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Report on method to assess occupants' comfort and health

Authors: David Keyson (TUD), OfficeVitae (Maarten Havranek (OfficeVitae) Piet Jacobs (TNO), Remi Hompe (VLA), Agata Rijs (Spie), Theo Klok (DWA) Coen Hoogervorst (Spie)

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SAMENVATTING

Vaak wordt het binnenklimaatcomfort in kantoren gemeten aan de hand van subjectieve feedback of met behulp van sensorgegevens. In dit rapport wordt een methode beschreven voor de integratie van gebouwprestaties, subjectieve comfortscores en sensorgegevens. Alle drie datastromen worden geïntegreerd met behulp van regels om een enkele eindscore voor binnen comfort te creëren, variërend van A tot D. De sensorgegevens omvatten metingen voor CO_2 en fijne deeltjes $PM_{2.5}$ die de kwaliteit van de lucht en de ruimteventilatie weergeven, die belangrijk zijn voor het comfort en de gezondheid.

Er werden een data platform ontwikkeld en dashboard, samen met een dashboard en een mobiele toepassing om het verzamelen van gegevens mogelijk te maken. Voor elk gebouw wordt een aparte databankvermelding gemaakt. Zo kunnen vergelijkingen tussen soortgelijke gebouwen worden gemaakt. In Python werd een algoritme voor het automatisch genereren van rapporten ontwikkeld om snel berekeningen en grafieken te kunnen genereren. Ter illustratie van de rapportagemethode wordt een voorbeeldrapport gepresenteerd dat is gebaseerd op een onderzoek dat is uitgevoerd bij DWA, een B4B-projectpartner. Om te testen hoe het dataplatform gegevens van een gebouwbeheersysteem (BMS) kan integreren, werd een API ontwikkeld om input van het bij Spie draaiende systeem te verwerken met behulp van een data “pull on demand“ routine. Om de privacy, integriteit en betrouwbaarheid van de gegevens te waarborgen, werden in het gegevensplatform verschillende beveiligingsmaatregelen geïmplementeerd, die in dit verslag worden beschreven.

Ter illustratie van de rapportagemethode voor binnencomfort is in bijlage 1 met toestemming van DWA een voorbeeldrapport opgenomen dat is gegenereerd uit het dataplatform voor DWA, dat een B4B-partner is.

SUMMARY

Frequently indoor climate quality comfort in offices is measured using subjective scales or sensor data. In both cases, the building's physical properties in relation to shaping comfort are not considered. The current deliverable describes a method for integrating building performance, subjective comfort scores, and sensor data. All three data streams are integrated using rules to create a single-end indoor comfort score ranging from A to D. The sensor data includes measurements for CO2 and fine particles PM2.5 which reflect on the quality of the air and space ventilation which are important for comfort as well as health reasons.

A data platform and dashboard were developed along with a dashboard and a mobile application to enable data collection. The data for each building is stored as a unique database entry to ensure data privacy. General benchmark comparisons in scores are thus made possible for a given building type. An automatic report-generating algorithm was created in Python to enable the rapid generation of calculations and graphics. To illustrate the reporting method, a sample data report is presented based on a study done at DWA, a B4B project partner. To test how the data platform could integrate data from a Building Management System (BMS) an API was developed to process inputs from the system running at Spie using a data pull-on-demand routine. To ensure data privacy, integrity and reliability, several securing measurements were implemented in the data platform and are outlined in this report.

To illustrate the reporting method for indoor comfort, a sample data report generated from the data platform for DWA, being a B4B partner, has been included with permission from DWA in Appendix 1.

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1 INTRODUCTION

This deliverable describes a measurement method and interfaces developed and refined for the B4B project to assess office environments' comfort and health-related factors. The platform and method were applied and tested with one of the B4B consortium partners at their office location. The method includes three elements, namely (a) measurement of subjective comfort, (b) measurement of objective indoor climate parameters using sensors, and (3) survey of building characteristics that can impact comfort and health. The three parameters combined lead to a total score for indoor comfort for a building or enclosed section, such as a building floor.

1.1 Indoor Climate Measurement

Generally, indoor climate refers to the conditions within a building or enclosed space, including temperature, humidity, and air quality. The measurement of indoor climate can be both objective and subjective. Objective measurements rely on fine particles, CO2, air temperature, and humidity sensors. Subjective measurement involves the perception and experience of individuals within the environment.

Subjective indoor climate measurements are important because they can help identify issues that may not be captured by objective measurements alone, such as discomfort or dissatisfaction with the thermal environment caused by draught. Common subjective indoor climate measurement methods include surveys, questionnaires, and interviews with occupants. Interviews have the advantage of gaining a high response rate but can be time-consuming and disruptive for the work environment also, recent experiences might not be remembered, given short-term memory.

Common subjective measures of indoor climate include:

- Thermal comfort: This refers to the subjective perception of temperature and airspeed and involves asking occupants how comfortable they feel in the environment.
- Air quality: This refers to the perceived freshness and cleanliness of the air and can be measured using questionnaires or surveys that ask occupants about symptoms such as headaches, eye irritation, or coughing.
- Noise levels: This refers to the perceived loudness and annoyance of noise within the environment, which can be external or internal to the building. It can be measured using surveys or questionnaires asking occupants about their noise experience. It's important to note that subjective indoor climate measurements may be influenced by individual factors such as age, health, and personal preferences. However, gathering feedback from occupants can provide valuable insights into how the indoor environment affects their comfort and wellbeing. It can help to identify areas where improvements can be made. A range of aspects in relation to comfort and health are discussed, including useful facts, figures and analysis, and practical methods that designers who are keen to assess and improve the user experience of buildings by Bluyssen (2009).
- Lighting in offices can affect health in several ways, including Eye strain: Poor indoor lighting or the lack of natural sunlight can cause eye strain, headaches, and blurred vision. This can lead to discomfort, reduced productivity, and even work-related injuries. Circadian rhythm disruption: Exposure to bright light in the evening can suppress the production of melatonin, a hormone that regulates sleep. This can disrupt the body's natural sleep-wake cycle, leading to insomnia, fatigue, and other health problems. Mental health: Poor lighting can have a negative impact on mood, leading to increased levels of stress, anxiety, and depression. Physical health: Lack of natural light can lead to vitamin D deficiency, associated with a range of health problems, including weak bones, muscle weakness, and an increased risk of chronic diseases. Productivity: Poor lighting can reduce productivity by causing fatigue, headaches, and eye strain, decreasing job satisfaction and performance. Therefore, it is important to have adequate lighting in offices to promote a healthy and productive work environment (Boubekri, 2014 & Holick, 2007).

