to corresponding pairs of questions, the investigators indicated that the validity of the developed questionnaire would have to be examined. The CO_2 concentra-

* Incidence: occurrence of new cases of disease in a given period.
** Non-specific symptoms are symptoms which cannot be directly explained by specific clinical symptoms or a specific cause and which are sometimes attributed to environmental factors.

tion in the classrooms studied exceeded 1,200 ppm for 27 to 97 percent of the time. The maximum CO_2 concentration reached in the classrooms varied from 1,900 to more than 4,200 ppm.

In 2005, in Sweden, 1,014 schoolchildren aged 5 to 14 years were studied at eight schools (23 classrooms).[30] Seven of the schools had a mechanical ventilation system. The daily average CO_2 concentration in 74 percent of the classrooms was lower than 1,000 ppm. In some classrooms the concentrations at the end of the school day exceeded 1,000 ppm. The investigators found no association between the CO_2 concentration and five of the six respiratory and allergic symptoms. They only found a marginal association for one of the six symptoms. In a previous study involving more than 600 children aged 13 and 14 years at eleven randomly selected schools, the same research group had not found an association between asthmatic symptoms and the ventilation rate*, the ventilation system or the CO_2 concentration, which varied during the school day from 550 to 1,725 ppm.[17]

Norwegian investigators reported an association between the CO_2 concentration and physical symptoms among 550 schoolchildren aged 15 years or older at five schools.[110] This study was only published as conference proceedings. The Norwegian investigators found more contrast in exposure than the Swedish investigators had found; the CO_2 concentration in classrooms varied during the day from 601 to 3,827 ppm. The statistically significant correlation between CO_2 and physical symptoms was stronger for non-specific symptoms, such as headaches and dizziness (correlation coefficient $r=0.22$; $p=0.000$), than for symptoms of irritation of the upper respiratory system ($r=0.10$; $p=0.024$). In an analysis in which the CO_2 concentration was divided into three categories (< 1,000 ppm, 1,000-1,499 ppm, ≥ 1,500 ppm), there was a statistically significant higher prevalence of non-specific symptoms in the group in which concentrations exceeded 1,500 ppm. The reason for the symptoms could not have been the CO_2 itself but other unmeasured factors affected by ventilation in the classroom may have been present which led to symptoms in sensitive groups, such as children with asthma.

Review of studies in offices. On the basis of the results of eight studies, the authors of a literature review concluded that the prevalence of non-specific symptoms in offices increases by an average of 23 percent if ventilation

* Ventilation rate: a figure which indicates the relationship between the air flow per unit of time and the volume of the room, expressed as the number of air changes or volume per hour (m^3/h).

decreases from 10 to 5 litres/second (L/s) per person*.[153] For an increase in ventilation from 10 to 25 L/s per person, the prevalence of symptoms would sup-posedly decrease by an average of 29 percent. As the health indicators in the various studies were measured in different ways, the Committee sees nothing more than weak indications in these studies.

Intervention study in offices. In 1993 a double-blind intervention study in Canada, CO_2 concentrations were alternately changed to 1,000 or 600 ppm by altering the ventilation in four offices.[154] These two different conditions did not lead to a difference in reported symptoms (adjusted odds ratio: 1.0: 0.8-1.2).

Observational studies in offices. In 1992 more than 7,000 office workers in the Netherlands were studied in 61 different buildings.[93] In this study high CO_2 concentrations were associated with a lower prevalence of symptoms. The authors attributed this to CO_2 concentrations being higher in naturally ventilated buildings, in which the rate of ventilation was apparently less. In comparison with naturally ventilated buildings, the incidence of physical symptoms appeared to be higher in mechanically ventilated buildings, and especially in air-conditioned** buildings. A possible explanation is that the quality of the supply of incoming air affects the incidence of physical symptoms. Another study in offices also showed that mechanical ventilation systems may be a source of pollution.[94]

In 2000 results were published in the United States of a study involving the occupants of 41 offices.[114] All the buildings had air conditioning. The CO_2 concentrations in and around each building were measured over a three-day period. The CO_2 concentrations were all below 800 ppm. An exposure-effect relationship was found between the CO_2 concentration and reported symptoms in mucous membranes and the lower respiratory system. The authors offered no explanation of why an association was found between CO_2 and physical symptoms in the 41 offices, in which ventilation can be deemed to have been good to very good, given the relatively low CO_2 concentrations.

