SIMPLE METHOD

Simple method to determine the effectiveness of

ventilation systems

DATE	28 april 2025
AUTHORS	A. de Lange, R. Traversari
ORGANIZATION	TNO
REPORT NUMBER	TNO 2025 R10910

Contents

1. Summary

This report pertains to the third phase of the work being carried out within Work Package 2 of the Clean Air for Everyone (CLAIRE) program. Work package 2 “ventilation properties” has two main objectives:

- Moving beyond the state of the art in understanding the behavior of aerosol particles under different types of ventilation systems and realistic operational circumstances;
- Developing a more sophisticated model-based understanding of effects, interactions and sensitivities, as well as methodologies.

This report outlines the theoretical framework for a simple method to determine the effectiveness of ventilation systems in rooms. This method was discussed and agreed upon during several meetings with the industry initiated by Binnenklimaat Techniek and Jaga.

2. Introduction

Work package 2 “ventilation properties” has two main objectives:

- Moving beyond the state of the art in understanding the behavior of aerosol particles under different types of ventilation systems and realistic operational circumstances;
- Develop more sophisticated model-based understanding of effects, interactions and sensitivities, as well as methodologies.

A smaller “Industrial research” component is also involved, as functional requirements for the assessment method to be developed are informed by end-user and industry needs, expectations and competencies.

This report describes a simple method that can be used by building owners or users to assess whether the amount of fresh air complies with the guidelines and building regulations.

The approach for this deliverable consists of four steps:

1. Defining a simple method based on literature that can be used by building owners and users to assess weather the amount of fresh air complies with the guidelines and building act.(Ministerie van van Binnenlandse Zaken en Koninkrijksrelaties, 2025)
2. Discussing the method with the installation sector organized by Binnenklimaat techniek and Jaga for feedback and improvement of the method
3. Updating the method based on step 2
4. Rediscussing the updated method with the installation sector organized by Binnenklimaat techniek and Jaga to receive comments to finalize the method
5. Finalizing the method

The CLAIRE project is powered by Health~Holland, Top Sector Life Sciences & Health, through its Public-Private Partnership (PPP) Allowance programme. Health~Holland is the trade name of the Dutch Top Sector Life Sciences & Health. Health~Holland is one of ten top sectors set up by the Ministry of Economic Affairs to harness Dutch innovation potential for a substantial contribution to global societal challenges.

For more about Health~Holland, visit https://www.health-holland.com/

2.1 Relation with other programs

WP2 of CLAIRE has a strong relationship with the P^{3}Venti program[a]; both are coordinated by TNO. It also has a relationship with the Mitigation Strategies for Airborne Infection Control (MIST) project[b] funded by NWO.

WP2 of CLAIRE relates in particular to P^{3}Venti program lines 1 “Analysis usage and interaction” and 3 “Experiments in a practical setting under operational conditions”. While CLAIRE focuses on primary

[a] p3venti.nl
[b] www.mist-project.nl

schools and long-term care facilities, P^{3}Venti focuses exclusively on long-term care facilities. We therefore propose to focus the CLAIRE project on primary schools, with approximately 80% of pilots being schools.
The MIST project has started at the end of 2022 with a duration of 4 years. In this project, more fundamental research will be performed regarding the behavior of aerosols, pathogens, ventilation systems and air purification in a number of use cases, resulting in strategies to reduce transmission. As TNO and TU/e both participate in all three of the programs/projects, they will ensure good inter-program synergy. As of yet, the precise relation between MIST and CLAIRE has not yet been determined.

Project CLAIRE is funded through the Top Sector Life Sciences & Health (Health~Holland) under project number LSHM22032.

3. Theoretical framework

The main objective of WP2 is to develop a "Method for assessing ventilation performance in confined environments". This method must be able to determine in a simple way and with some reliability whether the effectiveness of the system is in order. Based on the results, it can be determined whether further research into the ventilation system is desirable. This means that the system supplies an amount of fresh air that corresponds to the desired level, as detailed in the requirements for new buildings from the Living Environment Buildings Decree (Bbl), the programme of requirements for fresh schools, the programme of requirements for healthy indoor climate in long-term care, the programme of requirements for Healthy Offices, the programme of requirements for Healthy homes, etc. (Boerstra et al., 2024; Loomans et al., 2022; Platform Gezond Binnenklimaat, 2018; RVO, 2021). In these requirement programs, Class C typically represents the minimum design level as stipulated by the building regulations.
The basis for the development of this methodology is the measurements carried out in a number of rooms (10 classrooms and 4 common areas in long-term care). These measurements took place before as well as after interventions were carried out on the ventilation system (de Lange et al., 2025; de Lange & Traversari, 2024).