1.2 Relation Between Indoor Climate and Health

Indoor comfort and health are closely related because the indoor environment can significantly impact physical and mental well-being. Poor indoor air quality, inadequate lighting, uncomfortable temperatures, and excessive noise can all contribute to health problems. For example, poor indoor air quality can lead to respiratory problems, such as asthma and allergies. Inadequate lighting can cause eye strain and headaches, while excessive noise can increase stress and anxiety levels. Uncomfortable temperatures can also affect sleep quality and overall comfort, impacting our physical and mental health.

In particular, elevated levels of CO_2 in offices can have a negative impact on the health and well-being of occupants. Some of the potential effects include (Allen et al, 2016):

- Headaches: CO_2 can cause headaches and make concentrating difficult, reducing productivity.
- Fatigue: Elevated CO_2 levels can cause fatigue, drowsiness, and lethargy, making it difficult for employees to remain alert and focused. Poor indoor air quality: High levels of CO_2 in indoor environments can also indicate poor ventilation and poor indoor air quality. This can exacerbate health conditions such as asthma, allergies, and other respiratory problems.
- Decreased cognitive function: Studies have shown that increased levels of CO_2 can negatively affect cognitive function and decision-making abilities, making it difficult to perform tasks that require mental focus.

Sick Building Syndrome: Prolonged exposure to high levels of CO2 or contaminants, such as use of chemical products that emit volatile organic compounds (VOCs), causes Sick Building Syndrome, a condition characterized by a range of symptoms including headaches, fatigue, eye irritation, and respiratory problems.

On the other hand, a comfortable indoor environment can promote health and well-being. Good indoor air quality, comfortable temperatures, adequate lighting, and low noise levels can all contribute to a healthy indoor environment. Proper ventilation, humidity control, and air filtration can also help reduce the spread of infectious diseases and allergens.

In short, creating a comfortable indoor environment is important not only in terms of comfort but also for our health. By paying attention to the factors contributing to indoor comfort, healthy living environments can be fostered, and well-being can be promoted.

1.3 Considerations for Indoor Climate Measurement

Recently attention and the need to ensure the quality of the indoor environment in work settings has gained in importance following the COVID pandemic. Commercial companies have used CO2 measures to provide a COVID risk indicator. This is quite controversial, though good ventilation can reduce the risks of spreading airborne viruses. Furthermore, the current world energy crisis has increased the need to consider the efficient operation of heating and cooling systems as the main source of energy consumption of buildings. Regarding the environment and climate change, five sectors emit the bulk of the European Union's greenhouse gases: 28 percent comes from transportation, 26 percent from industry, 23 percent from power, 13 percent from buildings, and 13 percent from agriculture (Mckinsey.com report). In fact buildings contribute to almost 40% of global greenhouse gas emissions. According to the United Nations Environment Programme, the construction and operation of buildings are responsible for 39% of global carbon dioxide emissions. This is because buildings require energy for heating, cooling, lighting, and powering appliances and devices, which is often generated by burning fossil fuels.

In short, building designers and operators need to consider both occupant comfort and energy consumption to ensure that buildings are sustainable, healthy, and comfortable places to live and work. This requires a holistic approach considering the interplay between building systems, occupant behaviour, and the outdoor environment to achieve the desired balance.

1.4 Subjective versus Objective Indoor Climate data

By combining subjective and objective indoor comfort data, building managers and designers can gain a more comprehensive understanding of the indoor environment and make informed decisions about improving it. For example, it is difficult to measure the sensation of draft using sensors, as the amount of actual draft could vary with the slight sensor placement. Here the subjective perception of the sensor can serve as an excellent indicator of a potential problem in the building climate control system or the window insulation. Another advantage of subjective measures compared to many sensors is that the cost is relatively low and can thus cover the entire occupant space area. Thirdly, comfort models based on physical measures need to consider well-documented individual perceptions of comfort, which can be due to many factors, including culture, age, and health.

Any method for measuring indoor climate should be reliable yet also affordable. While sensor costs are dropping, monitoring each space in a building is still costly. Furthermore, research has shown that objective comfort measures might not match the subjective comfort experience.

To summarise, subjective and objective indoor comfort data are complementary and provide valuable insights into people's experiences and perceptions of indoor environments. For example, office occupants may experience discomfort in one area, while objective data may identify a problem with the ventilation system. By combining both types of data, building managers and designers can optimise indoor comfort and create healthier and more productive indoor environments while considering the building's physical indoor environment design and physical properties related to comfort. The data platform for the B4B project includes a building inspection survey and scoring system as described in section 4.0.

1.5 Rating Indoor Environments

Indoor climate scoring is a process of evaluating the indoor environment of a building based on a set of predefined criteria. The scoring system typically considers factors such as air quality, temperature, humidity, lighting, and noise levels, among others, to determine the overall indoor climate quality.

The scoring system can be used to assess the indoor climate of a building and identify areas that require improvement to optimise the comfort and health of occupants. The scoring system results can also be used to develop strategies for improving indoor air quality, temperature regulation, and other factors that affect the indoor climate.

Several n, such as the Building Research Establishment Environmental Assessment Method (BREEAM), Leadership in Energy and Environmental Design (LEED), and WELL Building Standard. These systems provide a standardised approach to evaluating indoor climate quality and well-being and can be used to compare different buildings or to track improvements over time.

Overall, indoor climate scoring is an important tool for assessing and optimising the indoor environment of a building, which can improve the health, comfort, and productivity of occupants. In the current report, a rating system is presented which focuses on indoor environment quality. The rating system is based on the Program of Requirements Healthy Offices (Boerstra 2021) and is certified by Binnenklimaat Nederland.

2 DATA PLATFORM: COMFORT AND BUILDING RELATED HEALTH FACTORS

As reported in Deliverable D3.1.1, subjective comfort based on scales from the PvE Gezonde Kantoren 2021 and Bluyssen P.M. et al, (2016) can be measured using several techniques. A study conducted under D31.1 demonstrated that using a voting box rather than an extensive questionnaire is possible to obtain qualitative feedback on comfort levels. The use of QR codes did not yield high response rates. In the current platform protocol, an extensive online survey is conducted once per year.

Questions for indoor comfort cover four areas based on the above two references: (1) perception of noise, (2) perception of light quality, (3) air quality and (4) thermal indoor climate. Additionally, general demographic information is asked. Below, the parameters under each of the areas are outlined.

Questions on Indoor Climate are asked on a 7-point scale, from negative to positive: Very Satisfied, Unsatisfied, Somewhat unsatisfied, Neutral, Somewhat satisfied and Very satisfied. Questions related to temperature, air quality in the workspace, noise and acoustics and the degree of control of the workspace. The sense of control coupled with the availability of indoor climate control has been found to influence the motivation to report subjective comfort (Keyson 2017).

2.1 Perception of Noise

Under these questions, the goal is to determine if the office occupant is bothered by noise in the workplace. A positive response leads to a number of questions in the online survey app. For example, disturbance could be due to telephone calls, talking in nearby areas, lack of privacy, installation noise, etc.