In a later analysis of the same study, a statistically significant exposure-response relationship was also described between the low CO_2 concentrations and irritation of the mucous membrane, especially dry eyes, sore throats, blocked paranasal sinuses, sneezing and wheezing among occupants of 100 randomly

* In a state of equilibrium the (△) CO_2 concentration is 500 or 200 ppm higher than the outdoor air concentration (900 or 600 ppm respectively, for an outdoor air concentration of 400 ppm).
** Air conditioning: climate control (control of air quality, humidity and temperature).

selected offices.[155] The likelihood of these physical symptoms occurring was two to three times greater in the highest CO_2 category than in the lowest (adjusted odds ratios 1.1 to 1.2 per 100 ppm increase of $\triangle CO_2$*). Peak levels of CO_2 in excess of 1,000 ppm occurred regularly in two buildings only. According to the authors, by increasing ventilation to achieve the lowest possible CO_2 concentration (40 ppm more than the concentration in outdoor air) the prevalence of the symptoms could be reduced by 64 to 85 percent. However, the Committee points out that these buildings bear very little resemblance to Dutch primary schools, most of which still lack air conditioning.

D.2 Effects on cognitive performance and sickness-related absence

Indoor air quality

Indoor air quality

Intervention study on absence in day nurseries. In a controlled trial at two day nurseries in Sweden, absence rates among toddlers and pre-school children were halved throughout a period of two years after the installation of a mechanical ventilation system with air filtration, which reduced the concentration of fine dust particles entering from the outdoor air by 78 percent.[156]

Experiments to investigate the cognitive performance of adults. Psychological and neuroscientific experiments investigating the effects of aromatic substances, even at olfactorily imperceptible concentrations, showed that male aromatic substances, such as sweat, can affect women's stress hormone levels, mood and concentration, and thereby possibly also their functioning, even when the odour is not consciously perceived.[157-159] However, these effects cannot be considered as adverse. The Committee is of the opinion that it is unlikely that this would lead to adverse health effects in primary school children.

Perceived indoor air quality

Intervention studies on cognitive performance in offices. An experiment at an office building in Denmark investigated the effect of a source of pollution (old carpet) on students' productivity.[103] Exposure to air polluted by the carpet was related to reduced productivity. The possibility was not excluded that some sub-

* $\triangle CO_2$: the difference between the CO_2 concentration in indoor and outdoor air.

jects were aware of the exposure from the start and that this had an unknown effect on productivity reporting. Despite these limitations, the experiment provides indications that perceived air quality in an office may lead to reduced productivity. In another experiment with largely the same group of subjects and the same source of pollution, the ventilation rate was manipulated.[102] Productivity increased with increasing ventilation. Here too, there is a possibility that the results were influenced by expectations at the start.

Carbon dioxide and other indicators of ventilation

Intervention studies on cognitive performance in Dutch schools. A report was published in 2007 on the effect of ventilation on the cognitive performance of 47 primary school pupils in grade seven and eight at one school.[120] The study has thus far only been published as a report and has not been subject to external peer review. Two groups of pupils in a double blind study were alternately tested in one classroom with limited ventilation and in another classroom with CO_2-controlled ventilation using outdoor air. The control situation was camouflaged using recirculation ventilation without intake of fresh air. The rate of ventilation was measured in respect of the CO_2 concentration in the classroom. The authors reported that children in the amply ventilated classroom (CO_2 concentration 620-874 ppm) made a statistically significant lower number of errors in computational tests and language tests than the number made by the children in the classroom with limited ventilation (CO_2 concentration 1,157-2,126 ppm). The effect on the speed of performing was not studied. The Committee makes a number of comments on this study. For example, measurements were not made consistently at the same times and little was known about the specific cognitive functions that were measured using the tests. The Committee is therefore of the opinion that this study only provides an indication that improving the ventilation in classrooms can lead to better cognitive performance by primary school pupils.

Ten years earlier, in the Netherlands the results were published of a study on ventilation and cognitive performance. The study involving 95 pupils from four schools also measured the effect that changing ventilation had on various attention tests.[122] In two schools ventilation was as normal on the first day and was increased on the second day. The opposite was done in two other schools. The extent to which children were aware of this is unclear. With normal ventilation the CO_2 concentration was higher than 1,200 ppm for 60 to 96 percent of the time, with peak concentrations exceeding 3,500 ppm. With extra mechanical ventilation the CO_2 concentrations at table height were no more than 1,200 ppm. Regardless of the rate of ventilation, the test results were better on the second day. This educational effect was considerably greater than the effect of the extra ventilation. Given the very dominant educational effect, it is not possible to draw conclusions on the independent effect of ventilation. On the other hand, following correction for the educational effect, it is not possible to exclude the possibility that a ventilation effect took place (p value: 0.051).