In the development of this method, coordination was held with a number of partners in the CLAIRE programme, such as representatives of Binnenklimaattechniek, Binnenklimaat Nederland and Jaga.

The method is intended to get an impression of the amount of fresh air that is supplied to a room. If the determined fresh air volume is lower than the desired amount, it can be decided whether further investigation by a competent installer or consultant is necessary. Applying this method gives a first rough indication of the amount and cannot be used to determine the exact amount.

4. Natural ventilation systems

The measurements before the intervention show that in systems that only use natural ventilation, the amount of fresh air is highly dependent on outdoor conditions. In particular, the wind speed and wind direction are of great importance. In winter, the temperature difference between inside and outside can to some extent also contribute to ventilation, especially when the temperature difference is large. There are also natural ventilation systems that use that principle. As a result, the supply of a minimum amount of fresh outside air cannot be guaranteed at all times. During the vast majority (approx. 90%) of the measurements carried out, less air than required was found to be supplied (de Lange & Traversari, 2024) Only in a few cases on very windy days were the requirements met.
Especially in a situation where many people are present in a room and a guaranteed minimum amount of fresh outdoor air per person is necessary to keep the risk of transmission of viruses and other pathogens within certain limits, this form of ventilation does not seem desirable.

5. Mechanical ventilation systems

Ventilation systems with a mechanical supply and/or exhaust are better able to guarantee the minimum required amount of fresh outside air, assuming a good design and the right adjustment, and maintenance. The measurements (de Lange et al., 2025; de Lange & Traversari, 2024) show that it is not necessarily the case that if a mechanical ventilation system is present, the required amount of fresh air is supplied in all cases. In addition, the supply of unheated outside air can cause (draught) complaints, especially in winter, with systems where the ventilation air is supplied through grilles above windows. This also applies if the windows are to be used as ventilation facilities. These comfort issues can be undesirable, especially in vulnerable people such as in long-term care, see also P^3Venti (Weersink et al., 2024). In addition to the air volume, the air distribution is also important for ventilation effectiveness.

6. Conclusion system type

In systems based on natural ventilation where a minimum amount of fresh outside air is required with the aim of keeping the concentration of pathogens below a certain value, air purifiers could be used. However, it is strongly preferable to first adjust the ventilation systems in that situation. Only if that is not possible or sufficient, air purifiers could be a temporary interim solution. Measurements show that the use of air purifiers can reduce the particle concentration in a room by capturing these particles (de Lange et al., 2025). However, these air purifiers often have a downside, especially in classrooms. They can be easily decommissioned, are susceptible to molestation, take up scarce space and produce noise.

7. Choice methodology

Estimating whether a ventilation system is sufficiently effective is very difficult even for experts. The effectiveness of a system is primarily determined by the amount of fresh outside air that is supplied and secondarily by the distribution of the air in the room. The measurements carried out within the framework of CLAIRE show that systems with a limited supply air volume are critical for air distribution. When a relatively low air volume is supplied, a situation often occurs in which there are areas in the room with high particle concentrations compared to the average concentration. When a larger amount of fresh outdoor air is supplied, the concentration distribution in a room often becomes more homogeneous. In practice, the positions of air supplies and discharges do not seem to have much effect on this. However, experts did indicate in a work session that furniture such as high cabinets etc. can have an impact on the air flow and thus the particle concentration distribution. The most important parameter is therefore the total amount of fresh outside air supplied. Estimating this without carrying out any form of measurements is quite challenging.

The air volume can be measured using specific measuring equipment such as an air velocity meter and an air flow meter. When using an air velocity meter, the flow area must also be determined and numerous other factors must be taken into account, including the distribution of the concentration in the room (inhomogeneity). The use of an air flow meter also requires knowledge and skills although it is less complex than using an air velocity meter.

Simple method to determine the effectiveness of ventilation systems

Organizations often have to hire this expertise as this requires specific expertise which means that it does not take place or takes place to a limited extent.