2.2 Sense of Control

The question asked here is the degree of control of the indoor climate. The seven-point scale is used.

2.3 Light

If the respondent indicates, they are not satisfied with the light in their workplace, a number of options appear in the app. Examples are too little daylight, too much daylight, too much artificial light, reflections, limited view outside, etc.

2.4 Thermal Indoor Climate

Questions on indoor climate relate to the perception of draft and location and temperature parameters.

2.5 Indoor Air Quality

Questions here related to the perception smell, dust, dampness and moisture or dryness in the air.

2.6 Health & Productivity

If health impact is indicated, several categories can be selected, including, sense of tiredness, eye irritation, headaches, dry throat, and unusual tiredness.

If a Productivity loss is indicated as a result of the indoor climate, survey respondent is asked to give a percentage for their felt loss of productivity.

3 DATA PLATFORM: PROTOCOL FOR INDOOR CLIMATE SENSORS

In combination with the subjective comfort measures, sensor data is collected in representative spaces in the office building. A standard list of room types was developed to enable comparisons between buildings. Using an online application, building facility managers can place sensors and indicate the location and room type in the app. Typically wireless sensors can be placed. In the case of the fine particles $PM_{2.5}$ sensor, only one is required in the building, provided it is not placed next to a ventilation unit.

For the accuracy of the sensors, reference is made to the RESET standard 2 (https://www.reset.build/standard/air#air_download). This uses three classes for the sensors. Class A concerns “calibration grade monitors”. These are used for the calibration of class B and C monitors. Class B concerns monitors suitable for building automation. Class C concerns consumer monitors suitable for “citizen science”. Section 3.1 below provides a proposal for the sensors' requirements to be applied in the Netherlands, a combination of the class A and B requirements of RESET.

3.1 Sensor Accuracy

Based on the RESET class A and B the following requirements were defined for sensors to measure indoor air quality and climate factors.

CO_2 B ±50 ppm + 3%

$PM_{2.5}$ A ±2 μg/m³ + 10%

Air temperature A 0.5 K

Relative humidity A/B ±5% for range 10 – 80%

For $PM_{2.5}$, a requirement is applied in accordance with RESET class A because the levels in Dutch offices are low, in the order of 2 – 10 μg/m³. This may require a laboratory-grade sensor. This does not have to be present for a whole year, see below protocol on measurement duration.

3.2 Selection of representative spaces in the building for sensors

As mentioned in the introduction, a representative number of rooms is advised to reduce the cost of sensor measurements in a building for indoor climate and air quality, with at least 1 sensor room per room or area type as outlined below. A typical office building installation would require at least 5 or 6 sensors.

Room or area types are which can be assigned in the sensor registration location application provided to the facility managers are as follows: 1-person room, 2-person room, 2-person meeting room, 3-person meeting room, large room between 4-8 persons, small meeting room less than 10 people, large meeting room. space between 10-25 persons, office garden, meeting room for more than 25 persons, classroom/instruction room, office garden, canteen/restaurant.

The number of floors should also be considered, with at least the ground and highest floor covered. Regarding orientation, both the south and north sides should be covered.

At least 1 room per air handling unit should be included. Smart combinations can be included: Northside on ground floor or Southside on top floor. The sensor monitoring plan should include any areas or rooms that have received complaints from building occupants.

3.3 Measurement duration

Measurements must be carried out with each sensor for at least one year. The sampling interval is a maximum 1 value per 15 minutes. For each sensor, at least 95% of the metrics values to be available for analysis.

An exception to the measurement duration is the determination of the $PM_{2.5}$ concentration. This can also be done in 1 location in the office with a shortened annual method in accordance with the Indoor Climate Netherlands measurement protocol for particulate matter determination offices (2015) are implemented.

3.4 Sensor Placement

Consideration of sensor placement in office buildings should follow the following guidelines:

According to Living zone NEN 1087: lower than 1.8 m in height, 1 m from the facade and 0.2 m from interior walls.

Mounting a sensor on an inner wall is permitted, provided that:

Not exposed to sunlight

Is not placed in the direct throw of ventilation facilities (inlet grilles, facade grilles, windows that can be opened)

Is not exposed to local heat sources (directly above heating, near screens, etc..)

3.5 Types of Sensor System Configurations

There are at least four recognized system configurations for the installation of the sensors (CO_2, temperature, humidity and particulate matter) supplied by the Indoor Climate Dashboard. Methods namely:

- The sensors are supplied in combination with a LoRa gateway with a 4G radio. This whole system is plug-n-play and will work after installation. This is the simplest installation procedure in terms of time and effort. In this case data is automatically sent the OfficeVitae backend.
- The sensors are supplied without a LoRa gateway and will use a partner's LoRa network present on location. The data from the sensors (DEVEUI, APPEUI and APPKEY) will be passed on by Indoor Climate Dashboard to the partner who then adds them to their LoRa server. From there, the data is then forwarded to the indoor climate dashboard backend via an HTTPS POST request in JSON format.
- All Data is collected locally and stored using sensors that meet the required specifications as outlined in Section 3.1. On 15 second intervals the data is sent to OfficeVitae to update the dashboard described in chapter 4.
- A fine particle sensor and gateway is placed at the building site. The Humidity and Temperature data is collected locally and stored using sensors that meet the required specifications. On regular intervals the data is sent to OfficeVitae to update the dashboard described in Section 6. This case can be quite common, as building management systems typically do not include fine particle sensors.

4 DATA PLATFORM: BUILDING COMFORT FACTORS

Factors relating to the building HVAC (heating, ventilation and cooling) system as well as the building insulation materials may influence the quality of the indoor comfort and health. As part of the B4B data platform scoring protocol for indoor environments, the building characteristics are gauged along with subjective comfort levels and data from climate and air quality sensors.

4.1 Building Risk factors

A number of building related risks are scored via the building inspection application, for factors relating to air quality, light, noise and temperature, including for example:

- Poor insulated glass U>3
- Poor thermal insulation
- Air heating
- Insufficient heating capacity
- Low room occupancy level >15 m^2
- Missing heating under glass
- Noise insulation of the façade
- Factors relating to internal noise, insulation, and HVAC systems.
- Nose risks relating to room divisions.
- Indoor air, ventilation, window adjustment
- Cleanness of air ventilation system
- Ventilation system characteristics
- Position of building in relation to outdoor area
- Light risk if under 400 Lux
- Over exposure to outdoor light
- Window shading

4.2 Scoring Method of Building Risk Factors

The Building Inspection List is divided into four themes: Climate, Sound, Indoor Air, and Light. Each theme is rated according to Figure 1 below. Each theme is divided into several sub-factors. Under each subfactor are several potential risks elements listed. For example, the theme Climate has four sub themes: Winter Comfort, Summer Comfort, Draft, and Local Interior Space Factors and Insulation. Each sub-factor has a predefined risk percentage. The risk level for each element under a sub-factor is determined by dividing the subfactor risk parentage by the number of elements.