Intervention studies on cognitive performance in schools outside the Netherlands. In Denmark, various independent experiments were conducted in mechanically ventilated classrooms and published in 2007 in two scientific papers.[124,125] The pupils were aged 10 to 12 years and the ventilation experiments were carried out 'blinded' for a period of a week. Computational skills and language skills were tested as part of the normal lessons. However, owing to mistakes made by teachers, observations were not made at crucial moments and the experiments could not be analysed according to the original design. The investigators also reported that they reduced the number of follow-up experiments owing to complaints from parents about the large number of tests. It remains unclear whether, and if so to what degree, the results were affected by the reported parental concerns.

The first paper mainly discussed the effects of supplying fresh air and the condition of the air filters in the winter.[125] The ventilation was manipulated in this study to increase it from 3.0 to 8.5 L/s per pupil. The average CO_2 concentration consequently decreased from 1,300 to 900 ppm. The authors reported a statistically significant increase in the speed at which four of the seven computational tests and language tests were performed. There were no statistically significant differences in the accuracy with which the cognitive tests were performed between the situations with a low level of ventilation and those with a high level of ventilation. Although in the situations with a low level of ventilation the reported ventilation volumes were considerably lower than the minimum level currently required in the Netherlands for new schools (7 L/s per person) they were comparable with the situation which exists in practice in the Netherlands. However, in the first winter experiment (with a used filter), the noise level in the classroom increased from 35 to 44 dB(A) when the level of ventilation was changed from low to high. It is unclear whether this was related to the ventilation system but, if it was, the difference was of such a magnitude that the experiment was no longer blinded. In the second winter experiment (with a new filter), the noise level increased from 33 to 36 dB(A).

The second paper described the effects of the ventilation rate and temperature in late summer.[124] The ventilation in this study was manipulated to increase it from 5.2 to 9.6 L/s per pupil. The authors reported a statistically significant increase in the speed at which four computational tests were performed. However, there were no statistically significant differences in the accuracy with which the cognitive tests were performed between the situations with a low level of ventilation and those with a high level of ventilation. In this paper, it is remarkable that the results of the tests carried out were very different (in the positive direction as well as the negative direction) from those described in the first paper, yet the same tests were used in the same school on pupils of the same age. In the experiment in the summer there was no difference in noise level between the ventilation conditions. The effects of temperature are discussed later in this annex.

Owing to the aforementioned limitations (faulty implementation of the experimental protocol, noise level differences, inconsistency between the first and second paper), the Committee is of the opinion that the substantiation of the favourable effect on the speed of performing reported by the Danish investigators is limited.

In an experiment in England eighteen schoolchildren aged ten to twelve were given cognitive tests to perform while the windows in their classroom remained either opened or closed during during lessons.[126] The tests were mainly to assess attention and reaction time, and were always performed at the end of the morning. They formed part of an independently developed test battery, the validity of which is difficult to assess. The CO_2 concentration when the windows were open remained relatively low (501 to 983 ppm) and increased when the windows were closed to 2,096-4,140 ppm. The tests were performed four times under both conditions. For two of eleven attention and reaction-time tests pupils scored a statistically significant few percent lower at a high than at a low CO_2 concentration. The investigators indicated that the experiment had been explained in detail to the participants and was consequently not performed under 'blind' conditions. However, in the discussion they failed to question whether this may have affected the results. They also indicated that there was a lack of clarity about the extent to which the detected differences are significant in terms of cognitive performance and that it was unclear to what extent pollutants present in the classroom may have been responsible. Especially in view of the fact that the experiment was not conducted under blinded conditions, the study's results are not useful for deriving a well-substantiated recommended exposure limit.

Observational studies on cognitive performance in schools. A study, which was not published as a scientific paper, was conducted at 20 primary schools in the province of Limburg in the Netherlands to examine the association between CO_2 in 24 classrooms (year 6) and the results of a number of cognitive tests.[121] No information was available on the validity and reproducibility of the tests. The average CO_2 concentration varied from 1,179 to 3,335 ppm and exceeded 1,200 ppm in 20 of the 24 classrooms investigated. The study showed no association between CO_2 and test results. No further interpretation is possible without making adjustments for possible confounding variables, such as absence, the quality of teachers and socio-economic status.