Another method to determine the supplied air quantity applies tracer gas (Penman, 1980; A. K. Persily, 1997). In this method, a known amount of easily measurable inert gas is fed into a room and the resulting concentration distribution is determined.
Often, the resulting concentration must be determined at many points to get a reliable average value. CO_2 can also be used as a tracer gas. CO_2 is easily measurable with relatively simple measuring equipment (Penman 1980; Smith 1988). It is also exhaled by people themselves. The amount of exhaled CO_2 depends on the metabolism of people present (age, activities and individual personal characteristics). If the number of people, the activity level, and the average CO_2 concentration in a room are known, a simple calculation can be used to make a good estimate of the amount of fresh outside air supplied. Some guidelines reflect the adverse effects of higher CO_2 concentration on the basis of which requirements are set for the maximum CO_2 concentration. However, a literature review (de Lange et al., 2024) shows that the results from the studies do not provide an unequivocal picture of whether and to what extent there is an effect of a CO_2 concentration in a room on:
1) cognitive performance,
2) physiological parameters,
3) comfort, perception and complaints,
4) absence and illness.

It is therefore not possible to indicate with certainty that the CO_2 concentration has an effect on this. This is due to the fact that most studies a) do not take into account confounding factors and b) the exposure duration was often relatively short and questionnaires for these studies covered a long period of time while the CO_2 concentration was only measured over a relatively short period of time.

There is also no unambiguous burden of proof for maximum CO_2 concentrations to be adhered to. In addition to the literature review (Lange et al. 2024), this is reflected in the many different values that are used internationally as a guideline/target value. Any limit value is therefore arbitrary and not sufficiently substantiated by scientific literature and consensus. However, there does seem to be a relationship between the CO_2 concentration and the inactivation rate of SARS-CoV-2: the higher the CO_2 concentration, the more stable the virus and the longer it takes for it to be inactivated (Haddrell et al. 2024).

Because CO_2 meters are often already available (primary schools) and the simplicity of this method based on naturally produced CO_2 can also be applied without much expertise, it is further elaborated in this document (Ventilation Master Plan 2021).

8. Methodology

Measuring the CO_2 concentration in a room seems relatively simple, but there are some important points of attention. This document presents the methodology step by step.

Step 1. Select CO2 meter

There are many different CO_2 meters for sale. According to the Building Decree 2012 (now the Living Environment Buildings Decree (Bbl)) it has been mandatory from 1 July 2015 to provide new primary schools with a simple CO_2 meter. A simple CO_2 meter only shows the current value of the CO_2 concentration and does not record in a memory. This meter is connected to the electricity grid and therefore does not work on batteries. This CO_2 meter must also have an "alarm function". However, an alarm function is not necessary for the proposed method.

For a CO_2 meter that is used to determine the amount of freshly supplied air, it is recommended that:

- it is self-calibrating and operates on the principle of a non-dispersive infrared (NDIR) gas sensor, and it has a memory function that stores and reads out the measured CO_2 values together with the time at which those values were measured.

Step 2. Install CO_2 meter

Experiments show that, contrary to what may be expected based on the density of CO_2 (about 1.5 times that of air), the highest CO_2 concentration is usually not low (at the bottom) in a room but relatively high in the room, at about 1.8 meters (Mahyuddin & Awbi, 2010). This is caused by the exhaled CO_2 having a higher temperature than the ambient air in the room, by diffusion, by the air flow (supply and exhaust at the top of the room) and by temperature stratification. In this study, the horizontal distribution of the CO_2 concentration in the room was found to depend on the amount of air supplied, but the differences were limited (76-123 ppm). To determine an indication of the amount of fresh air, it seems justified to measure only in one place in the room. It must be realized that the distribution also depends on ventilation type (mixing or displacement), location of supply and extraction, etc. Measuring in more places and averaging the values is better but is also more complex.

Place the CO_2 meter at a height of approximately. 1.8 meters in the room where the freshly supplied air volume is to be determined. Make sure that the CO_2 meter is affected as little as possible by doors, windows, window grilles and supply grilles. If there is a drain grate present, it can be a good position to determine the average value. Also, the CO_2 meter should not be placed too close to CO_2 sources like a person. Keep a distance of at least 70 cm from people. Ensure that there are no open flames (e.g. burning candles, fuel-fueled atmosphere element or gas stove) in the room during measurement. Doors that are open and create a connection with other rooms in the building where CO_2 is produced by people present should be avoided as much as possible because this can have an effect on the measured CO_2 concentration (Smith, 1988). It is therefore important that the indoor doors are kept closed as much as possible.