	Inspection Score Per Theme	
Rating	**Lower Limit**	**Upper Limit**
A	0,85	1,00
B	0,70	0,85
C	0,50	0,70
D	0,00	0,50

Figure 1: Score ranges by rating building inspection

4.3 Data Privacy

In terms of ICT, to enable the rapid collection of climate data from buildings, data platform systems must comply. The importance of data privacy from indoor climate sensors in office buildings is crucial for several reasons. Office buildings often have multiple floors, and many people work in them, so the data collected from indoor climate sensors can be particularly sensitive.

Data privacy is important in office buildings because the data collected from indoor climate sensors can reveal a lot about employees' daily routines, work habits, and even their health status. This information can be used to profile employees, track their movements, and even monitor their productivity without their consent. Such monitoring can lead to privacy violations, stress, and lower job satisfaction.

Furthermore, office buildings often have sensitive areas such as meeting rooms or boardrooms, and the data collected from indoor climate sensors can compromise the confidentiality of meetings or conversations. For instance, if a sensor captures sound or video footage, it can be used to eavesdrop or spy on employees, which is a serious breach of privacy.

Additionally, indoor climate sensors can collect information about employee preferences and habits, such as preferred lighting, temperature, or humidity levels. Such information can be used to create personalised environments for employees and to discriminate against certain individuals or groups based on their preferences or habits.

Therefore, ensuring that the data collected from indoor climate sensors in office buildings is securely collected, stored and used only for legitimate purposes is important. This includes implementing robust security measures, such as encryption and access controls, and providing clear guidelines and policies for the use of the data. It also requires educating employees about their data privacy rights and ensuring they have a say in how their data is collected and used.

4.3.1 The General Data Protection Regulation

The General Data Protection Regulation (GDPR) is a regulation of the European Union (EU) that provides a framework for protecting the personal data of EU residents. It applies to any organisation that collects, processes, or stores personal data of EU residents, regardless of where the organisation is located. The GDPR applies to climate sensor data if it contains personal data, such as data that can be used to identify an individual. Under the GDPR, organisations that collect personal data from indoor climate sensors must comply with several requirements, including:

- Lawful basis for processing: Organizations must have a lawful basis for collecting and processing personal data. This can include obtaining explicit consent from individuals, fulfilling a contractual obligation, or serving a legitimate interest.
- Transparency and accountability: Organizations must be transparent about their data collection practices and provide clear and concise information about how personal data is processed. They must also ensure that appropriate security measures are in place to protect personal data from unauthorized access or disclosure.
- Data subject rights: Individuals have the right to access, correct, delete, or restrict the processing of their personal data. Organizations must also provide individuals with a copy of their personal data upon request.
- Data breach notification: Organizations must notify individuals and authorities within 72 hours of becoming aware of a data breach that involves personal data.
- Data protection impact assessment: Organizations must conduct a data protection impact assessment (DPIA) when processing personal data in a way that is likely to result in a high risk to the rights and freedoms of individuals.

Regarding data sovereignty, the GDPR requires that all data collected on citizens must be stored in the EU, so it is subject to European privacy laws or within a jurisdiction with similar levels of protection. Additionally, it applies to both data controllers and data processors. It is thus important that the data from indoor climate sensors is secure, and that the flow of data can always be tracked while remaining within the EU. Products such as AirVisual offer low cost relatively high-quality measurements, however, connected online, via WIFI or Ethernet, data is sent to China to provide the analytics.

4.3.2 Data Platform Data Privacy

To help ensure data privacy for the data platform in support of the B4B project, several measures were taken, including:

- Each client has a separate database and can only view their data without access to other client data.
- Different user roles and different authorisation levels determine access rights.
- Applications are secured with usernames and passwords with two-level authentication
- There is no username coupled to the user of the comfort survey.
- No data analysis, data piping, or data storage through third parties outside the Virtual Private Server in Amsterdam where the platform runs.

4.4 Data Security

An important part of ensuring data privacy is data securing to prevent unauthorised access to data. Several measures were taken to help ensure data security in the B4B data platform, including:

- Access to the database is secured via SSH (Secure Shell) key and to which a valid IP address is assigned. Access via other IP addresses is not granted.
- Each building has a private 4-g router and private LoRa-communication gateway coupled to the VPS server in Amsterdam.
- The connection between the client and VPS server over the Internet is secured via an SSL/TLS certificate.
- A brute-force policy is in place such that client accounts are temporally blocked when multiple invalid access attempts occur.
- User applications are protected from external access by issuing temporary access tokens.

5 DATA REPORTING EXAMPLE

To illustrate how data reports are produced using the B4B data platform, a real-world case is presented in this section. Permission has been given by DWH, as a B4B partner, to present the data report and score produced from their building in Gouda. The data graphics and scores were automatically produced by the B4B data platform using Python Script.

Reporting data from climate sensors

Data from climate sensors are projected against a colour-coded background figure to indicate the score from A to D, based on the following criteria (Figure 2).

Parameter	A	B	C	D
CO2 (ppm)	< 800	< 950	< 1200	> 1200
Temperature (°C)	> 21 & < 25	< 21 & > 25	< 20 & > 26	< 19 & > 27
Humidity (%)	> 35 & < 70	< 35	/	> 70
Fine Particles (I/O)	< 0,25	< 0,5	< 0,75	> 0,75

Figure 2: Sensor scores score depending upon 95% of the sampled data falling with the label score.

The following example from the DWA case for an open office area shows the scores for CO_2, Temperature and Humidity. For example, the score for CO_2 is an "A" as 95% of the times sampled during office hours fall in the green zone, under 800 ppm. For this location, the Temperature score was "B" as more than 5% of the sampled data was in the "B" range, leading to a "B" score. The Humidity had a score of C as more than 5% of the scores in the "B" range were in the "C" range, as indicated in Figure 3 below.