In a pilot study conducted in the United States, investigators examined the association between the scores of annually performed cognitive tests and CO_2 concentrations measured only once in 54 classrooms of 54 primary schools (year 5).[127] The study was one of the few based on computational tests and reading tests which are regularly set to ascertain pupils' cognitive performance, although no further information was provided on validity and reproducibility. The CO_2 measurements were conducted under standardised conditions, with the mechanical ventilation system switched on and the windows closed. The authors did not discuss the question of whether this corresponded with normal ventilation practice throughout the year in the classrooms studied. Two classrooms were removed from the analysis because conditions during the measurements were 'unstable' and two others were removed because the measured ventilation was characterised as an 'outlier'. Ventilation expressed in litres per second (L/s) per person was low in this population* but not lower than that found in Dutch schools. Ventilation only exceeded 4.5 L/s per person in 12 of the 50 remaining classrooms. There was a marginally significant association between the scores for a computational test and ventilation but the exposure-response relationship was inconsistent. There was no association for the reading test scores. Adjustments were only made for the effect of socio-economic status and not for the effect of humidity and temperature, for example. Test scores can be affected by factors such as the amount of money spent by the school on education, the ratio of pupils to teachers, the experience and quality of teachers and absence from school, and it is difficult to interpret relationships to ventilation without having insight into these factors.[160] Given this cross-sectional study's numerous limitations no conclusions can be attached to it. The authors also indicate this and call for further studies.

Conference proceedings were published on a study in Norway in 1996 involving 550 children aged 15 years and older.[110] The correlation coefficient between CO_2 and the results of the cognitive tests was low ($r=0.11$; $p=0.009$). The authors reported the correlation as statistically significant but failed to take into account the study's 'multilevel' design: the children were clustered in 22

* Average 3.9 L/s (corresponding to a CO_2 concentration of more than 1,400 ppm)

classrooms of 5 schools. An analysis in which the CO_2 concentration was divided into three categories (< 1,000 ppm, 1,000-1,499 ppm, ≥ 1,500 ppm) was unable to demonstrate a statistically significant association between CO_2 and cognitive performance.

In 1967, in Florida academic performance in a school with air conditioning was compared with that in a number of other schools without air conditioning.[161] Performance in the air-conditioned school was found to be better. This was mainly concerned with reducing temperature and humidity in a hot and humid climate.

Ongoing study on cognitive performance in schools. A study recently started in England involving pupils aged 9 to 11 years at 20 primary schools, in which the investigators are attempting to limit some of the previous shortcomings. The design includes a cross-sectional component as well as an intervention component.[128] Provisional results of interventions in six schools indicate a statistically demonstrable improvement in pupils' cognitive performance after an increase in ventilation from 1.6 L/s to 6.8 L/s per person.[162]

Observational study on absence from school. In the United States a study was conducted on the relationship between absence from school and CO_2 in the air in classrooms of primary schools and secondary schools. CO_2 measurements were conducted in 436 classrooms at 22 schools, for five minutes at times which were not further specified during the school day.[163] Data on absence from school and the socio-economic status at the school level were obtained from the schools. No data were provided on the reasons for absence. Statistical analysis revealed an association between CO_2 and absence from school (p value: < 0.02) but a stronger association with the school's socio-economic status. The rate of absence from school was also clearly higher in temporary buildings. The analysis did not take into account the clustering of data per school: the data sets collected for each class were analysed independently of each other. This can lead to statistical significance being overestimated. Moreover, one school stood out because of a much higher CO_2 concentration and a clearly different rate of absence. No attempt was made to determine how much the results had been influenced by this ‘outlier’. The Institute for Risk Assessment Sciences (IRAS) presented the raw data on the schools in Figure 3, in which the x axis shows the median difference between CO_2 indoors and outdoors, and the y axis shows the median attendance rate as a complement of absence.[11] The aforementioned outlier appears to be responsible for the whole of the reported association. Also in view of the limita-

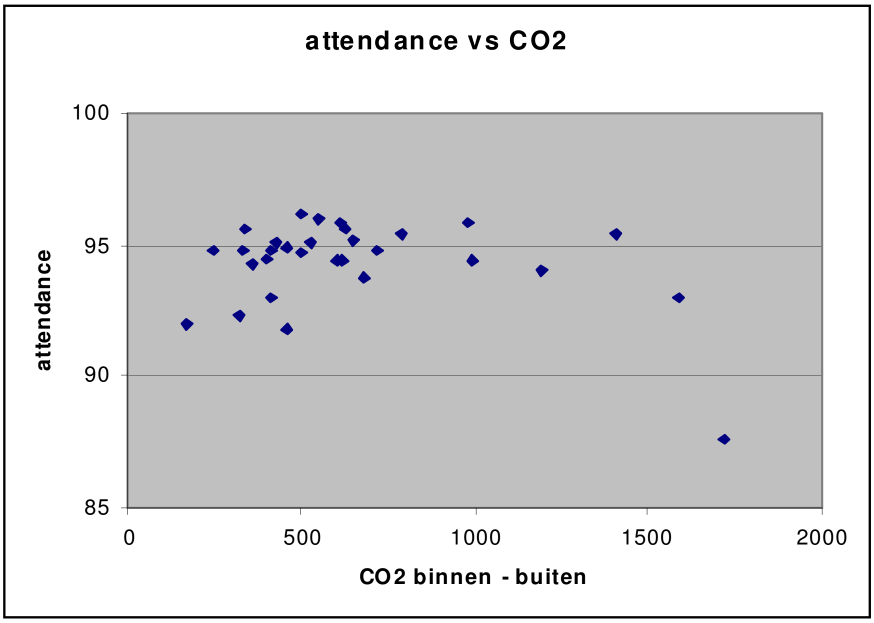

Figure 3 Attendance (as a complement of absence) from school, in relation to the difference between the CO_2 concentration in indoor and outdoor air ('binnen-buiten').