Step 3. Register number of people

Record at least one representative (working) day the average number of people per hour and the activity level in the room for which the amount of fresh outside air must be determined. Appendix 1 can be used for this. It is important that the occupancy of the space remains as constant as possible. Persily 1997 has calculated that in a room with 30 people per 100 m^2 and an air volume of 2.5 dm^3/s per person, a stable situation arises after approximately 2.8 hours (95% of the equilibrium concentration). With an air flow rate of 7.5 dm^3/s per person, the 95% value is reached after just 46 minutes.

Step 4. Calculate amount of fresh air supply.

For the hours for which the occupancy of the room and the activity level of the people in the room are known, see step 3, determine the average CO_2 concentration over those hours.

Using Equation 1, the average amount of freshly supplied air during an hour (Q_t) in m^3/h can be calculated based on the CO_2 concentration, the average number of people in the room and the average CO_2 emission based on age and activity level.

Equation 1

$$Q_t = \frac{n_t * C_t * 3600 * 1000}{C_{CO2;bi;t} - C_{CO2;bu;t}}$$

Wherein:

Q_t amount of freshly supplied air to the room in hour *t* [m3/h]

n_t average number of people in the room during hour *t* [-]

C_t average CO_2 production per person during hour *t*, according to table 1 [liter/s/person]

$C_{CO2;\,bi;t}$ average CO_2 concentration during hour *t* in the room in hour *t* [ppm]

$C_{CO2;\,Bu;t}$ average CO_2 concentration during hour *t* in outdoor air in hour *t*, [ppm]

It is assumed that if the measured concentration over an hour does not vary more than ΔC_{eq} determined by Equation 2, then the equilibrium concentration has been reached (A. K. Persily, 1997)

Equation 2

$$\Delta C_{eq} = \frac{166 * 10^3 * n_t * C_t}{V}$$

Wherein:

ΔC_{eq} maximum permissible spread of the measurements over one hour to achieve a reliable equilibrium concentration [ppm]

n_t average number of people in the room during hour *t* [-]

C_t average CO2 production per person during hour *t*, according to table 1 [liter/s/person]

V volume of the room [m^3]

In practice, however, achieving a stable equilibrium concentration will be very difficult, which reduces the reliability of the method. Consequently, the result will only provide an indication of the fresh air supply quantity.

An average outdoor air concentration of 400 ppm can generally be assumed. This value differs from the actual CO_2 concentration outside (approx. 420 ppm), but almost all CO_2 meters calibrate themselves on the basis of the outside air and assume that the CO_2 concentration in the outside air is 400 ppm. The value shown on the CO_2 meter is therefore actually an increase compared to the base value of 400 ppm. The actual CO_2 concentration varies over the year, with the concentration being highest in May and lowest in September. For the above reason, the use of a CO_2 meter intended for measurements in a room is not suitable for measuring the exact CO_2 concentration in the outdoor air. Based on (A. Persily & Jonge, 2017) the CO_2 emissions of people can be estimated, table 1. There is some spread in the CO_2 production of individuals, so that the actual production may deviate from the values given in table 1. This has an effect on the calculated fresh air quantity (Penman, 1980).

Table 1. CO_2 emissions in liters per second per person (based on an average respiratory quotient (RQ) of 0.85).

	Age			
Activity level	**To 12 year (48 kg[c])**	**From 12 year up to 21 year (73, 2 kg[c])**	**From 21 year to 65 year (average 40 year, 80,8 kg[d])**	**From 65 year (agerage 70 year, 78.4 kg[d])**
Quietly sitting/office work	0.0031 (MET = 1.3)	0.0051 (MET = 1.4)	0.0056 (MET = 1.4)	0.0039 (MET = 1)
Physical labor	0.0095 (MET = 4)	0.00145 (MET = 4)	0.0160 (MET = 4)	0.00155 (MET = 4)
The MET value or metabolic equivalent is a unit of measurement within physiology for the amount of energy that a certain physical effort costs, expressed in the oxygen consumption per kg of body weight per minute. The given mass in kg is the average weight of the persons. Both the MET value and the mass are the average of women and men. For children, a value of 1.3 Met has been retained at rest (Pontzer et al., 2021)				

Over one day, the average amount of air in the relevant hours can be averaged arithmetically to get an average value over a whole day. Doing multiple measurements makes the method more accurate. If there is a large spread between the values per hour, it is advisable to determine the amount of fresh air at several moments.