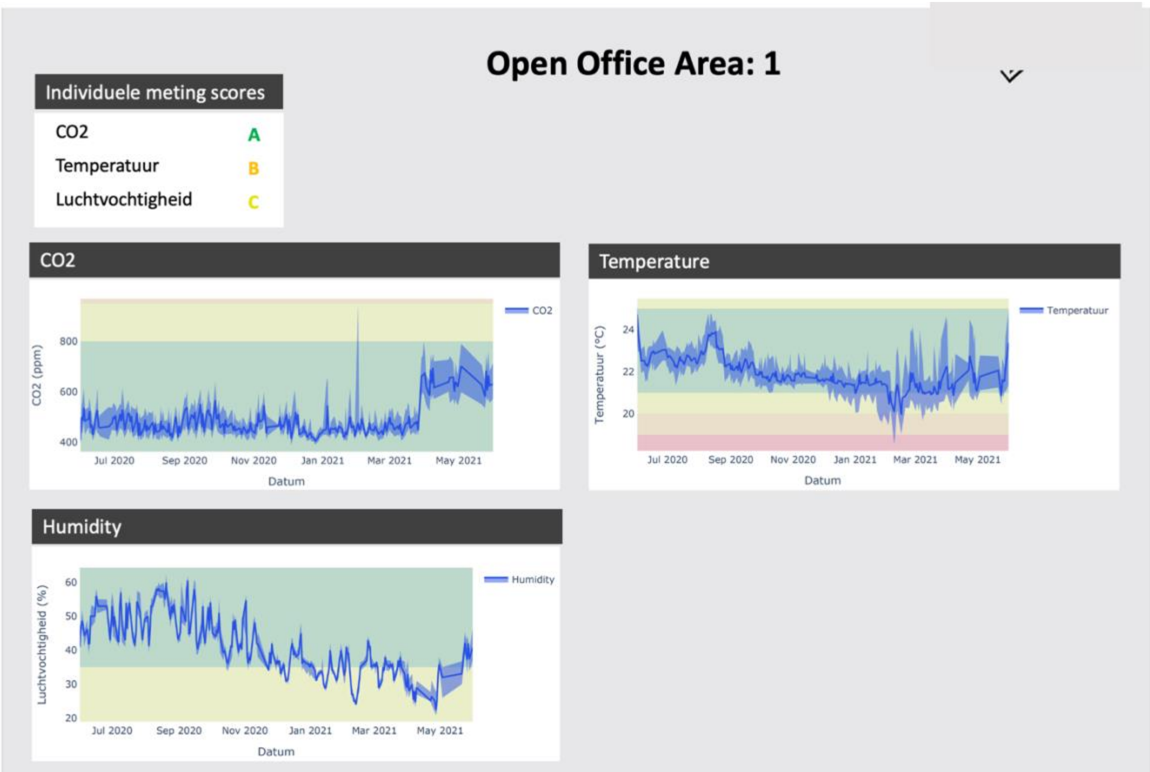

Figure 3: Example of sensor data representation by score

5.2 Combining subjective, sensor data, and building inspection scores

To provide a building or section with a single score, a method was developed to integrate scores from sensor data, the subjective comfort survey and the building inspection score. In the figure below, the four themes are listed: climate, sound, air quality and light.

A score is generated for each theme via the subjective comfort survey "Enquête" continuous sensor data "Continue monitoring" and the building inspection "Inspectie". In the case of sound and light, scores stem from the subjective survey and building inspection survey, as light and sound are not measured with sensors. The lowest score in the theme total column results in the final score. In the DWA example below, all themes scores an A, so the final building score was an "A" (Figure 4).

Thema	Enquête	Continue monitoring	Inspectie	Thema totaal
Klimaat	A	B	A	A
Geluid	A	X	A	A
Binnenlucht	A	A	B	A
Licht	A	X	A	A
Totaal binnenmilieu				A

Figure 4: Example of Combing Scores

6 SMART NOTIFICATION DASHBOARD

6.1 Dashboard description

Given that building inspectors may wish to examine the current score of a building, an algorithm was developed such that the inspector can indicate the desired target score in the absence of data history and then utilize the smart notification and dashboards to monitor progress in reaching, maintaining, or even exceeding the indicated building target score. Notifications are sent by email to the inspector. Additionally, a data dashboard was created for the B4B project, enabling the building inspector or client to view the current data or stored data for inspection, sensor and subjective comfort scores (Figure 5).

Figure 5: Two data dashboards were created for the B4B project connected to the data platform. The top figure shows the climate data for the entire DWA building. The lower figure shows the subjective comfort scores.

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APPENDIX 1

In this appendix the full data report produced in Dutch for DWA as a B4B project member is provided below with permission from DWA. The building was awarded an “A” overall rating score, being the highest possible score from a range from A to D. This work was done in collaboration with the B4B partner Binnenklimaat Nederland who issued the final indoor climate score for DWA. Note, that the method presented in this document was also applied to two other sites, in which a “B” and “C” score were determined. This suggests that the current scoring method is sensitive to potential differences in the indoor climate quality between buildings.

Over a period of one month an indoor fine particle measurement ($PM_{2.5}$) was taken at DWA and compared to the local outside levels as shown on page 32.

Binnenklimaat Nederland Certificering

Door Binnenklimaat Data Analytics
DWA Gouda
Gebouw: Harderwijkweg 7

Certificering Periode: 01-08-2021 tot 01-08-2022

Kantooruren (ma – vrij tussen 8 uur en 17 uur)
5 Sensor Locaties

BINNENKLIMAAT LABEL

BINNENKLIMAAT LABEL

Algemene beschrijving van het scoren van 3 onderdelen

1. Continue sensor monitoring

Het eerste onderdeel van de Binnenklimaat Nederland certificering is het objectief monitoren van verschillende meetwaarden door middel van sensoren, gedurende een langere tijdsperiode. Hiervoor zijn sensoren geplaatst in één van elke representatieve soort ruimte die te vinden is in het gebouw. De meetwaarden die gedurende deze periode gemonitord zijn, zijn als volgt:

- CO2 gehalte
- Temperatuur
- Binnenlucht
- Fijnstof

De gemonitorde waarden zullen elk leiden tot een score in de vorm van een **A**, **B**, **C** of **D**, waarbij A de beste waarde is en D de slechtste. De score voor Klimaat is het gemiddelde van Temperatuur en Luchtvochtigheid. De score voor Binnenlucht is het gemiddelde van CO2 en Fijnstof ($PM_{2.5}$). Voor elk van de gemonitorde ruimtes zal een analyse te vinden zijn in dit rapport. Deze analyse zal de resultaten per ruimte weergeven, met bijbehorende grafieken om de lezer het inzicht te geven waarom een bepaalde score is toegekend. Welke meetwaarden leiden tot welke scores staat uitgewerkt op de volgende pagina.

Uitleg grafieken en sensor data analysis

Per ruimtetype met een sensor zal voor elk van de gemeten waarden een grafiek te zien zijn. Deze grafiek toont de absolute waarden die gemeten zijn gedurende de meetperiode. In deze grafiek bevindt zich een blauwe lijn met daaromheen een blauwe bandbreedte. De lijn representeert de mediaan van alle gemeten waarden op een dag. De maximum waarde van de bandbreedte representeert het 95ste percentiel, wat inhoudt dat 95 procent van alle gemeten waarden zich onder deze waarde bevindt. De minimum waarde van de bandbreedte representeert het 5de percentiel. Op de achtergrond van de grafiek zijn de verschillende kleuren te zien. Deze kleuren geven aan welke absolute waarden worden getransformeerd tot de scores **A**, **B**, **C** of **D**.