tions of observational studies, the Committee sees no indications of an exposure-effect relationship between ventilation or CO_2 and the absence rate in schools.

Intervention study on sickness-related absence in offices. In 2002, investigators attempted to affect sickness-related absence from two offices in Massachusetts, the United States, by manipulating ventilation.[164] No association was found, possibly because of the narrow range in CO_2 concentrations that was ultimately achieved (no more than 312 ppm higher than the concentration in the outdoor air) and consequently the small contrast between the intervention group and the control group.

Observational study on sickness-related absence in offices. The same research group had previously investigated the sickness-related absence of 636 employees at a large firm in Massachusetts.[165] An expert estimated the rate of ventilation and some CO_2 measurements were also taken. Ultimately, the result was that working in conditions with 'moderate' ventilation was related to a 1.5 times higher risk of short-term, sickness-related absence. The percentages for short-term, sickness-related absence among office workers were roughly 2.00 and 1.45

percent for office workers in workspaces with 'moderate' and 'high' rates of ventilation respectively. In the total population of 3363 employees on whom data on short-term, sickness-related absence were available, the percentages were roughly 1.66 and 1.50 percent for workers in workspaces with 'moderate' and 'high' rates of ventilation respectively.

Other ventilation-related indoor environmental factors

Temperature

Intervention study on cognitive performance in schools. A Danish intervention study examined the effects of not only the ventilation rate at a mechanically ventilated school but also the effects of temperature in the summer months.[124] For a decrease in temperature from 25 to 20°C the authors reported a statistically significant increase in the speed of performing two computational tests and two language tests but no increase in the accuracy of the results.

Observational study on cognitive performance in schools. A study involving pupils in year 6 at 20 primary schools in the province of Limburg, the Netherlands, also studied the association between temperature and the results of two different attention tests.[121] In 29 percent of the classrooms studied the temperature rose to in excess of 25°C. The accuracy with which the computational test was performed decreased as the temperature in the classroom increased. However, the effect of possible confounding variables was not investigated.

Humidity

Sickness-related absence among adults in relation to humidity. A review paper published in 1985 on the effect of humidification – in situations with relatively low humidity in the winter – on the incidence of disease, described a reduction in the number of respiratory disorders and in sickness-related absence when relative humidity was increased to no more than 50 percent.[166] The measured values were lower to much lower than those observed in indoor air in the Netherlands.

Noise

Intervention studies on cognitive performance in schools. Likewise in a randomised experimental setting, investigators in London were able to demonstrate that exposure to environmental noise in the classroom had adverse effects on the speed of performing cognitive tests.[132] A natural experiment among 326 primary school pupils before and after the opening of a new airport in Munich showed that the higher noise level after the opening had an adverse effect on speech intelligibility, long-term memory and reading.[133] On the other hand, the reduction in noise levels after the old airport's closure had a positive effect on short-term and long-term memory and on reading. After the opening of the airport the same investigators had previously found a reduction in the motivation to solve difficult problems.[134]

Observational studies on cognitive performance in schools. In schools, too much noise from outside can lead to a reduction in pupils' cognitive performance.[135.136] This mainly applies to aircraft noise but also to road traffic noise. An extensive study in London primary schools delineated indoor and outdoor noise levels.[167] Follow-up data demonstrated that environmental noise had a clear adverse effect on the results of cognitive tests.[137] This applied to noise from outside as well as noise generated in the classroom.

Annex

E

Consulted stakeholders

Upon being requested, the following stakeholders provided suggestions regarding the 'indoor environment in schools':

- Council of school boards* in the Christian education sector
- Municipal Health Services in the Netherlands, 'Improving ventilation in primary schools' project group
- International Society of Indoor Air Quality and Climate (ISIAQ.NL)
- Netherlands Technical Association for systems/installations in buildings (TVVL: Nederlandse Technische Vereniging voor installaties in gebouwen)
- Dutch Council for primary education (PO Raad)
- Platform for the Indoor Environment Foundation (Stichting Platform Binnenmilieu**)
- Association for Cleaning (VSR: Vereniging voor Schoonmaak Research).