[c] Bron: Ruwe data van de Vijfde Landelijke Groeistudie (uit 2009)
[d] Bron: State line lengte een gewicht van personen, ondergewicht en overgewicht; vanaf 1981

Simple method to determine the effectiveness of ventilation systems

The calculated indication of the amount of fresh air can be compared with, for example, the requirements for new buildings from the Bbl, the program of requirements for fresh schools, the program of requirements for healthy indoor climate long-term care, the program of requirements for Healthy Offices, the program of requirements for Healthy homes, etc. (Boerstra et al., 2024; Platform Gezond Binnenklimaat, 2018; RVO, 2021). Class C represents the legal minimum design level in these programs of requirements. The system must be able to achieve this amount. In practice, this may differ because the system is not operating at design mode.

Based on this, it can be determined whether the calculated amount of fresh air is sufficient to meet the requirements/wishes.

This method can be further simplified. If a certain minimum amount of fresh air per person is assumed to be supplied, then the measured CO_2 concentration itself can also be considered as a rough indication. For a primary school, the minimum level of 21.6 m3 of fresh air per hour per person ((RVO, 2021), class C) and a production of 0.0022 liters of CO_2 per second per person, sitting quietly up to the age of 12 can be assumed (table 1). Based on this, it can be calculated that this leads to a maximum CO_2 concentration of approximately 770 ppm (767 ppm).[e]
If the measured CO2 concentration is structurally higher than 767 ppm, the amount of supplied air is lower than the desired/required 21.6 m3 per hour per person.

For long-term care, a fresh air volume of 25 m3 per hour per person is aimed for ((Boerstra et al., 2024)), class C). This, together with the CO_2 production of a quietly seated person aged 65 years and over, leads to a maximum CO_2 concentration of approximately 950 ppm (933 ppm).[e] Again, if the measured CO_2 concentration is structurally higher than 950 ppm, the amount of supplied air appears to be lower than the desired/required 25 m3 per hour per person.
However, if the measured CO_2 concentration is higher than 770 ppm or 950 ppm, respectively, this does not pose an acute problem with regard to cognitive performance, physiology, comfort, perception and complaints or absence and illness (de Lange et al., 2024). The only thing that can be said is that there is very likely less fresh outside air being supplied than desired/required.

Binnenklimaat Techniek has a tool "Indicator of infection probabilities via aerosols V3.0",[f] which can be used to calculate the amount of supplied air (Qv) based on the measured CO_2 concentration, the number of people present during the measurement and the activity level. This tool also indicates whether the Building Decree is complied with. However, as indicated in the background document for this tool, different CO_2 emission values are used for the different populations (Table 1). These emission factors cannot be adjusted in the model. When using this tool, the calculated ventilation amount (Qv) will therefore deviate from the method described in this document. This is not a major bottleneck because the determined ventilation amount is only an indication. However, no value should be assigned to the calculated probability of infection in this tool.

[e] Assuming a CO2 concentration in the outdoor air of 400 ppm due to the calibration of CO2 meters.
[f] see https://indicatorbesmettingskansen.nl/project/bewerken/ventilatie/

Stap 5. Defining actions

If the amount of fresh outside air determined under step 4 meets the requirements, no further action needs to be taken other than checking the amount periodically, for example every 6 months.

If the amount of fresh outside air determined under step 4 is lower than the desired amount, the following steps can be taken:

5a. Determine the indicative amount of fresh air again on another day, if it remains well below the desired amount, then continue with 5b.

5b. Are the ventilation facilities used as intended in the design? See for example www.ventilerenzogedaan.nl? If not, use the facilities as intended and redetermine the amount, steps 2 to 4. Please note: with natural ventilation systems, the amount of outside air supplied is highly dependent on the conditions outside such as temperature, wind direction and speed. For this reason, the amount can vary greatly per day and even per hour. The minimum amount of air supplied is particularly important here. To determine these reliably, a longer measurement period is often necessary.