Continue sensor monitoring

BINNENKLIMAAT LABEL

Scorebepalingen

De bepaling van de score per sensorlocatie, tijdens kantooruren, wordt berekend met behulp van criteria geformuleerd door het Binnenklimaat Label. Binnen welk criterium zo'n waarde valt zal bepalen welke Binnenklimaat Label score deze meting representeert. Om tot een uiteindelijke score van een meetwaarde te komen moet 95% van de metingen die waarde hebben of hoger. Om bijvoorbeeld tot de score B te komen voor CO2, zal 95% van de gemeten waarden een A of een B moeten zijn. Omdat elke grootheid anders benaderd wordt zijn er voor elke groothied verschillende criteria. In de grafiek hieronder zijn deze criteria met desbetreffende scores benoemd:

	D	C	B	A
Temperatuur [°C]	< 19 °C	≥ 19 °C ≤ 27 °C	≥ 20 °C ≤ 26 °C	≥ 21 °C ≤ 25 °C
CO_2 [ppm]	> 1200	< 1200	< 950	< 800
RV [%]	> 70	< 70	< 70	35 < RV < 70
$PM_{2.5}$ [µg/m³]*		< 20	< 15	< 10
$PM_{2.5}$ eis I/O**	> 1	< 1	< 0,5	< 0,25

*uurgemiddelde PM2.5 concentratie

** Minimaal 1 week aaneengesloten te meten; gedurende de meetperiode is het zo dat: i. de PM2.5 buitenconcentratie minimaal 4 uur < 5 microgram/m³ is, en: ii. deze minimaal 4 uur > 20 microgram/m³ bedraagt. Is na één week meten niet aan beide voorwaarden voldaan dan zal langer moeten meten tot alsnog sprake is geweest van genoemde 'gunstige' buitenmeetcondities.

Algemene beschrijving van het scoren van 3 onderdelen

BINNENKLIMAAT LABEL

2. Inspectie Data

Het tweede onderdeel Binnenklimaat Nederland Kantoren certificering zijn de resultaten van de Inspectielijst. Er zijn een aantal vagen per risicothema:

- Klimaat
- Geluid
- Binnenlucht
- Licht

Voor alle thema's (klimaat, geluid, binnenlucht en licht) zijn meerdere subthema's waar risicofactoren bij horen. Als het risico tijdens de inspectie wordt waargenomen, word dit item aangekruist. Het risciopercentage per thema, word berekend als gemiddelde van de scores van de subthema's. De score per thema leid tot een score in de vorm van een A, B, C of D, waarbij A de beste waarde is en D de slechtste. Hoe lager het risico is, hoe hoger het percentage is per thema, als volgt:

	Score inspectie per thema	
Klasse	Ondergrens	Bovengrens
A	0,85	1,00
B	0,70	0,85
C	0,50	0,70
D	0,00	0,50

Algemene beschrijving van het scoren van 3 onderdelen

3. Enquêtedata

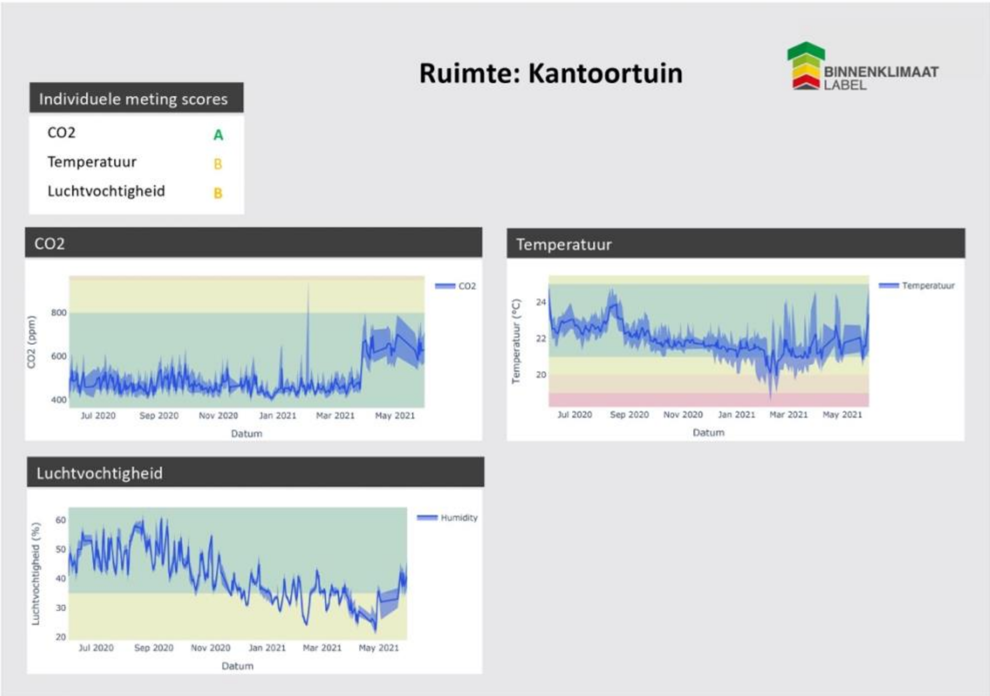
Het derde onderdeel Binnenklimaat Nederland Kantoren certificering zijn de resultaten van de Binnenklimaat Nederland Enquête. De Enquête bevat vragen om de tevredenheid van de gebruikers van het gebouw te meten met betrekking tot:

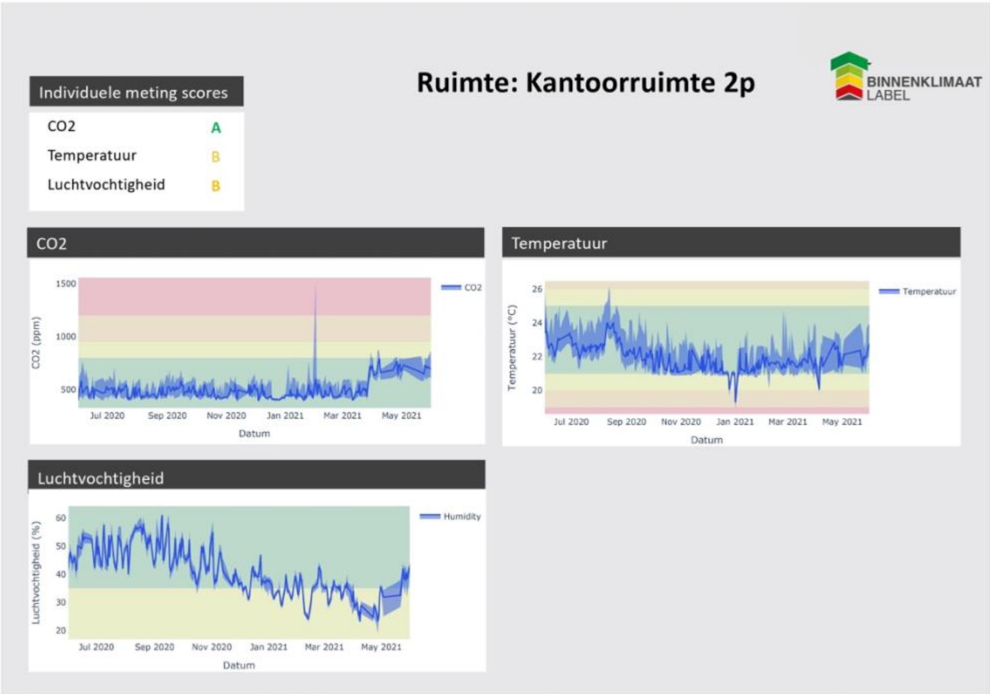
- Klimaat
- Geluid
- Binnenlucht
- Licht