The Committee has summarised the responses to its questions as follows:

* Council of school boards (Besturenraad): the body which promotes the interests of and provides services to schools and school boards.

** This platform includes representatives of the Asthma Fund, Municipal Health Services in the Netherlands, ISIAQ.nl (International Society of Indoor Air Quality and Climate), ISSO (institution for the study and promotion of research in the field of building services), Milieuplatform Zorgsector (environmental platform association in the health care sector), Nederlandse Woonbond (Netherlands Union of Tenants), Building Research Foundation (SBR), SenterNovem, SEV (Foundation for Experiments in Public Housing), VACpunt Wonen (knowledge and advice centre for the occupancy quality of homes and the residential environment), Viba-Expo (permanent exhibition of ecologically tested building products).

What do you perceive to be the most important problem for a healthy indoor environment in schools?

- lack of good, usable natural ventilation systems
- poor installation, maintenance and use of mechanical ventilation systems
- lack of knowledge among teachers of the correct ventilation method
- dusty classrooms owing to poor cleaning
- too many children in a small area
- division of responsibility between municipal authority and school board.

Which indoor environmental factors do you consider to be the most relevant from the prevention point of view?

- air quality (particulate matter, volatile organic compounds, pathogens): classroom layout/furnishing, inadequate ventilation, contaminated mechanical ventilation systems
- excessive temperatures in the summer, draughts in the winter, noise nuisance (from outside as well as from mechanical ventilation systems).

In terms of the type and size, which sensitive groups do you believe are relevant?

- (young) children, especially those with allergic and asthmatic symptoms
- teachers with allergic and asthmatic symptoms.

What measures do you expect government to take?

- clear criteria for a healthy indoor environment and the associated funding
- tightening of Building Decree and Occupational Health and Safety Regulations (especially on ventilation air volumes, room temperature and the noise levels of ventilation systems) and more supervision of their observance
- requirements for, and inspection of, ventilation facilities and indoor climate upon delivery
- annual inspection in all schools, also covering cleaning and maintenance
- emission requirements for volatile organic compounds
- requirements for school's location (not alongside motorways).

What other matters would you like to draw to the Committee's attention?

- asbestos in school buildings
- quality mark for the quality of the indoor climate in school buildings
- consideration of secondary education, special education and day-care centres for children
- integrated approach to air quality and energetic quality.

The responses, suggestions and associated key publications were discussed in the Committee.

Annex **F**

Model for calculating changes in CO_2 concentration

The mass balance was adopted as basis for designing a mathematical model for determining the CO_2 concentration in indoor air. People present in the room produce CO_2; ventilation removes CO_2. The following differential equation shows these processes*.

$$V*(dC/dt) = q - a*V*C \qquad (1)$$

Where V is the volume of the room [m^3], C is the concentration [kg m^{-3}], t is the time [s], q is the production rate of carbon dioxide [kg s^{-1}] and a is the ventilation rate [s^{-1}].

The carbon dioxide concentration C_t at time t follows from the solution to equation (1) subject to the initial condition C = 0 at t = 0:

$$C_t = q/(a*V) * (1 - e^{-at}) \qquad (2)$$

The final equilibrium concentration C_E achieved during a long stay in the room concerned is provided by:

$$C_E = q/(a*V) = q/Q\text{, where Q is the ventilation flow rate} \qquad (3)$$

* Assuming 'mixed mode' ventilation (report Van Ginkel, 2009).

This equilibrium concentration depends on the source level and the ventilation flow, but is independent on the volume of the room.

If all the people leave the classroom, the source term q equals zero. The solution to equation (1) is therefore:

$$C_t = C_1 * e^{-at} \qquad (4)$$

Where C_1 is the initial concentration at the time the room is vacated.

A formula for calculating the ventilation rate can also be derived from equation (4):

$$a = - \ln(C_t / C_1) / (t - t_1) \qquad (5)$$

As the concentration of carbon dioxide in the outdoor air is higher than zero, for C_t and C_1 we enter the differences from the outdoor air concentration: respectively $C_t – C_{outdoor}$ and $C_1 – C_{outdoor.}$,

so:

$$a = - \ln((C_t – C_{outdoor})/(C_1 – C_{outdoor})) / (t - t_1) \qquad (6)$$

Annex **G**

Legislation and regulations on indoor environment in schools

Housing Act

Also from the health point of view, pursuant to the Housing Act the 2003 Building Decree stipulated structural requirements for buildings, including requirements for ventilation.[168] The structural requirements for buildings are specified in the 2003 Building Decree according to the purpose of the building (e.g. educational purposes) and in relation to new buildings and existing buildings.[169] The specifications include requirements for the rate of ventilation. However, there are also requirements for 'structural divisions such that' the formation of allergens is sufficiently limited.