5c. If the amount of freshly supplied air is lower than desirable even when the facilities are used correctly, contact an expert installer or consultant. They can accurately determine the supplied air volume with good measuring equipment.

5d. If a pandemic situation or a situation with many airogenic infections occurs and it is not possible to bring the fresh air volume to the desired level in the short term, consider temporarily applying a (mobile) air purifier. An air purifier is certainly not a panacea and also not a substitute for supplying sufficient fresh outside air. With an air purifier, the concentration of particles (pathogens) can be reduced. An air purifier also has a downside: it often produces noise, takes up space, often has to be placed in the middle of a room for optimal operation and is susceptible to acts of violence.

Step 6. Conditions

Like any methodology, this method has a number of limitations that must be taken into account. This includes the following points:

- This methodology is not suitable for systems that are regulated on the basis of CO_2 concentration. The method is also not suitable for situations with a strongly fluctuating occupancy (number of people and age composition) in a room.

- The accuracy of this methodology depends on the way in which the values used for the number of people and the CO_2 emissions are determined. Because the CO_2 concentration is only measured at one point in the room, this method is less accurate at lower air volumes because the concentration distribution in the room is less homogeneous. As the space increases, the accuracy decreases.

- Indoor doors that are open have an effect on the measured CO_2 concentration and should therefore be kept closed as much as possible during the measurements.

- With natural ventilation systems, the amount of outside air supplied is highly dependent on the conditions outside, such as wind direction and speed. For this reason, the amount can vary greatly per day and even per hour. The minimum amount of air supplied is particularly important here. To determine this reliably, a longer measurement period is often necessary. Keeping doors open also often has an effect on this amount.

- It is not possible to indicate an unambiguous limit value for a CO_2 concentration from the point of view of health or performance, neither for children nor for adults (de Lange et al., 2024). There is no consistent evidence for this from the scientific literature.

References

Boerstra, A. C., van Heumen, S. P. M., Jacobs, P., Kompatscher, K., Kort, H. S. M., de Kort, J. M. A., te Kulve, M., Loomans, M. G. L. C., & Traversari, A. A. L. (2024). *Programma van Eisen Gezond Binnenklimaat Langdurige Zorg 2024*.

de Lange, A., Kompatscher, K., Traversari, R., & Bezemer, R. (2025). *TNO 2025 R10401: Investigate the effect of different types of ventilation systems on the particle exposure risk in classrooms.*

de Lange, A., & Traversari, R. (2024). *TNO 2024 R10059: RESULTS Experiments in-situ, WP2, experiments phase 1*.

de Lange, A., Traversari, R., Kompatscher, K., & Egter van Wissekerke, N. (2024). *Literatuurstudie effect van CO2 op cognitieve prestaties , fysiologische parameters , comfort en beleving en absentie* (Issue september).

Haddrell, A., Oswin, H., Otero-Fernandez, M., Robinson, J. F., Cogan, T., Alexander, R., Mann, J. F. S., Hill, D., Finn, A., Davidson, A. D., & Reid, J. P. (2024). Ambient carbon dioxide concentration correlates with SARS-CoV-2 aerostability and infection risk. *Nature Communications*, *15*(1), 1–11. https://doi.org/10.1038/s41467-024-47777-5

Loomans, M. G. L. C., Hensen Centnerova, L., Jacobs, P., Beuker, T., & Atmar, W. (2022). *Programma van Eisen Gezonde Woningen 2022*. https://www.binnenklimaattechniek.nl/document/publicatie-programma-van-eisen-gezonde-woningen-2022/

Mahyuddin, N., & Awbi, H. (2010). The spatial distribution of carbon dioxide in an environmental test chamber. *Building and Environment*, *45*(9), 1993–2001. https://doi.org/10.1016/j.buildenv.2010.02.001

Masterplan Ventilatie. (2021). *Ventilatie in relatie tot COVID-19 en een goede binnenluchtkwaliteit - Aanbevelingen voor praktische implementatie en bewaking*. https://www.binnenklimaattechniek.nl/document/rapport-covid-19-in-relatie-tot-ventilatie-en-binnenluchtkwaliteit_binnenklimaattechniek-pdf/

Ministerie van van Binnenlandse Zaken en Koninkrijksrelaties. (2025, January 1). *Belsuit bouwwerken leefomgeving (Bbl)*. Https://Wetten.Overheid.Nl/BWBR0041297/2025-01-01.