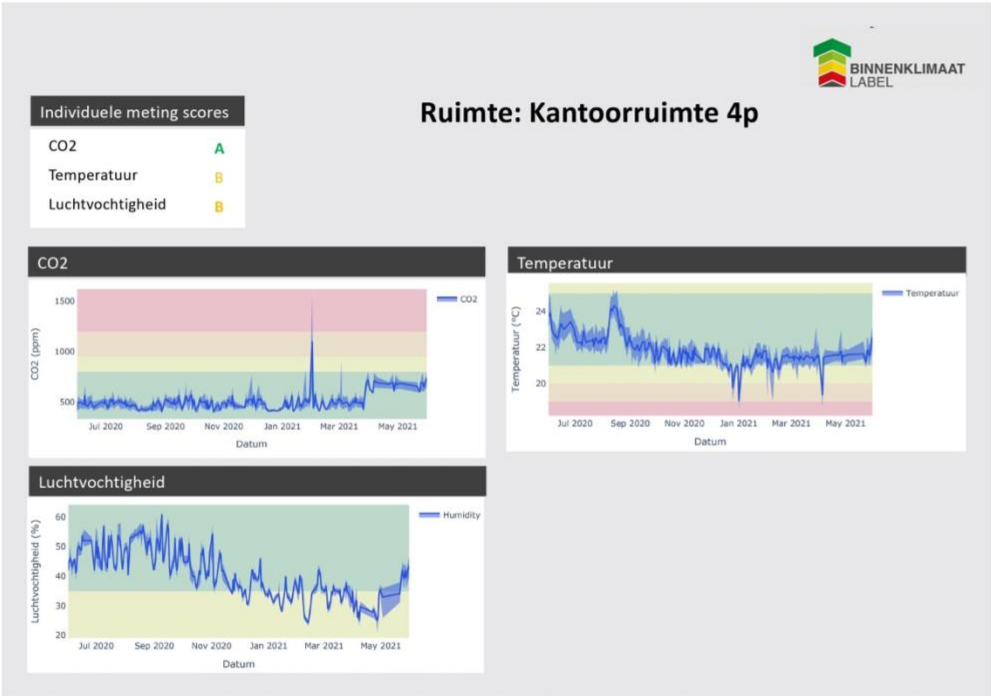
De score per thema is afhankelijk van het percentage van de gebruikers die aangeeft ontevreden te zijn over het thema.
Elke vraag wordt beantwoord op een 7-puntsschaal. Als het antwoord 1, 2 of 3 is dan telt deze mee bij het percentage ontevredenen.
Is het antwoord 4, 5, 6 of 7 dan telt deze mee bij het percentage tevredenen.

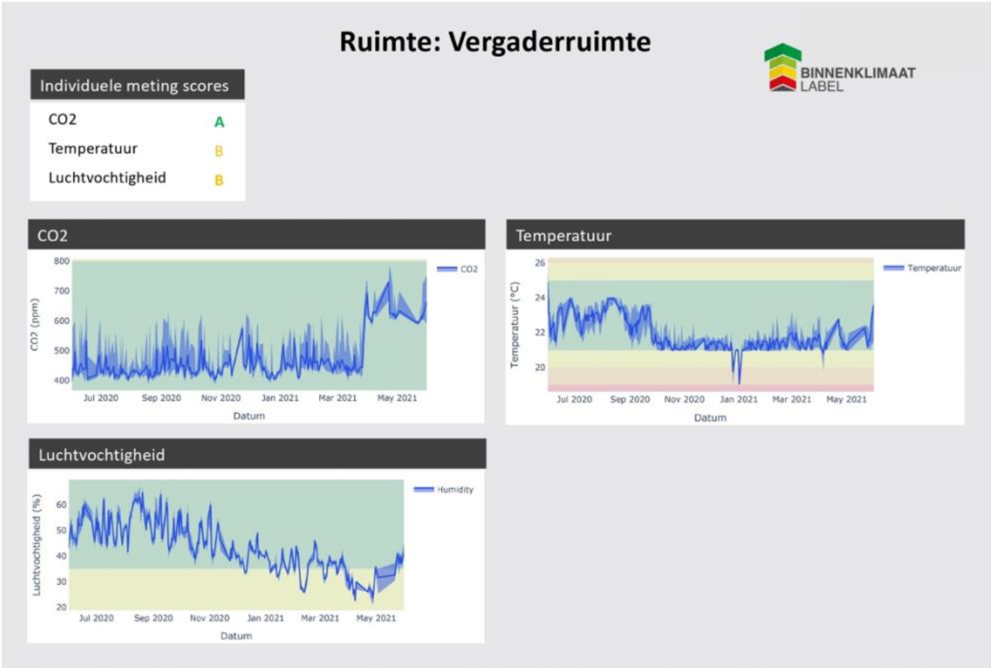
Met onderstaande tabel wordt het percentage omgezet naar een A, B, C of D klasse.
Bijvoorbeeld: als 25% van de respondenten een antwoord van 1, 2 of 3 heeft gegeven op de vraag hoe tevreden ze zijn met de temperatuur; dan valt het in klasse B. Als 45% een antwoord 1, 2 of 3 op luchtkwaliteit gaf, is de score C.