Although the Building Decree includes stipulations on the presence and capacity of ventilation facilities, it does not specify the means to be used to achieve that capacity.[143] The capacity requirements are derived from a given average pollution level of the indoor air which has to be ventilated. The method of ventilation is not specified. This therefore provides scope for freedom of design. A determination method laid down in the standards of the Netherlands Standardisation Institute (NEN) is cited for the required method to be used for determining the capacity.

The Building Regulations of 2003 ensure a match between the performance requirements in the Building Decree and the cited standards, including two

Dutch standards[*] on ventilation: NEN 1087 for new buildings and NEN 8087 for existing buildings. The standards stipulate that solely taking into account human occupants, the CO_2 concentration and the volumes of aromatic substances must be normative for ventilation.

Netherlands Code of Practice NPR 1088 provides details of practical applications showing how to comply with the requirements on new housing. The Netherlands Code of Practice for schools is currently being updated to bring it into line with the requirements in the present 2003 Building Decree. Unlike in the case of new buildings, the minimum ventilation capacity requirement stipulated in the Building Decree for existing buildings is not dependent on the occupancy rate[**]. Pursuant to the Housing Act, those parts of a building which are replaced or altered must comply with the requirements for new buildings. Following the handover the requirements for existing buildings apply as the minimum. The extent to which a building must continue to comply with certain requirements for new buildings is not stipulated.

Pursuant to the Housing Act, not only do the structural requirements in the Building Decree apply but also requirements set out in municipal building regulations on the building's prescribed use.[143] Section 8 of the Housing Act requires municipal authorities to draft municipal building regulations. Practically all municipal authorities draft their municipal building regulations on the basis of the Model Municipal Building Regulations 1992 of the association of Netherlands municipalities (VNG). These regulations stipulate amongst other things that the maximum occupancy rate stated in the planning permission must not be exceeded. The municipal authority is responsible for granting and enforcing the planning permission. If a 'health-damaging' situation arises, the municipal authority can impose restrictions on the building's use, by for example stipulating the maximum number of pupils permitted for a given ventilation rate.

The 2003 Building Decree includes the following particular requirements for ventilation in new buildings:

- airing facilities[***]
- minimum ventilation capacity (minimum possible fresh-air flow).

* Dutch standard (NEN-norm): a standard issued by the NEN (Netherlands Standardisation Institute/Nederlands Normalisatie-Instituut); NEN standards which are not referred to in the Building Decree or other statutory regulations have no legal status but are private agreements concluded between the parties concerned.

** The forthcoming amendment of the Building Decree will include a change to a person-related requirement for schools.

*** Airing facility: movable part of wall or roof (window, hatch or door) enabling a relatively high degree of ventilation to be created.

An airing facility quickly removes extra pollutants that are produced temporarily. No requirements are set in the 2003 Building Decree for airing facilities in schools. The Minister of Housing, Communities and Integration intends to include airing facilities for all classrooms as a performance requirement in the next amendment to the Building Decree.[170]

The aim of the 2003 Building Decree's minimum ventilation capacity requirement for a room in a new building is a performance requirement 7 L/s or 25 m^3 per hour per person, whereby an equilibrium concentration below 1,200 ppm CO_2 can be achieved. However, these capacity requirements have been made dependent on the occupancy classification*: for buildings used for educational purposes (occupancy classification B2) 1.3-3.3 m^2 per person.

Other standards and recommended exposure limits

Given the same exposure time, the concentration of hazardous substances in the indoor air, such as particulate matter, formaldehyde and volatile organic compounds, can be checked against outdoor air standards or against exposure limits recommended by the National Institute for Public Health and the Environment (RIVM) or the Health Council of the Netherlands.

The Air Quality Act, which entered into force in November 2007, includes outdoor air quality exposure limits for air pollutants, including, suspended particles (particulate particles: PM_{10}**). These values are based on the subsidiary directives of the European Union.

In 2004 and 2007 RIVM defined a number of ‘health-based recommended exposure limits’ for assessing the quality of the indoor environment of homes, offices and schools.[144,150] They only took into account exposure through inhalation. The recommended exposure limits for indoor air quality have no legal status but are intended to assist in improving the quality of the indoor environment (see Annex H).

A Committee of the Health Council of the Netherlands is producing an advisory report for the Minister of Social Affairs and Employment on new health-based recommended occupational exposure limits to protect personnel, including teaching staff. An advisory report was published in 2008 on extreme temperatures, and an advisory report is expected in 2010 on biological agents.[117]

* Occupancy classification: a given range in floor area per person, in line with the intended use and interior design of the building.