Penman, J. M. (1980). An experimental determination of ventilation rate in occupied rooms using atmospheric carbon dioxide concentration. *Building and Environment*, *15*(1), 45–47. https://doi.org/10.1016/0360-1323(80)90028-1

Persily, A., & Jonge, L. De. (2017). Carbon dioxide generation rates for building occupants. *Indoor Air.*, *27*(5), 868–879. https://doi.org/10.1111/ina.12383.Carbon

Persily, A. K. (1997). Evaluating building IAQ and ventilation with indoor carbon dioxide. *ASHRAE Transactions*, *103*(Transactions (1997) 103(pt 2)), 193–204.

Platform Gezond Binnenklimaat. (2018). *Programma van eisen Gezonde Kantoren 2018*.

Pontzer, H., Yamada, Y., Sagayama, H., Ainslie, P. N., Andersen, L. F., Anderson, L. J., Arab, L., Baddou, I., Bedu-Addo, K., Blaak, E. E., Blanc, S., Bonomi, A. G., Bouten, C. V. C., Bovet, P., Buchowski, M. S., Butte, N. F., Camps, S. G., Close, G. L., Cooper, J. A., … Speakman, J. R. (2021). Daily energy expenditure through the human life course. *Science*, *373*(6556), 808–812. https://doi.org/10.1126/science.abe5017

RVO. (2021). *Program van Eisen frisse scholen 2021*. https://www.rvo.nl/sites/default/files/2021/06/PvE-Frisse-Scholen-2021.pdf

Smith, P. N. (1988). Determination of ventilation rates in occupied buildings from metabolic CO2 concentrations and production rates. *Building and Environment*, *23*(2), 95–102. https://doi.org/10.1016/0360-1323(88)90023-6

Weersink, A. M. S., Salemink, G. A. M., & Struck, C. (2024). *Technische en gebruiksinventarisatie ventilatiesystemen in bestaande gebouwen voor langdurige zorg , op basis van een taxonomie en vragenlijst* (Issue april). https://p3venti.nl/assets/rapportages/p3venti_rapportage_saxion_inventarisatie-gezondheidszorggebouwen.pdf

Appendix 1. **Example registration sheet number of attendees.**

Location:		
Date:		
Room:		
Time (hh:mm)	**Number of people present**	**Estimated average age and activity level**
xx:00		☐ Under 12 years of age ☐ From 12 years to 21 years ☐ Older than 21 years ☐ Quietly sitting/office work ☐ Physical labor[g]
xx:10		☐ Under 12 years of age ☐ From 12 years to 21 years ☐ Older than 21 years ☐ Quietly sitting/office work ☐ Physical labor[g]
xx:20		☐ Under 12 years of age ☐ From 12 years to 21 years ☐ Older than 21 years ☐ Quietly sitting/office work ☐ Physical labor[g]
xx:30		☐ Under 12 years of age ☐ From 12 years to 21 years ☐ Older than 21 years ☐ Quietly sitting/office work ☐ Physical labor[g]
xx:40		☐ Under 12 years of age ☐ From 12 years to 21 years ☐ Older than 21 years ☐ Quietly sitting/office work ☐ Physical labor[g]
xx:50		☐ Under 12 years of age ☐ From 12 years to 21 years ☐ Older than 21 years ☐ Quietly sitting/office work ☐ Physical labor[g]
xx:60		☐ Under 12 years of age ☐ From 12 years to 21 years ☐ Older than 21 years ☐ Quietly sitting/office work ☐ Physical labor[g]
Gemiddelde uur xx		☐ Under 12 years of age

[g] In this context, physical work is understood to mean: walking through space, bending/lifting, indoor sports.

		□ From 12 years to 21 years □ Older than 21 years □ Quietly sitting/office work □ Physical labor[g]
xx+1:00		□ Under 12 years of age □ From 12 years to 21 years □ Older than 21 years □ Quietly sitting/office work □ Physical labor[g]
xx+1:10		□ Under 12 years of age □ From 12 years to 21 years □ Older than 21 years □ Quietly sitting/office work □ Physical labor[g]
Etc.		