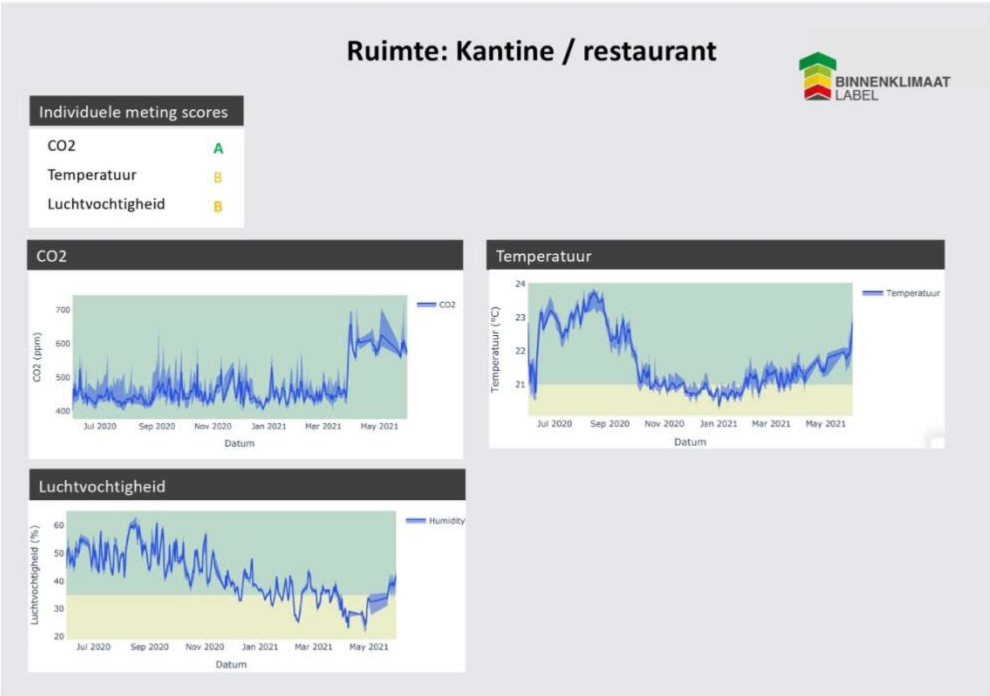
	C	B	A
Binnenlucht	<50%	<30%	<15%
Geluid	<50%	<30%	<15%
Licht	<50%	<30%	<15%
Klimaat Temperatuur	<50%	<30%	<15%


Ruimte: Kantoortuin
BINNENKLIMAAT LABEL
Individuele meting scores
CO2 A
Temperatuur B
Luchtvochtigheid B
CO2
Temperatuur
Luchtvochtigheid
Datum


Individuele meting scores
CO2 A
Temperatuur B
Luchtvochtigheid B
Ruimte: Kantoorruimte 2p
BINNENKLIMAAT LABEL
CO2
CO2 (ppm)
1500
1000
500
Jul 2020 Sep 2020 Nov 2020 Jan 2021 Mar 2021 May 2021
Datum
Temperatuur
Temperatuur (°C)
26
24
22
20
Jul 2020 Sep 2020 Nov 2020 Jan 2021 Mar 2021 May 2021
Datum
Luchtvochtigheid
Luchtvochtigheid (%)
Humidity
60
50
40
30
20
Jul 2020 Sep 2020 Nov 2020 Jan 2021 Mar 2021 May 2021
Datum


BINNENKLIMAAT LABEL
Individuele meting scores
CO2 A
Temperatuur B
Luchtvochtigheid B
Ruimte: Kantoorruimte 4p
CO2
Temperatuur
Luchtvochtigheid
Datum


Ruimte: Vergaderruimte
BINNENKLIMAAT LABEL
Individuele meting scores
CO2 A
Temperatuur B
Luchtvochtigheid B
CO2
CO2 (ppm)
Datum
Temperatuur
Temperatuur (°C)
Datum
Luchtvochtigheid
Luchtvochtigheid (%)
Humidity
Datum



Ruimte: Kantine / restaurant
BINNENKLIMAAT LABEL
Individuele meting scores
CO2 A
Temperatuur B
Luchtvochtigheid B
CO2
CO2 (ppm)
Datum
Temperatuur
Temperatuur (°C)
Datum
Luchtvochtigheid
Luchtvochtigheid (%)
Humidity
Datum

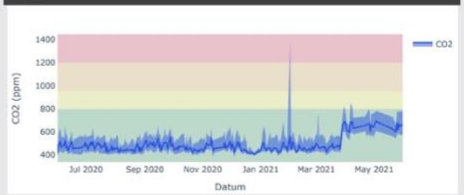
Gehele gebouw

Ruimte: Alle 5 ruimtes
Sensor: Alle sensoren

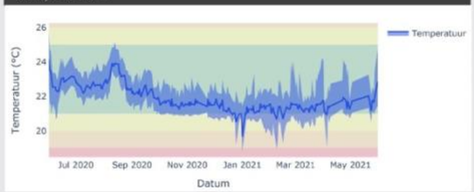
Alle locaties	
Variabele	Continue monitoring
Temperatuur	B
Vochtigheid	C
CO2	A
Fijnstof	A

BINNENKLIMAAT LABEL

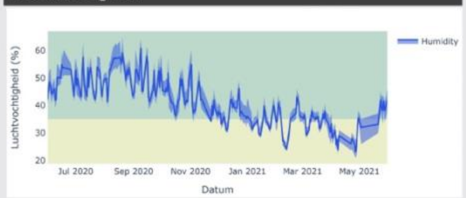
CO2



Temperatuur



Luchtvochtigheid



BINNENKLIMAAT LABEL

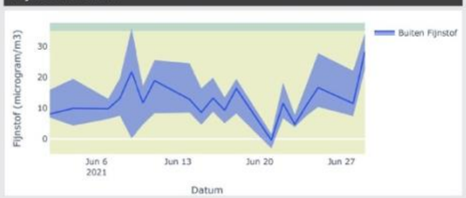
Gehele gebouw

Ruimte: Alle 5 ruimtes
Sensor: Alle sensoren

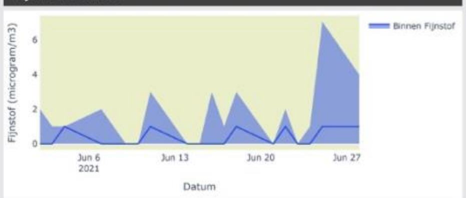
Alle locaties

Variabele	Continue monitoring
Temperatuur	B
Vochtigheid	C
CO2	A
Fijnstof	A

Fijnstof Buiten



Fijnstof Binnen



Continue sensor monitoring score: Alle Locaties

BINNENKLIMAAT LABEL

Alle locaties	
Variabele	Continue monitoring
Temperatuur	B
Vochtigheid	C
CO2	A
Fijnstof	A

Overall Binnenklimaat Label Score

Overall score

De overall Binnenklimaat label score is opgebouwd uit de scores voor:

- Klimaat
- Geluid
- Binnenlucht
- Licht

Deze themascores worden gemiddeld over de drie Binnenklimaatcomponenten (Enquête, Continue sensor monitoring en de Inspectielijst). De laagste themascore bepaalt de overall labelscore voor het gebouw.

Het overall Binnenklimaat label score voor het DWA Gouda Gebouw, Harderwijkweg 7 is: A.

Thema	Enquête	Continue monitoring	Inspectie	Thema totaal
Klimaat	A	B	A	A
Geluid	A	X	A	A
Binnenlucht	A	A	B	A
Licht	A	X	A	A
Totaal binnenmilieu				A

Overall Binnenklimaat Label: A