** PM_{10}: particles (‘particulate matter’) with a median aerodynamic diameter of less than 10 µm.

Annex **H**

Health-based recommended exposure limits

In 2004 the National Institute for Public Health and the Environment (RIVM) defined 'health-based recommended exposure limits for the indoor environment' for a large number of chemical substances and for noise.[144] They were updated in 2007, also in response to the updating of a WHO publication.[150] The recommended values are mainly concerned with dwellings but could also be applied to other locations where people spend considerable time, such as offices and schools. The recommended values are based on the Maximum Permissible Risk (MPR), as defined in the past in Dutch environmental policy. The MPR for the air compartment is usually referred to as the Permissible Concentration in Air. In the case of substances with a 'threshold value' this is the concentration at which lifelong exposure has no adverse effect on health. This also takes into account risk groups such as children, and sick or pregnant people. The MPR for carcinogens with a genotoxic effect has been defined as one case of cancer per million persons exposed. The recommended exposure limits indicate the extent to which residents or occupants of buildings are able to endure particulate matter, chemical substances and noise indoors. Lower levels present no risk or a permissible risk of damage to health. The possibility of risks to health cannot be excluded in the case of higher levels. The recommended exposure limits have no legal status but can be used for assessing and improving the quality of the indoor environment in buildings. They can therefore be used as basis for policy. In its determination of the recommended exposure limits, RIVM also used recommended exposure limits drawn up by the Health Council of the Netherlands, such as those for volatile organic compounds in accommodation spaces and for noise.[23,171] Moreover, the Health Council determined a large number of recommended exposure limits for situations in the workplace but not specifically for schools.

Chemical indoor environmental factors and particulate matter

Table 8 shows various recommended exposure limits for particulate matter and chemical agents which are important for the quality of the indoor environment in schools.

Table 8 Recommended exposure limits for chemical indoor environmental factors and particulate matter.

Agent	Recommended exposure limit	Unit	Duration of exposure
Particulate matter (PM_{10})	50	µg/m^3	24 hours
	20	µg/m^3	Annual average
$PM_{2.5}$	25	µg/m^3	24 hours Annual average
	10	µg/m^3	
Formaldehyde	1.2	µg/m^3	Lifelong
Volatile organic compounds	200[a]	µg/m^3	Annual average

[a] Recommended exposure limit of the Health Council of the Netherlands, based on sensory observations as most critical effect.

In 2004 RIVM did not determine a 'health based' recommended exposure limit for CO_2 in the indoor environment, as its expertise in this field was insufficient.[144]

Microbiological indoor environmental factors

RIVM has not determined health-based recommended exposure limits for biological agents.[144,150] In particular, the concentrations of fungi, endotoxins and allergens in homes would supposedly fluctuate too much to enable any statements on the likelihood of health effects. A WHO expert panel took the view that a concentration of 10 µg of the Der p1* dust mite allergen per gram of dust as the concentration at which asthma attacks occur in sensitised people and 2 µg per gram of dust as a possible exposure limit at which sensitisation occurs in susceptible people.[172] The WHO did not determine any acceptable concentrations for the various other biological agents.[151] This was mainly because of the usually

* Der p1: Dermatophagoides pteronyssinus, a common species of dust mite in Europe.

simultaneous exposure to several agents, the complexity of measuring exposure accurately and the large number of health effects that can be attributed to exposure.

Physical indoor environmental factors

RIVM proposed a recommended exposure limit for environmental noise (see Table 9). The institute based its proposal on the 'perception threshold' stated by the Health Council of the Netherlands for severe nuisance of an average of 42 dB(A) over a 24-hour period.[171] This is the lowest exposure level at which noise has been observed to have an effect in epidemiological studies. The value was derived from exposure-response relationships of TNO (Dutch organisation for Applied Scientific Research) for adults exposed over a period of at least a year to traffic noise, as measured outdoors. The proportion of adults experiencing severe nuisance at this level of exposure was no more than a few percent. No such perception threshold was derived for children.

Table 9 Recommended exposure limit for noise.

Agent	Recommended exposure limit	Unit	Duration of exposure
Noise	42	dB(A)	Daily exposure level

RIVM did not determine indoor environmental health-based recommended exposure limits for some factors. For example, RIVM did not determine a recommended exposure limit for CO_2, as its expertise in this field was insufficient.[144] Likewise, RIVM has not determined health-based recommended exposure limits for biological agents.[144,150] In particular, the concentrations of fungi, endotoxins and allergens in homes would supposedly fluctuate too much to enable any statements on the likelihood of health effects.